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Perceptible Affordances and Feedforward for Gestural Interfaces: Assessing Effectiveness of Gesture Acquisition with Unfamiliar Interactions

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Thesis Declaration

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Abstract

The move towards touch-based interfaces disrupts the established ways in which users manipulate and control graphical user interfaces. The predominant mode of interaction established by the desktop interface is to ‘double-click’ an icon in order to open an application, file or folder. Icons show users where to click and their shape, colour and graphic style suggests how they respond to user action. In sharp contrast, in a touch-based interface, an action may require a user to form a gesture with a certain number of fingers, a particular movement, and in a specific place. Often, none of this is suggested in the interface.

This thesis adopts the approach of research through design to address the problem of how to inform the user about which gestures are available in a given touch-based interface, how to perform each gesture, and, finally, the effect of each gesture on the underlying system. Its hypothesis is that presenting automatic and animated visual prompts that depict touch and preview gesture execution will mitigate the problems users encounter when they execute commands within unfamiliar gestural interfaces. Moreover, the thesis claims the need for a new framework to assess the efficiency of gestural UI designs. A significant aspect of this new framework is a rating system that was used to assess distinct phases within the users’ evaluation and execution of a gesture.

In order to support the thesis hypothesis, two empirical studies were conducted. The first introduces the visual prompts in support of training participants in unfamiliar gestures and gauges participants’ interpretation of their meaning. The second study consolidates the design features that yielded fewer error rates in the first study and assesses different interaction techniques, such as the moment to display the visual prompt. Both studies demonstrate the benefits in providing visual prompts to improve user awareness of available gestures. In addition, both studies confirm the efficiency of the rating system in identifying the most common problems users have with gestures and identifying possible design features to mitigate such problems.

The thesis contributes: 1) a gesture-and-effect model and a corresponding rating system that can be used to assess gestural user interfaces, 2) the identification of common problems users have with unfamiliar gestural interfaces and design recommendations to mitigate these problems, and 3) a novel design technique that will improve user awareness of unfamiliar gestures within novel gestural interfaces.

Glossary of Terms

- HCI - Human-computer interaction: Involves the design, implementation and evaluation of interactive systems in the context of the user’s task and work (Dix et al. 2004).
- UI - User Interface: The user interface (UI), in the field of human–machine interaction, is the space where interactions between humans and machines occur. The goal of this interaction is to allow effective operation and control of the machine from the human end, whilst the machine simultaneously feeds back information that aids the operators' decision-making process. (Wikipedia: User Interface, 2016).
- OS - Operating System: An operating system is software that manages computer hardware and software resources and provides common services for computer programs. Application programs usually require an operating system to function (Wikipedia: Operating system, 2014).
- GOMS - Goals, Operators, Methods and Selection Rules: is a specialized human information processing model for human-computer interaction observation. GOMS reduces a user's interaction with a computer to its elementary actions (these actions can be physical, cognitive or perceptual). Using these elementary actions as a framework, an interface can be studied. (Card et al., 1983).
- GUI - Graphic User Interface: In computing, a GUI is a type of interface that allows users to interact with electronic devices through graphical icons and visual indicators, as opposed to text-based interfaces, typed command labels or text navigation. The actions in a GUI are usually performed through direct manipulation of the graphical elements. As well as computers, GUIs can be found in hand-held devices such as portable media players, gaming devices and smaller household, office and industry equipment. (Martinez, 2011)
- WIMP - Windows, Icons, Menus and Pointing device: Merzouga Wilberts coined the term in 1980. WIMP interaction was developed at Xerox PARC (Xerox Alto, developed in 1973) and popularized with Apple’s introduction of the Macintosh in 1984, which added the concepts of the ‘menu bar’ and extended window management. (Linzmayer, 1994).
- UX - User experience is a term for a user's overall satisfaction level when using your product or system (FatDUX Group ApS, 2013).

- Affordances: A situation where an object’s perceivable characteristics intuitively imply its functionality and use. “Actions latent in the environment, objectively measurable and independent of the individual’s ability to recognise them, but always in relation to the actor and therefore dependent on their capabilities”. (Gibson, 1979).
- Perceived or Perceptible affordances: A perceptible affordance is a desirable property of a user interface – software which naturally leads people to take the correct steps to accomplish their goals. “Actions that users understand just by looking at an object, before start using it”. (Nielsen, 2008).
- Feedforward: This is an interface design technique, which “informs the user about how to interact with UI elements and what the result of an action will be”. (Vermeulen et al., 2013).
- Gestures in the context of HCI: Any physical movement that a digital system can sense and respond to without the aid of a traditional pointing device such as a mouse or stylus (Saffer, 2009: 2).
- Self-Revealing Gestures: This is a design technique for gestural interfaces that posits that the only way for a user to acknowledge touch-based interactions with a gestural interface is to induce it. “Objects are shown on the screen to which the users react, instead of somehow intuiting their performance”. (Wigdor, 2009: 145).
- NUI - Natural User Interfaces: These are interfaces that allow physical input modes, e.g. touch, eye gaze, voice. NUIs allow a more ‘natural’ interaction with digital artefacts, by simulating physical rules and the manipulation of objects found in real life, and by setting aside external input devices such as the mouse (Wigdor and Wixton, 2011: 1-5).
- RTD: Research through design is an approach to scientific inquiry that takes advantage of the unique insights gained through design practice to provide a better understanding of complex and future-oriented issues in the design field (Godin, 2014: 1667).
- TUI - Tangible User Interfaces: These are user interface in which a person interacts with digital information through the physical environment. Physical representations are computationally coupled to underlying digital information. E.g. users can interact with an interface by physically placing different objects elements on a screen and change its digital properties through physical inputs (Ishii, 2008).

CHAPTER 1 - INTRODUCTION

1.1 Introduction

A user interface is the medium “through which people and computers communicate” (Hartson, 2003: 315). Users commonly instruct computers using input techniques such as the keyboard, mouse or touch. The computer (or computer-based device) replies using output techniques such as the screen display, tactile and audio feedback. This communication requires a mutually understood ‘language’, which is a set of conventions for how to relay commands and information in either direction.

In the 1970s, when the keyboard was the main input technique used to interact with computers, the primary language was the CLI - Command Line Interface (Raskin, 1997: 98). In the 1980s, with the popularisation of the mouse, the language of the GUI - Graphical User Interface (Martinez, 2011: 119) was introduced and the WIMP (Windows, Icons, Menus, Pointing device) desktop metaphor became prevalent (Linzmayer, 1994). More recently, from the 1990s onwards, the software industry has worked on defining language conventions for touch and gestural interfaces. The HCI research community frequently terms these technologies ‘NUIs’ (Natural User Interfaces) because they allow a more ‘natural’ interaction with digital artefacts, by simulating physical rules and the manipulation of objects found in real life and by setting aside external input devices such as the mouse (Wigdor and Wixton, 2011: 1-5).

Since the release of the Apple iPhone (Appleinsider, 2007), the rising tide of interaction with computers via touch and multi-touch has changed the way we physically interact with everyday devices (Norman, 2014), such as touch based computers and phones (e.g. MS Surface, iPad and iPhone) or ‘open-air’ gesture-based gaming (e.g. Nintendo Wii, Microsoft Xbox 360 with Kinect). The adoption of gestural input technologies has been rapid. According to *Business Insider* (Heggestuen, 2013), by the end of 2013, 6% of the global population would own a tablet, 20% own a PC, and 22% own smartphones. Gartner estimates that smartphone sales will represent 88% of global mobile phone sales by 2018, up from 66% in 2014. Sales of tablets will reach 256 million units, an increase of 23.9% from 2013. Ali et al. (2012: 93) state that gestural technologies are “increasingly viable as a suitable alternative to keyboard or touchscreen-based input, especially when users are encumbered". Bennett et al. (2011: 2) contend, "gesture-based interaction promises to provide users with a more intuitive and richer interaction vocabulary, offering greater interaction bandwidth for lower input effort".

Despite the global adoption of touch technologies, users are still faced with unfamiliar user interfaces, gestures vocabularies, and input modes. Issues emerge from this paradigm shift, as Wigdor and Wixton (2011: 9) warn, however, that NUI technologies "require [the] learning of a new vocabulary to interact". Derboven et al. (2012: 714), advise, "Although multi-touch applications and user interfaces have become increasingly common in the last few years, there is no agreed-upon multi-touch user interface language yet". Ideally, the actions that a user can perform with an interface, and how the actions can be executed, should be obvious just by looking at the interface (Vanacken, 2008: 1). However, screen objects such as buttons, links, icons and tools, generally activated by a pointer are being presented in different shapes and forms than those originally found in conventional WIMPs or GUIs. In addition, the features commonly visible in desktop environments, such as the 'minimise application' button of Windows, Mac OS and Linux environments, or drag-and-drop interactions (Spool, 2005; Nielsen, 2008; Lunn, 2010), are often invisible in gestural interfaces.

Notwithstanding the fact that a range of more complex gestures, such as a two-fingered 'pinch' for zooming, are now an increasingly familiar part of gesture-based interaction dictionaries (Freeman et al. 2009 and Gustafson et al. 2010), unsurprisingly, first-time users often have a difficult time discovering what can be done with the interface and how it can be done (Norman and Nielsen, 2010). In the absence of adequate representation in the interface, users must discover these features either by trial-and-error (Wright et al., 2000; Novick et al., 2009; Cheung et al., 2012) or by learning via documentation, online forums or word-of-mouth. A user may eventually discover that a gesture exists and over time develop a repertoire of gestures they consider useful. However, Derboven et al. (2012: 714) argue that "the lack of well-known standards in multi-touch interface design and in the use of gestures makes the user interface difficult to use and interpret".

Touch input technologies are thus increasingly in everyday use, and users are thus frequently faced with unfamiliar interfaces. However, without clear information, users are unaware of the availability of, for example, both swipe and multi-touch gestures, and their effects. Menus and toolbars that are activated by gestures lurk hidden from the user's sight. Random learning may not provide an efficient method to overcome these issues. Giving the user an interface for gestures that helps to reveal the available gestures and actions should mitigate users' unfamiliarity with, and problems in learning, new gestural commands and interfaces.

1.2 Motivation for Research

The current status quo of interface design for gestural interactions presents challenges to users. They may struggle to anticipate what controls are available, where to find them, how to trigger their action and understand their effects (Kurtenbach and Buxton, 1991; Norman and Nielsen, 2010; Norman, 2012; Vermeulen et al., 2013; Norman, 2014).

As just noted, this can result in many user errors. Empirical studies strongly support the significance of this problem, as seen in Bau (2008), Freeman (2009) and Wobbrock (2009). Moreover, according to Norman and Nielsen, the new interfaces utilising gestural interactions are being designed and released without careful consideration of established interaction conventions and principles: "Yes, new technologies require new methods, but the refusal to follow well-established principles leads to usability disaster".

Norman (2012) more recently reiterates: "One of the powers of modern computers is discoverability, you can explore, but with gesture systems it's a pain. It's amazing how many things people don't know about the computers they use and there's no way to find out". Norman (2014), further contends: "Yes gestures are fun. I enjoy them. And yes, some gestures are natural. But how many? I would say a handful — around five. How learnable are the non-natural gestures? More importantly, how many different gestures can you easily learn, retain, and use appropriately. Answer: Far fewer than is required even today, while gestures are still in their infancy". To illustrate the multitude of gestures available in a popular device such as an Apple iPad, see Appendix B.

Prior learning helps with individual applications, but across different OS platforms learning how to control an application without strong visual cues can be problematic. Schöning (2009: 1-4) questions whether we need multi-touch interactions at all. Emphasising the key HCI principles of simplicity and consistency, he argues that standard haptic devices should remain single-touch. However, this argument seems to be finding little favour in upcoming practice as multiple-touch and gestural interactions are becoming increasingly popular in mainstream devices.

One could follow Schöning's (2009: 1) polarised argument for single-touch only, however, an opposing approach would be to demand that users adapt to the full potential of the new techniques. A more nuanced and balanced position would be to recognise the problems of learning radically new interactions, but also embrace the opportunities they present. HCI has a long-established history of harnessing the opportunity of new technologies while adapting current interactions in ways that provide a channel through which user behaviour can gradually evolve. A pragmatic approach to this dilemma is to understand how to mitigate the problems of the new opportunities, an approach which also provides the opportunity to discover new theories and practices in HCI.

One can learn from well-established HCI rules that provide *dos* and *don'ts* for interface design, while willingly abandoning paradigms that carry forward poorly into the new interface technologies. The next section expands on this subject.

1.2.2 HCI Theories and New Technology

Nielsen (2008) explains that "perceived or perceptible affordances" (Norman, 1988; Gaver, 1991; St. Amant, 1999; McGrenere, 2000; Hartson, 2003; Turner, 2005 and Kaptelinin and Nardi 2012) are actions you understand just by looking at the object, before you start using it (or feeling it, if it is a physical device rather than an on-screen UI element).

Studies of perceptible affordances have most often been applied to WIMP-GUI pointer and keyboard desktop interfaces. In the GUI environment, objects can represent actions and are labelled, or contain a picture describing their purpose, such as a "Save file" button. The appearance of a button affords that the control requires "pushing" in order to activate the underlying command. In GUI interfaces and the desktop metaphor, conventional affordances are usually static: they contain no movement and rely on iconic or symbolic conventions displayed in expected locations with fixed labels or icons to imply an interaction (e.g. toolbar menus). However, in gestural interfaces there may not be a control object (visible or otherwise) and the gesture to execute the action may be more complex than a simple ‘push’ (e.g. rotating two fingers, or a four-finger swipe). These are not easily communicated by a button or the on-screen labels used predominantly in WIMP-GUIs.

In order to improve UI design for novel technologies, other authors elaborate on the concept of ‘feedforward’ (Djajadiningrat et al., 2002; Wensveen et al., 2004; Freitag, 2012; Vermeulen et al., 2013) and explain it as a powerful design technique that *previews* to users how they should manipulate the interface and the effects of their interactions. Vermeulen et al. (2013), explain feedforward as an interface design technique that “informs the user about how to interact with UI elements and what the result of an action will be”.

Research that addresses the learnability of gestural interfaces has already begun. Several studies have already proposed techniques that exploit different forms of feedforward to assist the user learn a new gesture (Wensveen et al., 2004; Lao et al., 2009; Derboven et al., 2012; Golod et al., 2013; Vermeulen et al., 2013). Empirical studies have confirmed the efficiency of this approach (Wigdor et al., 2009; Freeman et al., 2009; Nacenta et al., 2009). They have, for instance, implemented *gesture-completion paths*, which are, as described by Bau and Mackay (2008), pathways depictions that are revealed whilst users perform gestures over a touch screen. While these authors seldom explicitly draw on feedforward, many of the proposed designs can be explained by that principle.

As will be reported in future chapters, there is potential to combine affordances and feedforward – as well as expanding on the concept – to adapt it to the design of easier to learn gestural interfaces. Combining affordances and feedforward follows on from the previous work in the field of HCI into the use of feedforward, but differs in that it is applied in order to support the user identify available actions. Previous work in the field of HCI has only used the technique to support the user in executing gestures they are already aware of. For example, guidance might be given to direct a movement while a gesture is being executed. What is different about combining affordances and feedforward is that feedforward techniques are extended and improved so that available actions as well as gestures are revealed to users that they may not yet be aware of.

1.3 Problem Statement

As will be seen later in this thesis, Chapter 2 & Chapter 3 report in full the outcomes of a systematic review of existing research and practice in the domain of gestural user interfaces. This underlined the reality that users of all ages and levels of computer expertise struggle to learn new gestures - and this was also readily seen in informal observations that were undertaken at the same time. The main problems identified through this review were:

1. *Users lack of awareness of how to initiate a touch gesture is influenced by the lack of supporting designs*: As will be reported in future chapters, this thesis proposes the potential of combining affordances and feedforward – as well as expanding on the concept – to adapt it to the design of gestural interfaces. This insight is derived from established authors in HCI, such as Norman (1988), Preece (2007), Schneiderman (2010) and Raskin (2005), who argue that the interface should 'speak for itself'. As most instructions occur after touch has commenced, they provide inadequate support for the critical moment of registration (according to Wu, (2006) the number of fingers and configuration to touch the screen of a given device are not well indicated).

2. There is a *lack of visual designs before interaction to communicate to the user the available multi-touch gestures and hidden user-interface menus and tools*: User success in discovering gestures is strongly influenced by the timing of the display of supporting visual prompts.

3. *There is no systematic understanding of which parts of identifying and performing gestures most contribute most to the errors that users make*: Users' lack of awareness of how to continue touch in gestural systems makes them prone to errors. In making a gesture, particularly more complex and less frequently used gestures, users often make slips in the number of fingers, movement etc. that the gesture requires.

The two initial problems are fundamentally design issues. Therefore, this thesis primarily adopted the approach of research through design (Frayling, 1993; Koskinen, 2011) to investigate them. Two empirical studies tested targeted design interventions that should mitigate users' unfamiliarity with given gestural interface.

The third problem is methodological. At present, there is a lack of a framework for analysing the strengths and weaknesses of different design and interaction techniques in communicating available gestures to users. To address this need, we introduce a method created to assess the user experience with gestural technologies.

1.4 Research Questions

The research questions that have driven this research follow directly from the problems stated above. They are as follows:

Question 1: Following the principle of perceptible affordances, what are the visual properties of design interventions that can inform users how to start a gesture in a given touch system?

Question 2: How can the concepts of feedforward and feedback be applied to aid users in discovering new gestures and will providing guidance before action, reduce the rate of user error?

Question 3: Which parts of gestural interactions are users failing to assess and execute? For instance, common errors were observed in the registration of number of fingers, the continuation with the appropriate direction, etc.

1.5 Research Hypotheses

As described in the problem statement section, users are still unfamiliar with gestural interactions and the interfaces of touch devices do not explicitly demonstrate to users how to perform gestures. Three core hypotheses are proposed for this thesis, which aim at addressing the research questions presented in the previous section:

Hypothesis 'a': Ensuring the registration points are clearly depicted in the user interface will improve gesture learning and reduce user error in executing gestures.
Null hypothesis: Visual depictions of touch points will not improve learning or execution of gestures.

To support this hypothesis, the first empirical study introduces visual prompts as design interventions, and provides a formative evaluation (see Chapter 6), while a summative test is found in the second study (Chapter 7).

Hypothesis 'b': Displaying automatic visual cues *before interaction* is a way to facilitate discovery of gestures and will reduce errors in execution.
Null hypothesis: Automatic events will not improve discovery or execution of gestures and results will be similar to 'tap-to-preview' UI.

To support this hypothesis, the second empirical study used revised and improved designs for the visual prompts. It confronts different combinations to display the prompts, e.g. automatic versus 'tap-to-preview', static versus animated, etc. (see Chapter 7).

Hypothesis 'c': A rating system that segments users' gestural interactions into smaller phases will help to reveal issues with users' evaluation and execution of gestures.
Null hypothesis: Statistical analysis will show no significant differences between evaluation and execution of gestures, or between phases.

The two empirical studies aimed at supporting this hypothesis, by testing and improving the rating system, introduced in this research (see Section 4.7.3).

1.6 Contribution to the Field

The three major contributions of the research are:

1. *A 'gesture-and-effect' model (GEM) and corresponding rating system*: This model assists the analysis of what users do as they detect the visual prompts and respond with action. As noted in research question 3, we lack knowledge of what errors users make, and the rating system derived from the model helps separate out different types of user error.

The model was founded upon Norman's Theory of Action (Norman, 1988:45-53), Wu's (2006) model of Registration, Continuation and Termination and Golod et al.'s 'gesture phrase', which separates a gesture into microinteractions. The model separates and divides the user's evaluation and execution of unfamiliar gestures into discrete sequential steps. The model is also used to construct a means of assessing user success in evaluating the presence and required gesture of an unknown action - a measure of user performance that is not reported in the previous work. As with the model, the rating system separates user action into different phases of the evaluation and execution of gestures. The rating system drew from Bragdon et al.'s, (2009) performance category of gesture-based interfaces.

2. *Identifying common problems that users experience in performing gestures, and design recommendations to mitigate these errors:* As noted in research question 3, users fail to assess and execute parts of gestural interactions. Furthermore, there is a of lack empirical data about user errors. The 'gesture-and-effect' model and corresponding rating system (contribution 1), provides a more detailed account of user errors in identifying and performing unfamiliar gestures. The experimental data demonstrates that users make errors both in evaluating cues and in performing gestures. Often these errors are related, and while mistakes occur throughout evaluating cues and performing gestures, there are particular weak-points that cause higher rates of error. Based on the relative success of a range of different designs, recommendations are made for the design of gestural cues, which mitigate the most common user errors.

3. *The self-previewing gestural (SPG) concept of interaction*: Research questions 1 and 2 concern, firstly, the visual properties of design interventions that inform users how to start gestures, and secondly, how feedforward and feedback can be applied. New design ideas were required to address these questions. The self-previewing gesture is a novel design idea that improves user awareness of available gestures compared to the standard techniques that support gesture learning. The standard techniques are limited to improving on the performance of an already identified gesture (Bragdon et al., 2009; Bennett et al., 2011), and do not seek to help users identify new gestures.

This research took a different focus from previous researchers and instead, followed the prior example of Freeman et al. (2009), who provided visual cues for touch and focussed on showing visual prompts to participants *before* they touch the screen. Freeman et al.'s approach was adapted, which displayed cues at a separate location, and instead provide cues in-situ at the relevant locale in the interface. The SPG approach exploits both perceptible affordances (Research Question 1), and feedforward/feedback (Research Question 2).

Empirical studies were undertaken during the course of this research and quantitative and qualitative findings confirmed the efficiency of the SPG technique. The SPG technique reduces the error rate for both evaluation (or identification) and execution (or performance) of previously unknown gestures, when compared to interfaces that are intended to support the acquisition of new gestures. The comparison interfaces utilised took state-of-the-art approaches that either mirrored standard industrial practice, or were established by prior research. The success of SPG confirms the potential of both perceptible affordances and feedforward, when adapted to help the learning of unfamiliar gestures.

1.7 Summary

The rising tide of interaction with computers via touch, multi-touch and gestures, is unquestionable. However, novel interfaces for gestural interactions present challenges to users, who struggle to learn and execute new gestures. This problem is well established by HCI researchers.

To bridge this gap, this research will investigate how to improve the discoverability of gestures. It proposes a practical evaluation tool for assessing the accuracy of users' interpretations and performance of unfamiliar gestures. It employs research through design approach to tackle these problems, and test novel design interventions in prototype software to test the underlying hypotheses. Finally, the findings of two empirical studies help construct a list of common errors, with following design recommendations for future gestural interfaces.

1.8 Thesis Overview

This section provides an overview of the chapters that compose this thesis.

Chapter 1 'Introduction': This chapter introduces the thesis, research motivation, problem statement, questions, hypotheses and contribution to the field.

Chapter 2 'Literature Review': This chapter comprises a review of the theoretical foundations that supported generations of new theory. It starts with a brief distinction between graphical user interfaces (GUI) and natural user interfaces (NUI), followed by a review of perceptible affordances and feedforward theories to design UI. Next it covers existent frameworks developed to understand and validate the HCI design of gestural interfaces.

Chapter 3 ‘A Selection of Approaches to Design Gestural Interfaces’: This review builds on existent taxonomies and interface techniques, in order to frame past and current approaches for touch-based interface design.

Chapter 4 ‘Methodology’: This chapter situates the thesis within laboratory-based research through design and research and practice in HCI. It makes a comparison of design and empirical methodologies from a selection of authors in the HCI field, who conducted empirical studies with gestural interfaces. This comparative analysis corroborated the choice of methods utilised to undertake two empirical studies presented in this thesis, and the techniques used to analyse the quantitative and qualitative data produced.

Chapter 5 ‘Introducing Self-Previewing Gestures and the Gesture-and-Effect Model for Touch Interfaces’: This chapter elaborates on the theory of perceptible affordances and introduces the concept of ‘self-previewing’ gestures. It describes the GEM that investigates users’ assessments of gestural interfaces and the execution of gestures.

Chapter 6 ‘Assessing the Role of Feedforward in Gestural Interfaces’: This chapter reports on the first empirical study, which aimed at providing initial evidence to answer the research questions The study focused on gauging participants’ interpretation of visual prompts (the SPG) that depicted touch points over the screen and suggested gestural interactions. The first version of the GEM was used to assess the user’s interpretation and interactions of two different visual cue sets, displayed in an iPad application prototype.

Chapter 7 ‘Assessing the Efficiency of Self-Previewing Gestures in Touch Interfaces’: This chapter describes the second and final empirical study, which aimed at addressing all research questions and supporting the thesis hypotheses. It aimed at investigating which designs and interaction techniques, in combination, were more efficient in training users in the available gestures. The final version of the model was utilised and confirmed its efficiency in localising issues within participants’ evaluation and execution of gestures.

Chapter 8 'Design Recommendations for Gestural Interactions': This chapter synthesises the results from the two empirical studies. It compares the findings with existent work in the field and provides a list of the most common problems users experienced when confronted with unfamiliar gestural interfaces. Finally, it draws design recommendations to mitigate each problem and provides visual recommendations to exemplify possible design solutions.

Chapter 9 'Conclusion and Future Work': This chapter reiterates the thesis key findings and contribution to the field, discusses limitation of research and future work, and provides a conclusion to the work undertaken.

Appendices: These sections comprise papers published in conferences and materials utilised for the studies, including recruitment posters, consent forms, tables that organise raw data and coding schemes.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

One of the core aims of this thesis is to comprehend how people assess visual cues within unfamiliar gestural interfaces.

The literature review is structured in four parts: The *first* part makes a distinction between Graphical User Interfaces (GUI) and Natural User Interfaces (NUI). Clarifying the differences between the two approaches will help explain the specifics of each technique and the transition from GUIs to NUIs.

The *second* part of this review covers relevant theories that help frame the interface design activity for WIMP (Windows, Icons, Menus, Pointer) and post-WIMP interfaces. The theory of Perceptible Affordances (Norman, 1988; Gaver, 1991; McGrenere, 2000; Turner, 2005; Kaptelinin and Nardi, 2012) has been used for the last thirty years in the design of WIMP interactions. Affordances have been an effective design technique for depicting to users the available interactions (commands) in the interface. However, the absence of a pointer, icons and windows in touch-based interfaces has challenged the established notions of affordances in the context of interface design.

A new concept within interface design, called Feedforward, has been introduced to complement affordances (Djajadiningrat et al., 2002; Wensveen et al., 2004; Freitag, 2012; Vermeulen et al., 2013). This technique displays additional information when users interact with a digital interface to help anticipate the results or consequences of an action, before that action is taken. In contrast to the established concept of feedback[1], in which the user receives confirmation that something has occurred as a result of an

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[1] Norman (1998) explains that Feedback is one of the most commonly used design principles in interaction design next to visibility, constraints, mapping, consistency, and affordances. Usually feedback is considered to be a stream of information returned to the user about the result of a process or activity.

action, feedforward previews what could be achieved through a particular function before it is invoked.

The *third* part of this review addresses frameworks and models that aim to explain the way in which people interact with computers – fundamental concepts of HCI. Donald Norman's Theory of Action (Norman, 1988:45-53) has been used by the HCI community to identify the various steps a user's thinking goes through when evaluating features available in a computer system interface. It also separates a user's intentions from the *actions* they take to realise them and the interpretations they make of an interface after it responds to their action.

The *fourth* part draws upon a selection of design processes for gestural interfaces. The work of Beaudoin-Lafon (2000) on an 'Instrumental Interaction model' extends the existing principles of direct manipulation in WIMP interfaces and alters them to fit gestural and other post-WIMP forms of interaction. Jacob et al. (2008) endeavour to unify a range of different post-WIMP interaction styles that were emerging at the time. They identify different design trade-offs that may need to be made and synthesise their insights into a framework they call reality-based interaction (RBI).

2.2 The Differences Between GUI and NUI

This section begins by comparing the predominant WIMP-GUI paradigm with the emerging approaches of post-WIMP interfaces in general, giving particular attention to natural user interfaces (NUI).

2.2.1 WIMP-GUI Characteristics

The first WIMP-GUI is Mac OS, from 1984. The predominant interaction paradigm within GUI for the last thirty years has been the mouse and keyboard as well as the office work and desktop metaphor that prevailed within its UI. The existence of a pointing device and a cursor were an essential condition to keep a tracking state for the mouse pointer. Precision was required to click on links, select menus and unfold sub-menus.

Dourish (2004) explains that GUIs are Human-Centred Design interface models in which a broad array of activities can be performed, with no specific activity that defines their purpose. According to Sorensen (2009: 47), because a GUI does not provide a full sensorial experience, it is likened to a *performative* process rather than an exploratory one. Using a GUI "necessitates a certain skill set, steeped in memory and recall on the part of the user." Therefore, 'skill' in these computational modes is like "remembering a recipe in order to use an application for a desired outcome". Sorensen continues by explaining that personal computing requires in general 3-5 small tasks in order to access a larger application to perform a major task such as word processing: there are more objects of interest than meets the eye, e.g. sub-menus within menus and so on.

Beaudoin-Lafon (2000: 447) explains, "In fact, WIMP interfaces…often use *indirect* manipulation of the objects of interest, through (direct) manipulation of interface elements such as menus and dialog boxes". However, in touch-based interactions, generally, user interaction and interface response occur over the same physical space, bridging the gap between input and output by displaying both on the same surface. This helps to integrate perception and action seamlessly into one environment, by enabling users to manipulate content directly, rather than through user interface controls, hence not requiring intermediates such as the mouse or keyboard. Ishii (1994) contends:

> "The GUI, tied down as it is to the screen, windows, mouse, and keyboard, is utterly divorced from the way interaction takes place in the physical world. When we interact with the GUI world, we cannot take advantage of our dexterity or utilize our skills for manipulating various physical objects: the feedback is not instantaneously felt, or even seen - decoupling of sense and time restricts any form of embodiment".

2.2.2 NUI Characteristics

NUI technologies emerged with the aim of speeding up our interactions in an intuitive way and encompassing human capabilities through direct physical interactions. The concept that drove NUIs from the very start was that "the content itself serves as the interface without needing a separate user interface with metaphors and icons" (Wixon, 2008).

By avoiding intermediaries such as the mouse and keyboard and a cursor pointer, these technologies allow a very desirable condition within HCI: that of the user becoming the tool encompassing the *embodied*[2] condition. Dourish (2004) suggests that "HCI from its very beginning took on the trappings of the traditional computational model, and set out its account of the world in terms of plans, procedures, tasks and goals". In his view, the technology has evolved but interfaces and the paradigms for interaction have remained similar. Dourish emphasises the need for a review of these paradigms to better encompass natural physical interactions, which do not require a pointing device and keyboard in a traditional sense.

In other words, Sorensen (2009: 43) adds:

> "As we act through technology that has become ready-to-hand, the technology itself disappears from our immediate concerns. We are caught up in the performance of the work; the equipment fades into the background and (…) the interaction between tool and user is substantiated by the result felt in the present".

As an example of direct versus indirect manipulation of digital content in an iPad, it is possible to use a pinch gesture with one's fingers instead of a zoom button to maximise or minimise a picture. As a result, the exploratory activity on the part of the user dramatically shifts to *real* direct manipulation: there are no intermediaries between the user and the 'screen', such as a pointing device (mouse) and cursor.

Vinh (2011) suggests that user guidance - especially in multi-touch environments - is often regarded as unnecessary and merely a quick fix for a poorly designed application. While exploring a system, users should be able to find out which functionality is available with as little assistance as possible. This view is complementary to the idea that multi-touch interfaces should be 'natural', self-explaining and intuitive (Derboven

[2] Embodied interaction is about the "relationship between action and meaning, and the concept of practice that unites the two. (…) Actions both produce and draw upon meaning; meaning both gives rise to and arises from action" (Dourish, 2004: 206).

et al., 2012: 716). However, this idealistic view often contrasts with the way users actually explore and use multi-touch interfaces (Westerman, 2008).

In addition, as mentioned by Wigdor and Wixton (2011: 147), NUI in general does not provide 'modifiers', 'accelerators' or shortcuts to change input mode. "No *Shift* key to input capital letters or *Alt, Ctrl* keys to be combined with other keystrokes to speed up well-known commands e.g. Copy, Paste, Edit, etc." This could hinder interactions from an expert user who is already familiar with specific software packages. This is an issue of context of use and design trade-off as well. For instance, would an experienced user be interested in undertaking complex multi-touch gestures in a touch device? Opportunities to afford modal shifts (e.g. touch and hold for additional options) during gestural interactions are still being investigated by academic research and industry and solutions are being introduced in small increments.

Schneiderman et al. (2010: 583) explain that an approach similar to the scaffolding concept could help users to learn new interfaces:

> "Designers can begin by improving interfaces for common tasks and then provide training and help methods so that using a computer becomes a satisfying opportunity, rather than a frustrating challenge. Evolutionary learning with multilayer interfaces would allow first-time users to succeed with common tasks and provide a clear, nonthreatening growth path to more complex features".

Tutorials have been used to instruct users towards different instalments. However, the solution is often displayed outside the context of interaction, hence requiring larger memory load from users. For instance, Novick et al. (2009) verified in an empirical study that the overall rates of success with trial-and-error were higher than with the use of a help system.

2.2.3 From GUI towards NUI

Cognitive psychology (Sternberg, 2006) reveals how the mind attempts a direct mapping of what is known already in the search for visual metaphors present in NUIs. If the interface does not, 'make sense' (cognitive dissonance), the user tries different interactions to check how those visual cues might work. Exploring the interface should eventually lead to learning and interactions might not remain unfamiliar for too long.

However, ‘eventually’, could be a long time period and the inability of users to intuitively obtain the gist of novel visual cues has been a major concern in the design interaction field.

When faced with the possibility of interacting through physical modes – what are the controls, where are they located (as they are sometimes hidden away or easily overlooked) and how are they activated? A NUI requires learning and, “the natural element of a NUI is not about the interface at all but natural is the way users interact and feel about the product, while using it” (Wigdor et al., 2011: 9). Norman and Nielsen (2010) make reference to this issue: “…the lack of consistency and inability to discover operations, coupled with the ease of accidentally triggering actions from which there is no recovery, threatens the viability of these (NUI) systems”.

However, this thesis is not, in any sense, preaching about the end of the ‘mouse and keyboard’ as we know it. Despite the increasing ubiquity of NUI, the desktop computer maintains its prevalence with regards to tasks that require precise manipulation (Linzmayer, 1994; Schneiderman, 2010:592-595; Martinez, 2011); hence it is likely that GUI will remain in years to come. Wigdor et al. (2011:18) explain that the NUI will not supplant the GUI, which is too well adapted to office work. Keyboards and pointing devices serve this purpose effectively (no one would type a long report with a virtual keyboard). Buxton (2012) states:

> “This is not a ‘all or nothing’ issue and following my claim that everything is best for something and worst for something else, the desktop PC will continue to exist and develop for the many things for which it is well suited, and other devices will take over from it for the things for which it is less well suited”.

Norman (2012) adds, “there are advantages for precision with the stylus, the finger for ease of use and fun and the keyboard and mouse for text and getting real work done. You notice that you can’t do real productivity on a tablet”.

As an example of most appropriate use of point-and-click interaction, in vector image software such as Adobe Illustrator, touch would not be the ideal way to work with precision. First, because the hand would occlude target areas (the user would not be able to see editing nodes). Second, because another step would have to be added in response to the previous shortcoming (the necessity of zooming-in constantly in order to select *vector points* with more precision). A pointing device and cursor is therefore better suited to allow interactions within such specialised tasks.

Hofmeester et al. (2012), in common with other authors (Wigdor, 2011 and Wobbrock, 2009) argue that *natural* interactions do not exist in a computer system: “since this gesture does not follow commonly known user interface conventions or copies an interaction from the real world, it was not easily discoverable for users.” From Hofmeesters’ perspective, using air gestures, voice or eyes to interact can be regarded as direct manipulation, even though it is still ‘unnatural’ to use these as input techniques (excluding the simple act of single touching, dragging or swiping gestures). To efficiently input information in any system, users need to learn arbitrary commands. Like in any dialogue, the two parties (human-computer) “need to constantly reconnect to agree upon fundamental metaphors” (Marcus, 2002).

2.2.3.1 Hybrid Solutions

There is no need for a cursor-pointer within NUI physical interactions; but in some cases physical modes of interaction co-exist as additional features on a WIMP-GUI (Sorensen, 2009: 43) and some cumbersome hybrids emerged.

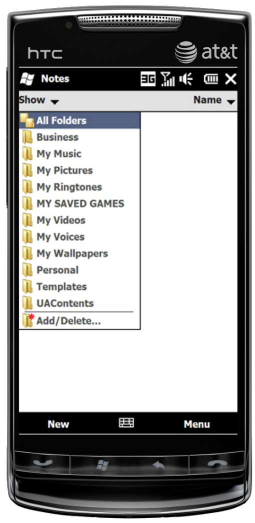

Figure 1: HTC PURE Windows mobile 6.5 displays a WIMP-GUI like menu within a small screen (source: Lina Pio - twitter @linapio - London, March 2012). The Berne Convention allows the non-profitable use of software print screens.

As an example, this issue could be observed in some mobile systems (e.g. Figure 1 shows the HTC PURE Windows mobile 6.5) in which a GUI akin to a traditional Windows Operating System (OS) is displayed. Very few adaptations were created to accommodate the constraints of a mobile small screen: resulting in menus with small text and subsequent reading and selection accuracy issues, for young and elderly alike.

Raskin (2005) explains some of the reasons why new interface designs are held back or even why mixed solutions emerge: "often due to company's (e.g. Macintosh and Windows) need to maintain compatibility with earlier versions of the interfaces and the misperception that users will inevitably revolt if old, familiar interfaces methods are abandoned". Beaudoin-Lafon (2000) adds, "Designers find it faster and easier to stick with a small set of well-understood techniques. Likewise, developers find it more efficient to take advantage of the efficient support for WIMP interaction provided by current development tools".

The visual output in many cases remains the same, although the activity to achieve the outcome is different, such as a desktop metaphor with touch-based interaction. Perhaps, pinching, spinning, and swiping as gestural commands are more intuitive than clicks of a mouse, allowing for feedback in a more real-time rapid response, however, the same principle applies: a series of learned actions are required to perform a task for a variable output. Bill Gates, on that matter, told BBC News (2008): "We're adding the ability to touch and directly manipulate, we're adding vision so the computer can see what you're doing, we're adding the pen, we're adding speech". As Gates succinctly comments, multi-touch and touch-based technologies in many cases extend only as an additive rather than transformative quality to the GUI.

The difficulties with human-computer interaction that emerge when gestural interfaces are used also challenge existing practices within HCI, such as perceptible affordances. The next section builds on established theories to further scrutinise possibilities to 'represent' the GUI and the recent gestural and surface interactions.

2.2.4 'Undoing' an action according Shneiderman and Dix

In Shneiderman's original definition of direct manipulation the ability to undo was central (Shneiderman 1982).

According to Dix (1996), “the emphasis in direct manipulation is upon implicit undo, where the user uses ordinary actions to undo the effects of others”. Schneiderman (1998) later confirms: “actions need to be reversible, so the consequence of an action can easily be undone”. For instance, in WIMP-GUIs, a user may press ‘ctrl + x’ on a keyboard to cut selected text. The text is removed and the user notices this event. In case the user decides to undo this operation and restore the system to its previous state (put the text back in its original location), he/she is aware – or has learned through conventions – that within the ‘edit’ menu they will find an ‘undo’ command, or similar. NUI’s, which fundamentally differ from the predominant desktop-metaphor paradigm, present a challenging context for undo actions. For instance, mainstream touch devices (e.g. smartphones and tablets) rarely provide ‘undo’ buttons or ‘undo’ options within ‘edit’ menus. One can actually seldom find ‘edit’ menus. The baseline UI implementation in gestural systems, observed in several devices, was that the interface embeds an ‘undo’ gesture that is in many cases different from the starting gesture.

In some cases concatenated, or sequences of gestures, are required to restore the system to its previous state. For instance, in Apple iOS running on an iPad a user may ‘minimise’ a program by performing a pinch gesture with three or more fingers. However, the same gesture will not ‘maximise’ the program – neither inwards nor outwards. Only a double tap on the physical ‘home’ button (iOS version of 2014) will change the system mode to display current minimised applications. Now consider the repercussions of having that physical button broken.

2.3 Theories to Understand Novel Interfaces

On of the core aims of the thesis is to comprehend how people assess visual cues within unfamiliar interfaces.

This section provides a limited selection of prevalent theories within HCI, which help in understanding the theories and frameworks that give structure to the GUI. By reflecting back on progress previously made on WIMP, it is possible to trace the rationale that later supported the understanding of novel interfaces, in particular gestural ones. The review starts with prevalent theories, such as perceptible affordances (Norman, 1988; Gaver, 1991; St. Amant, 1999; McGrenere, 2000; Hartson, 2003; Turner, 2005 and Kaptelinin & Nardi, 2012) and feedforward (Djajadiningrat et al., 2002; Wensveen et al., 2004; Freitag, 2012; Vermeulen et al., 2013), which describe how to make visual cues visible to users and UI more responsive and informative, in order to educate them about the available interactions.

2.3.1 Perceptible Affordances

While the concept of perceptible affordances is well established in the world of the WIMP and GUI interface, the arrival of new interaction techniques reveals shortcomings in the current use of affordances in gestural interfaces. However, a review of the most prominent authors and their research on affordances is pertinent, for perceptible affordances have been one of the most important pillars in HCI theory.

The notion of 'affordance' was introduced by Gibson in 1979 and appropriated by Norman in 1988 within the context of HCI. The term is used in HCI to better understand how to make a system usable and how to shape (or 'afford') the functions that users anticipate a system may have. Gibson introduced the term *affordances* in an article (Gibson, 1977) and later explored the concept in his book, *The Ecological Approach to Visual Perception*, from 1979. Gibson defined affordances as 'action possibilities' that is, "actions latent in the environment, objectively measurable and independent of the individual's ability to recognise them, but always in relation to the actor and therefore dependent on their capabilities."

According to Nielsen (2008), "perceived or perceptible affordances" are actions you understand just by looking at the object, before you start using it (or feeling it, if it is a physical device rather than an on-screen UI element). For instance, a checkbox affords turning on and off and a slider affords moving up or down.

For contrasting purposes, Figure 2 displays two examples. The first is a faulty affordance and the second establishes an arbitrary convention. The image on the left depicts two shower taps, which because of their shape 'afford' rotation. However, it is assumed that no person would be able to infer – without previous usage – which one triggers the water and which one controls the heat. There are no visual cues, e.g. a visual representation or a specific shape or colour to 'afford' the concept of hot or cold water.

Figure 2: Examples of affordances (shower taps - picture taken by the main researcher) and symbolic representation (chess pieces - Chess for Apple iPhone iOS7, March 2013). The Berne Convention allows the non-profitable use of software print screens.

The adjacent image shows a modern digital chess game which runs on iPhone iOS 7. Following the same rationale, one would only be able to play chess by learning its conventions and rules. The picture displays the chessboard in a mode set by the user, which shows the range of movement of the white bishop. The user only discovers such features by selecting the piece. Chess pieces are defined in a symbolic and arbitrary fashion: neither their shape nor size conveys the rules of how they should be moved. Perhaps the shape of the pieces themselves could suggest how they are supposed to be moved. For comparison purposes, perhaps the digital interfaces of novel touch-based systems should be doing the same; by indicating which UI elements are active, selectable and conveying the gist of how they could be activated and what would happen if they were activated.

Lewis Carroll’s tale of *Alice's Adventures in Wonderland* (1865) and its “drink me” and “eat me” metaphors (Figure 3) may serve as an example of how users experience NUI technologies for interaction. In Carroll’s tale, Alice was in a room that was recognisable and within the physical constraints she understood. However, there was a tiny door, which she was supposed to enter to continue her adventure but could not get through for obvious reasons. On a nearby table lay a tiny key and a flask that said, “Drink me.” The objective was to walk through the door and she assumed that drinking what was offered would help her accomplish this. Alice was not certain though about the results of drinking. It would render Alice minute enough to grant her access to the door. Alas though, in Alice’s tale she forgets to fetch the key before drinking the potion.

Figure 3: The ‘Eat me’ and ‘Drink me’ metaphors in *Alice's Adventures in Wonderland* and *Through the Looking-Glass* by Lewis Carroll (2009 edition).

Perhaps, that is how some people have been experiencing novel technologies for computers interaction: a supposedly known territory with unknown rules. In many cases, there are no “labels” or affordances at all informing users of the actions that would trigger or display hidden menus, toolbars or modes. The manipulation vocabulary is unfamiliar and the results are unexpected. They remain invisible until users stumble upon them with trial-and-error, or are informed by experienced users how to operate the system or use the help/tutorial system.

Next, we continue on the various characteristics of perceptible affordances as described by different authors.

2.3.2 Norman and Perceptible Affordances

According to Norman (1988), it is important to make a distinction between affordances and learned conventions. The former is an intuitive understanding of what a *stimulus* is trying to convey - which will match a persons’ understanding and physical abilities. The latter can only be grasped by learning an arbitrary rule. It would not present itself in a “natural form” which one would understand just by looking or sensing it (e.g. the chess example from the previous section).

Regarding computing technology, Norman (1999: 40) explains:

> In today’s screen design sometimes the cursor shape changes to indicate the desired action (e.g. they change from arrow to hand shape in a browser), but this is a convention, not an affordance. After all, the user can still click anywhere, whatever the shape of the cursor. Now if we locked the mouse button when the wrong cursor appeared, that would be a real affordance, although somewhat ponderous. The cursor shape is visual information: it is a learned convention. When you learn not to click unless you have the proper cursor form, you are following a cultural constraint.

As an example of an arbitrary learned convention, Figure 4 shows a pull down menu, found in many different software applications. In the example, there are no visual characteristics that actually inform the user that one may hover a pointer over items and reveal options as a result. Perhaps a small arrow pointing down would have helped the user know which items withhold sub-items.

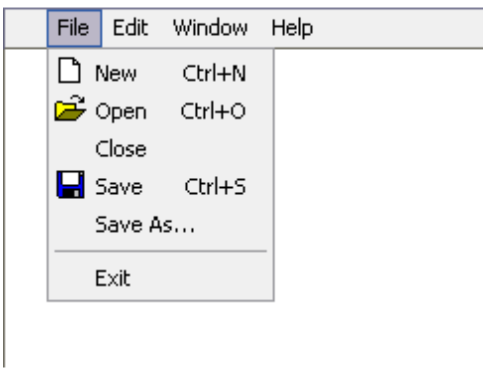

Figure 4: A menu is an example of a learned convention (Wikipedia, 2015).

Norman (1988: 10) elaborates on door handles and affordances, by explaining that “vertical door handles afford pulling, while flat horizontal plates afford pushing: the interaction of a handle with the human motor system determines its affordances”. When grasping a vertical bar, the hand and arm are in a configuration from which it is easy to pull, which explains the ‘push’ and ‘pull’ confusion on Figure 5.

Figure 5: Vertical door handles afford pulling (703 Creative - July, 2015).

When it comes to digital user interfaces a user generally relies on vision to make sense of what is possible to accomplish. More recently, Norman (2008) termed perceived affordances as *signifiers*, in the context of HCI. He contended that any interface suggests its available interactions, e.g. any interactive component or control that 'declares': *I am a button and I can be pressed* or *drag me around*.

2.3.3 Gaver and Perceptible Affordances

Gaver's (1991) classification framework on perceptible affordances was highly relevant for the understanding of the various properties affordances can embed. Gaver describes perceptible affordances as being 'inter-referential': "the attributes of the object relevant for action are available for perception. What is perceived (e.g. visual, tactile, auditory) is what is acted upon".

Gaver also contextualises affordances into two different approaches: the cognitive and ecological. The cognitive one is a decontextualized approach to design in which "people have direct access only to sensations, which are integrated with memories to build up symbolic representations of the environment and its potential goal-oriented action". In contrast, he explains that the notion of affordances "is in many ways the epitome of the ecological approach, encapsulating ideas about ecological physics, perceptual information, and the links between perception and action. In this account affordances are the fundamental objects of perception".

One persistent theme that drove Gaver's research from the very start was that tools and controls within systems should be self-evident (or in Gaver's words 'inter-referential'). Their use should be obvious as well as their intended effect. Extending Norman's concept of affordances, Gaver (1991) also explains the notion of affordances as one that explicitly requires exploration. There is perceptual information that suggests the potential for activation but action is required for proper learning. McGrenere (2000) in similar fashion explains, "designing the utility of an object is related to but separate from designing the usability of an object: the *trick* with designing for UI is to show what is really possible to be done rather than what is apparently possible".

2.3.3.1 Gaver's types of affordances

The concept of *apparent* perceptible affordances as addressed by Gaver and the introduction of the concepts of *complex* and *sequential* affordances yielded valuable inspiration into how to design the SPG concept. As can be observed in Figure 6, "if there is no information available for an existing affordance, it is *hidden* and must be inferred from other evidence. If information suggests a non-existent affordance, a *false* affordance exists upon which people may mistakenly try not to act."

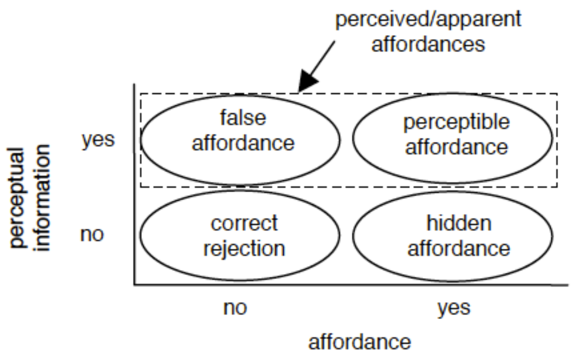

Figure 6: Perceptual information that specifies affordances (Gaver, 1991).

The perceptible affordance 'affords' and is only existent to a person the moment it connects the potential this individual has ito identify the perceptual information and its implied function. An affordance does not become 'perceptible' or 'apparent' if the individual does not carry the correct attributes, skills, culture or previous experience that would enable he/she to acknowledge its existence. This is a matter of designing a product or message in the appropriate 'language' that an individual is able to grasp.

Gaver continues his explanation by making a distinction between perceptual information for affordances that can be obtained via relatively passive perception (e.g. a digital button that resembles a real-life one) and those that require additional information, which he regards as *complex* affordances. The latter explicitly require exploration, such as a digital scrollbar. A user coming across a scrollbar for the first time might not be able to determine the possibility of scrolling a window by sliding the scrollbar 'button' up and down or sideways. Additional visual cues should be provided to convey this information, which usually take the form of small arrows indicating direction of movement. Uncovering hidden information within the window while scrolling teaches the user about the outcome of their actions and this constitutes a *nested* affordance, according to Gaver.

2.3.3.2 Relevance of Gaver's work

Gaver goes on to describe other forms of affordances: *complex* affordances, which unfold into *sequential* ones, "…affordances that can be revealed over time", and *nested* affordances which are grouped in space, "…an onscreen window may appear to afford uncovering if the occlusion of its contents is apparent, and a scrollbar may afford dragging". Nested affordances are therefore grouped in space, while sequential affordances are sequential in time (i.e., acting on an affordance leads to information indicating new affordances).

Gaver explains "the role of a good interface is to guide attention via well-designed groups of sequential and nested affordances" (1991:82). For instance, in the case of gestural interfaces, a *hidden* affordance for a swipe gesture would reveal in *sequence* another nested affordance in the form of a *hidden* menu. The 'self-previewing' design concept introduced in this thesis, provides a gesture that reveals itself, automatically and in the context of the interaction, making itself 'apparent'.

From this PhD perspective, by explaining that sequential affordances are only available at certain points in time – and therefore concatenating 'nested affordances', Gaver was, without knowing, describing what would later come to be theorised by other authors as feedforward (to be reported later in this chapter).

2.3.4 McGrenere and Perceptible Affordances

McGrenere et al. (2000) clarify the concept of affordances by comparing the work of Gibson (1979) and Norman (1988). They emphasise the most important contributions from nineteen different papers about affordances, including Gaver's (1991) and his framework for separating perceptual information available on interfaces.

McGrenere explains that Gibson divided affordances into three fundamental properties in his ecological approach:

1. An affordance exists relative to the action capabilities of a particular actor.

2. The existence of an affordance is independent of the actor's ability to perceive it.

3. An affordance does not change as the needs and goals of the actor change.

McGrenere et al. (2000) explain Gibson's affordances by way of introducing the idea of the actor-environment mutuality; the actor and the environment make an inseparable pair:

> "The existence of the affordance is independent of the actor's experiences and culture, whereas the ability to perceive the affordance may be dependent on these. Thus, an actor may need to learn to discriminate the information in order to perceive directly. In this way learning can be seen as a process of discriminating patterns in the world, rather than one of supplementing sensory information with past experience".

This 'independency' of an actor's ability to perceive an affordance is the most contrasting point between Gibson's and Norman's affordances. Norman (1988) would couple affordances with past knowledge and experience: "I believe that affordances result from the mental interpretation of things, based on our past knowledge and experience applied to our perception of the things about us" and "an affordance would only exist if there was information to specify the possibility for action and the actor had learned how to interpret the information".

2.3.4.1 Relevance of McGrenere's work

McGrenere et al. (2000) make a correlation between the 'degree of perceptual information' and the 'degree of affordance', explaining that improvements in design can maximise both dimensions (Figure 7). In a review of the work of Gaver (1991), McGrenere et al. describe *perceptual information* as the "physical attributes of the thing to be acted upon" (Gaver, 1991: 81). The *degree of affordance* relates to the information about those attributes that is available in a form compatible with the perceptual system of an actor, and (implicitly) these attributes and the action they make possible are relevant to a culture and a perceiver.

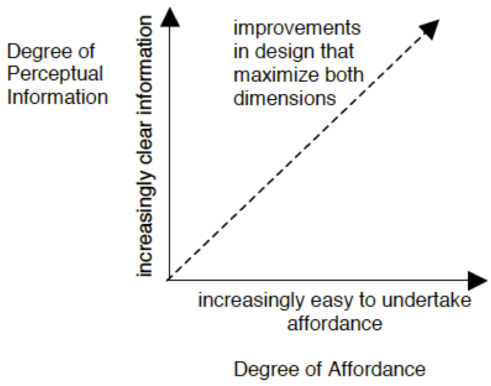

Figure 7: Affordances on a continuum model (McGenere, 2000).

McGrenere et al. (2000) explain the possibility of envisioning perceptible affordances in a continuum in which:

> "A two-dimensional space where one dimension describes the ease with which an affordance can be undertaken, and the second dimension describes the clarity of the information that informs the existing affordance…The goal of design would be to first determine the necessary affordances and then to maximize each of these dimensions".

2.3.5 Hartson's Review of Affordances in Interaction Design

Hartson (2003) examines Norman's distinctions of four types of affordances, and expands on the usefulness of these in terms of their application to interaction design and the evaluation of physical objects, e.g. electronic switches, cork puller or a door handle.

Hartson distinguishes between four types of affordances based on the role they play in supporting users during interaction: cognitive affordance, physical affordance, sensory affordance, and functional affordance. They are described as follows with examples that relate to GUI and gestural interfaces. The examples are particularly relevant to the thesis topic.

- Cognitive affordances: Hartson (2003) defines cognitive affordances as being similar to Norman's perceived affordances (1988): "a design feature that supports, facilitates, or enables thinking and/or knowing about something". Hartson adds that this type of affordance greatly depends on cultural conventions or constraints. As an example, a button labelled 'send' will help users to know what is going to happen if they click on it. In the case of gestural interactions there are no affordances to indicate the presence of a gesture, only its effect.
- Physical affordances: According to Hartson, a physical affordance is "a design feature that helps, aids, supports, facilitates, or enables physically doing something". This mirrors Norman's 'real affordances' such as a button that is sufficiently large to allow users to reliably click on it. Gestural interfaces also rely on GUI. For instance, Windows 8 touch guidance (Windows Dev Center-b, 2014) recommends the use of a minimum 7x7 mm target size (ideally 9x9 mm) with 2mm padding.
- Sensory affordances: Hartson defines a sensory affordance as "a design feature that helps, aids, supports, facilitates, or enables the user in sensing (e.g. seeing, hearing, feeling) something". According to Vermeulen (2012) "Sensory affordances play a supporting role for cognitive and physical affordances. Hartson thus explicitly separates sensing from understanding." In the above example, for instance, of a button large enough to reliably click on, it is recommended to have high contrast between foreground and background to improve visibility (such as a button which is darker than its placeholder below). Jacob et al. (2008) describe this as 'expressive power'.
- Functional affordances: Functional affordances add purpose to a physical affordance. It ties *usage* to *usefulness*. For example, a 'sort' button triggers an internal system that sorts a series of numbers. This saves the user considerable effort and encourages its use. In the Apple iOS on iPad users can press the

physical home button or perform a pinch gesture with 3 or 4 fingers (usage) to minimise an application (usefulness).

Despite the fact that Hartson's (2003) considerations do not address digital UI, his review of Norman's Theory of Action (1988) sheds a new light on how the aforementioned affordances converse with Norman's gulfs. This review can be found in Section 2.4.2.

2.3.6 Feedforward

Feedforward is a HCI design technique that aims at making explicit the action that is required to perform an interaction and its effect. Whilst perceptible affordances only 'suggest' the available interactions, feedforward provides users with the additional information necessary to manipulate touch and gestural interfaces, such as a preview of how to perform the interaction and the possible effects.

As this is a recent topic of research, there is a moderate array of literature on the topic, mostly describing technical solutions for application of the technique (Dohse et al., 2008; Tanase et al., 2008; Schoning et al., 2009; Annett et al., 2011; Wilson & Benko, 2011). In this section therefore, the technique and the production of theory is reviewed, as developed by Djajadiningrat et al. (2002), Wensveen et al. (2004), Freitag et al. (2012) and Vermeulen et al. (2013) in order to support the production of new theory (Chapter 6: 5.2.2) and the design phase of application prototypes (Chapter 5: 6.4.3 and Chapter 7: 7.2) during the course of this research.

2.3.7 Djajadiningrat's Feedforward

Djajadiningrat et al. (2002) state that most interpretations from the HCI design community regard affordances "as the key to solving most usability problems". The authors argue that the essence of usability in electronic products lies not in communicating the necessary action and instead shift our attention to feedforward and inherent feedback. The authors have defined feedforward by disambiguating it from related concepts such as feedback and perceived affordances and produced the first definition of feedforward, described as follows (2002: 288):

> We distinguish between information *before* the user carries out the action (pre-action), and *after* the user carries out the action (post-action). These phases

> correspond with Feedforward and Feedback. Feedforward informs the user about what the result of his action will be. Inviting the appropriate action is a prerequisite for Feedforward but it is not sufficient. The product also needs to communicate what the user can expect. Feedback informs the user about the action that is carried out, shows that the product is responding, indicates progress, confirms navigation, etc. Note that, unlike Feedforward, Perceived Affordances *do not* communicate the purpose of an action.

Whereas feedback informs the user about the action that is carried out (as confirmation), feedforward informs the user about what the result of their action *will be*.

The 'inherent feedback' is described by Djajadiningrat et al. as a technique for designing products in such a way that the user should experience the feedback as a natural consequence of his actions, meaning it is important that an interface or a system demonstrate the bond between an action and consequences from that action.

2.3.7.1 Relevance of Djajadiningrat's work

Djajadiningrat et al. (2002: 286) explain that "both appearance and action are carriers of meaning," for example, the way a control looks and the action that it requires expresses something about the control's purpose. In general there are two ways to approach this expressiveness: the semantic approach and the direct approach, represented in Figure 8.

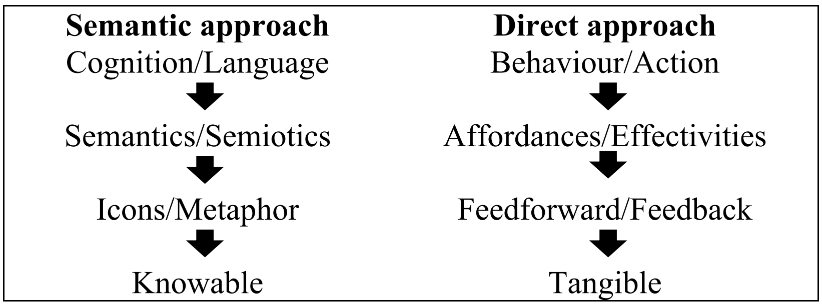

Figure 8: Semantic and Direct approaches in HCI (Djajadiningrat, 2002: 286).

The authors explain that the first approach starts from semantics and cognition. The basic idea is that using the knowledge and experience of the user; the product can communicate information using symbols and signs (Krippendorff & Butter, 1984; Aldersey-Williams et al., 1990). Often this leads to the use of iconography and representation. In the semantic approach the appearance of the product and its controls become signs, communicating their meaning through reference. Djajadiningrat et al. (2002) explain, “Products resulting from this approach - be it hardware or software - often use control panels labelled with icons or may even be icons in themselves”.

The direct approach takes behaviour and action as its starting point. Here the basic idea is that meaning is created in the interaction. Djajadiningrat et al. go on by explaining that affordances only have relevance in relation to what we can perceive and what we can do with our body: our ‘effectivities’. In this approach, respect for perceptual and bodily skills is highly important and tangible interaction is therefore a logical conclusion.

2.3.8 Wensveen et al.’s (2004) and the Six Aspects of Coupling

Wensveen et al. (2004) present a design framework to analyse person-product interaction. Instead of using the notion of ‘coupling’ and ‘embodied interaction’ (as seen in Dourish, 2004) in an abstract sense, “the framework gives six practical characteristics for coupling action and information i.e. time, location, direction, dynamics, modality and expression” (2004: 177).

2.3.8.1 The Six Aspects of Natural Coupling

Wensveen et al. (2004: 178) contend that there are six aspects taken from the physical world, which describe characteristics of both the action and the reaction of a user interacting with a given system.

They explain “unifying action and reaction on each of the six aspects of natural coupling makes the interaction intuitive”. Whilst the authors use examples from the physical world such as a pair of scissors cutting a piece of paper to illustrate the aspects, the examples used in the description of the aspects below are made with gestural interfaces characteristics. This is in order to highlight how the theory resonates with the main theme of the thesis:

1. Time: The product’s reaction and the user’s action coincide in time. For instance, when a user touches and holds over a screen object on a touch-based device, the visual UI displays possible actions.

2. Location: The reaction of the product and the action of the user occur in the same location. With the desktop metaphor, in many cases, a user needs to manipulate a control to see the results in another portion of the screen, such as when the user has to manipulate a scrollbar with the pointing device (mouse or trackpad) to see the results in a window view (for instance to scroll a text page in a document). In gestural interfaces the results are usually displayed in the same physical location, for instance a user touches and drags his finger over the screen and the view immediately below the contact is dragged along.

3. Direction: The direction or movement of the product's reaction (up/down, clockwise/counter-clockwise, right/left and towards/away) is coupled to the direction or the movement of the user's action. This aspect is similar to the previous: in a pointer based interface, when scrolling a text page the results are traditionally reversed: to move the scrollbar down brings the page of a document up. In touch-based interfaces the gesture and results are usually coupled.

4. Dynamics: The dynamics of reaction (position, speed, acceleration, force) is coupled to the dynamics of the action (position, speed, acceleration, force). In many gestural interfaces (e.g. iOS and Android) some applications simulate inertia. When a user performs a larger swipe the object manipulated on the screen responds accordingly, for instance, a menu can be displayed faster with a quick swipe of a finger or dragged slowly. This event resonates with Jacob et al.'s (2008) concept of 'naïve physics' for digital interfaces, in the way screen events connect with real-life human experience.

5. Modality: The sensory modalities of the product's reaction are in harmony with the sensory modalities of the user's action. In the authors' example, they describe the importance of the human sensations of a person who is able to see, hear and feel a pair of scissors cutting a piece of paper in order to achieve the natural coupling. In digital interfaces such aspects are harder to achieve. So far commercial products still do not offer resistance or texture of materials in a virtual interface. However, these aspects can be further explored in tangible user interfaces (TUI).

6. Expression: The expression of the reaction is a reflection of the expression of the action. The authors explain that this aspect of coupling is influenced by the personalised experience a user can give to it: depending on his/her mood, the results of cutting the

piece of paper can be different for each user, e.g. the angle, precision, patience, etc. Indeed in a gestural interface, and similar to the 'Dynamics' aspect (point 4), a user can use pressure and speed to simulate larger virtual brush strokes in a paint application to achieve different aesthetic results.

Wensveen et al. (2004: 179) explains that the six unification aspects are not limited to mechanical products but can also be used to couple action and reaction in electronic products.

2.3.8.2 The Three Types of Feedforward

Wensveen et al. (2004: 180) define three different types of feedforward: inherent, augmented and functional feedforward. They are described as follows:

- Inherent Feedforward: The product offers information related to its inherent possible actions and appeals primarily to the perceptual motor skills of the person (e.g., pushing, sliding, rolling)
- Augmented Feedforward: is information from an additional source about the action possibilities of a product or system, or the purpose of these action possibilities. It appeals primarily to the cognitive skills of users (e.g. on-screen messages, and lexical or graphical labels)
- Functional Feedforward: goes beyond the action possibilities and their specific purpose and instead informs the user about the more general purpose of a product and its functional features. A possible strategy for functional feedforward is making the functional parts visible.

2.3.8.3 Relevance of Wensveen et al.'s work

Wensveen et al.'s framework concatenates the different types of information the user can receive from and about an interactive system i.e. inherent, augmented and functional information (encompassing feedback and feedforward) with the six aspects of a natural coupling between action and reaction i.e., time, location, direction, dynamics, modality and expression.

The authors present an adaptation of their framework to assess electronic products, GUIs, NUIs and TUIs. Wensveen et al. (2004: 182) explain that NUIs "that make use of gestural and speech interfaces exploit the cognitive and perceptual motor skills of a person”. The authors explain that technologies for gestural input lacked inherent feedback and feedforward and completely relied on couplings through augmented feedback and feedforward. As a result, users received little information about these action possibilities.

The argument presented in this thesis about the current lack of perceptible affordances for gestural interactions resonates with the rationale of NUI's ‘action-function’ coupling presented by Wensveen et al. Indeed if ‘Action’ and ‘Inherent information’ were preceded by affordances that indicated how to initiate gestures, users would be better informed as to how to perform the gesture itself (represented by the ‘Augmented information’) and aware of the effect/impact over the system (‘Functional information’).

2.3.9 Vermeulen et al.’s Feedforward

Vermeulen et al. (2013) reframed feedforward by disambiguating it from related design principles such as feedback and perceived affordances, and identified new classes of feedforward. The authors produced a comparative table of different authors' descriptions of the different qualities of affordances, feedforward and feedback.

A key argument of the paper is that feedforward is not yet fully matured within the body of HCI research. Therefore, its meaning and purpose within HCI is not yet fully understood, and in turn there is no existing canon of evaluation methods that assess this attribute when designing new interfaces. The authors carefully disambiguate feedforward from closely related design principles, such as feedback and perceived affordances. They furthermore identify new classes of feedforward.

Vermeulen et al. explain Kaptelinin and Nardi's (2012) definition of two different types of affordance: instrumental technology affordances, which are comprised of a handling affordance (an action possibility) and an effecter affordance (the purpose of an action). For example, the ability to drag the scroll box of a scrollbar is the handling affordance, whilst the ability to display a certain portion of the document in the window is the effecter affordance. The authors also describe a set of ‘auxiliary technological affordances’ such as maintenance, aggregation and learning affordances. The authors focused on instrumental technology affordances – and in particular effecter affordances – as these appear to be quite similar to feedforward.

2.3.9.1 Relevance of Vermeulen et al. work

The critical contribution of this paper to the thesis is to support the likelihood of feedforward being capable of providing a pivotal technique for creating designs that improve user performance when encountering new interactions.

Vermeulen et al.'s reframing of Hartson's (2003) four types of affordances (Chapter 2: 2.3.5) are highly relevant. Figure 9 illustrates these definitions and shows how perceived affordances, feedforward and feedback relate to each other and are linked to Hartson's four types of affordances.

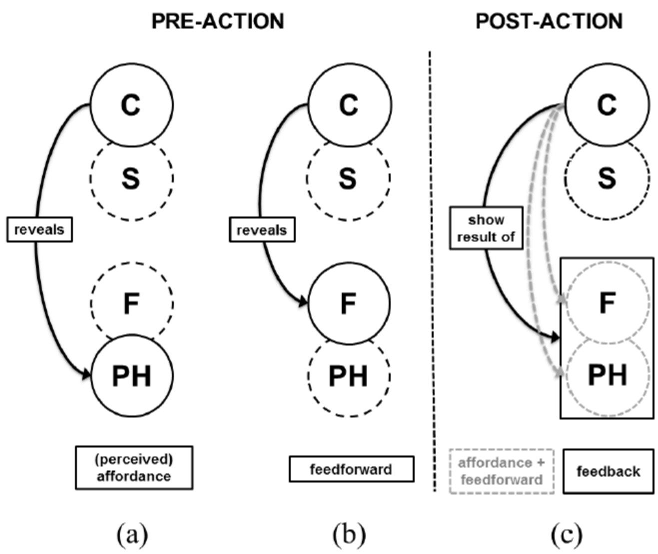

Figure 9: Perceived Affordances, Feedforward and Feedback as reported by Hartson's Cognitive, Sensory, Functional and Physical Affordances (Vermeulen, 2013: 1938).

Both perceived affordances and feedforward tell users something about a particular action through a combination of physical and functional affordances. While perceived affordances reveal the physical affordance (PH), which tells users that there is an physical action available and how to perform it, feedforward reveals the functional affordance (F), which tells users what will happen when they perform that action.

Norman always implied that perceived affordances were provided with a well-defined sensory (S) and cognitive affordance (C). Vermeulen et al. explain, "feedback provided after performing an action might afterwards again serve as feedforward for the action that logically follows the previous one." In its simplest form, it is "nothing more than evidence for the user that he has acted on the action possibilities, as if it were a trace of the bygone action."

This design approach for SPG is in line with Vermeulen et al.'s elaboration on feedforward, as it describes "information that is offered *before* the action takes place." Bau and Mackay (2008) reinforce this by stating, "feedforward mechanisms provide information about a gestures shape and its association with a particular command, *prior* to the execution or completion of the gesture".

2.4 Building on Frameworks for a gesture-and-effect Model

Wigdor e al. (2009), state that, "currently there is no generalized visual language for conveying the various error conditions to the user [when unable to perform a gesture]. It is left to the application designer to reflect the state of the contact in some visual property of the application."

Several approaches (e.g. Cuomo and Bowen 1992; Lim al. 1996; Rizzo et al. 1997; Kaur et al. 1999; Hartson, 2003; Vermeulen et al., 2013) have used Norman's 'Gulfs of Evaluation and Execution' (1986) and Norman's Theory of Action (1988) and found it helpful for classifying and uncovering usability problems. Wensveen et al. (2004) built a 'Design Framework to Couple Action and Function' based on Norman's structured model. More recently, Vlist et al. (2012) wrote an article named 'Semantic Connections' built upon Norman's theory and Golod et al. (2013) produced the 'Design Principles of Hand Gesture Interfaces.'

All the aforementioned approaches to Norman's theory share something in common: a re-interpretation of his model in respect to usability issues and the introduction of novel interaction techniques and visual interfaces that diverge from WIMP-GUI. The authors did not, though, attempt to operationalize Norman's concept into a practical and instrumental tool for analysis. This is a gap this thesis aims at covering, by adapting the theory of action into an actual model and corresponding rating tool.

The next section summarises Norman's Theory of Action (1988) and explains its importance as the overarching concept that guided the development of a working model to assess gestural interfaces. It also presents a selection of authors that re-interpreted

Norman's theory and as a result updated some of the existing rules that define the model and its gulfs.

2.4.1 Norman's Theory of Action

According to Norman, in order for a person to execute an action, such as opening a door or clicking on a link, etc. they require a notion of the goal to be achieved and a plan towards that goal. Finally, the 'actor' should check if the goal was accomplished. To understand the 'Theory of Action' and its stages as a whole, it is important to first investigate the stages of execution and evaluation in separate.

2.4.1.1 Stage of Execution

Execution formally means to perform or do something. The goal has to be translated into an intention, which in turn has to be made into an action sequence. Thus, the formulation of stages of execution follows:

- Start at the top with the goal, the state that is to be achieved.
- The goal is translated into an intention to do some action.
- The intention must be translated into a set of internal commands, an action sequence that can be performed to satisfy the intention.
- The execution stage occurs in sequence, performed upon the world.

2.4.1.2 Stage of Evaluation

Evaluation formally means to examine and assess. The formulation of the stages of evaluation can be described as:

- Evaluation starts with our perception of the world.
- This perception must then be interpreted according to our expectations.
- Then it is compared (evaluated) with respect to both our intentions and our goals.

The theory proposes that stages take place sequentially, in terms of seven stages of an activity. The sequence is described as follows.

2.4.1.3 Seven Stages of Action

The ‘Seven Stages of Action’ constitute three stages of execution, three stages of evaluation and the goals. Norman (1988:45-53) combined the stages of Execution and Evaluation into the Theory of Action, and the model can be seen on Figure 10.

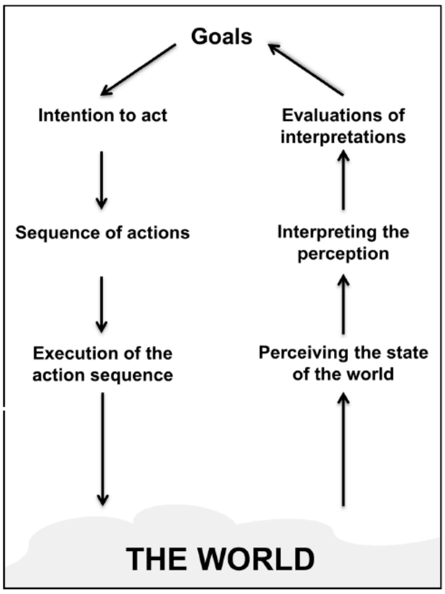

Figure 10: Norman’s Theory of Action (Norman, 1988: 47).

1. Establish a goal.
2. Form an intention.
3. Specify an action sequence.
4. Execute an action.
5. Perceive the state of the world.
6. Interpret the state of the world.
7. Evaluate the outcome with respect to goals and intentions.

Norman explains, “The seven-stage structure can be a valuable design aid, for it provides a basic checklist of questions to ask to ensure that the Gulfs of Evaluation and Execution are bridged (Norman, 1988: 52).

2.4.1.4 The Gulfs and the Model

The terms 'Gulfs of Evaluation and Execution' were introduced by Norman in a book entitled *User-Centred System Design: New Perspectives on Human-Computer Interaction* (1986).

The gulfs were later integrated in Norman's 'Theory of Action' (Norman 1988: 45-53) in his book, *The Psychology of Everyday Things*, which became a very influential view of human problem solving for the latest thirty years. The book was later republished as *The Design of Everyday Things*.

As can be seen in Figure 11, Norman explains that the 'Gulf of Execution' represents the difference between an individual's intentions and the physical actions that are actually possible in a physical system. The 'Gulf of Evaluation' reflects the amount of effort a person must exert in order to correctly interpret the actions necessary to properly engage with a physical system.

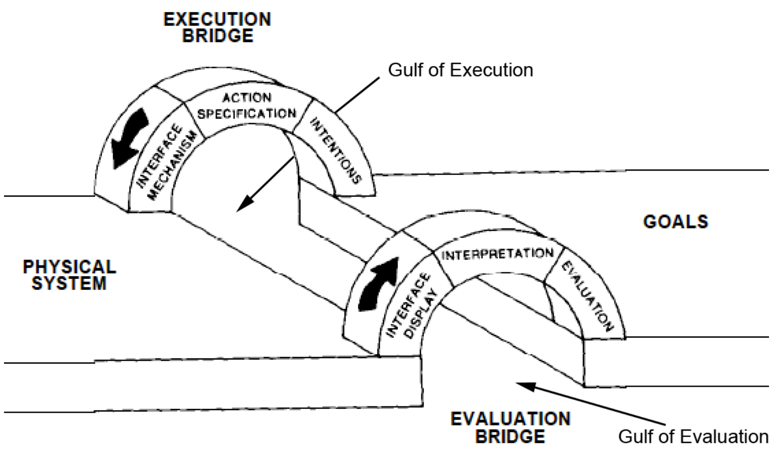

Figure 11: Norman's Gults of Execution and Evaluation (Preece et al., 2007: 121).

According to Norman's cycle of evaluation and execution, for users to effectively control a computer system they have to be able to identify what content is present, identify features for control of such content, be able to execute a specific command and receive feedback that informs them whether or not they have achieved their intended goals.

2.4.1.4.1 The Gulf of Execution

Thus, to determine the gulf of execution, we may ask how well the action possibilities of the system match the intended actions of the user. Norman explains that “in the rhetoric of the GOMS (Goals, Operators, Methods and Selection Rules) model, bridging the gulf of execution means that the user must form intentions, specify action sequences, execute actions, and select the right interface mechanisms”.

2.4.1.4.2 The Gulf of Evaluation

It is assumed that people need to perceive the world, to interpret and evaluate it in order to decide how to carry out an action, and not otherwise. Baerentsen (2002) explains:

> Perception is fundamentally an activity of picking up the appropriate and necessary information in the environment that specifies the possibilities and constraints for motivated activity and its operational makeup. The consequence for a user interface is that it must provide possibilities for exploration of the intended use and its possible forms.

The gulf of evaluation is the degree to which the system provides representations that can be directly perceived and interpreted in terms of the expectations and intentions of the user (Norman, 1988). Or put in other words, the gulf of evaluation is the difficulty of assessing the state of the system and how well the artefact supports the discovery and interpretation of that state (Norman, 1991).

To sum up, the gulfs of evaluation and of execution refer to the “mismatch between our internal goals on the one side, and, on the other side, the expectations and the availability of information specifying the state of the world and how me may change it" (Norman, 1991). For a surprisingly large number of everyday tasks, the difficulty resides entirely in deriving the relationships between mental intentions and interpretations and physical actions and states.

2.4.1.5 Relevance of Norman’s work

It is important to notice, that Norman’s theory is only meant as an approximation of what happens and has been deliberately simplified. It is intended to help designers and researchers to think about how best to design interfaces to enable users to monitor their actions with respect to their goals in terms of various stages of action.

It is understood that human beings are driven by goals (Vicente, 1999) and once a goal is set, tools, menus, and any additional information becomes secondary. Baerentsen (2002) explains with regards to activity theory that “although a motive and a goal remain constant, the ways of achieving the results may differ according to circumstances”.

Preece et al. (2007: 120) explain that in reality however, human activity does not proceed in such an orderly and sequential manner. It is more often the case that some stages are missed, others repeated, while others appear out of order. Furthermore, many users do not have a clear goal in mind but react to what appears on the screen.

St. Amant (1999) contends, “users only rarely consider the buttons and other icons in an interface explicitly; instead, they treat the interface as a window onto a larger work environment, flexibly creating abstractions on the fly and shifting between problem-solving viewpoints”. St. Amant stresses the need to understand in detail how and why users interpret visual and interaction cues in the ways that they actually perform interactions - this depending on research in a wide variety of areas in HCI and cognitive science.

According to Dourish (2004: 72), in Suchman’s model (1987), interaction is an on-going, improvised activity: “Actions are organised in response to the features of the setting in which they arise: action is a ‘situated’ phenomenon.” Chow et al. (2011: 98) argue that interactive systems can be designed with specific attention to the embodiment of intentionality (‘evocative meaning-making’) and temporality.

Norman concludes the chapter on his model by producing the following recommendations for interface design. Each point provides support for one or more of the seven stages of action and can be applied to tangible interfaces such as a radio or a washing machine display and also to digital ones, such as a website or a mobile application. The recommendations are:

• Good conceptual model. The designer provides a good conceptual model for the user, with consistency in the presentation of operations and results and a coherent, consistent system image.

• Good mappings. It is possible to determine the relationships between actions and results, between the controls and their effects, and between the system state and what is visible.

• Feedback. The user receives full and continuous feedback about the results of actions.

2.4.2 Hartson's Affordances and Norman's Gulfs

Hartson (2003) associates four types of affordances (reported in topic 2.3.5) with Norman's stages-of-action model (Figure 12, annotation outside the box) and the gulfs of evaluation and execution. Hartson (2003: 328) explains the human 'Goal' is placed at the top of the picture, which represents a user formulating an intention to act in their work domain. The goals are separated into tasks and then into specific intentions, which are mapped to specifications for action sequences.

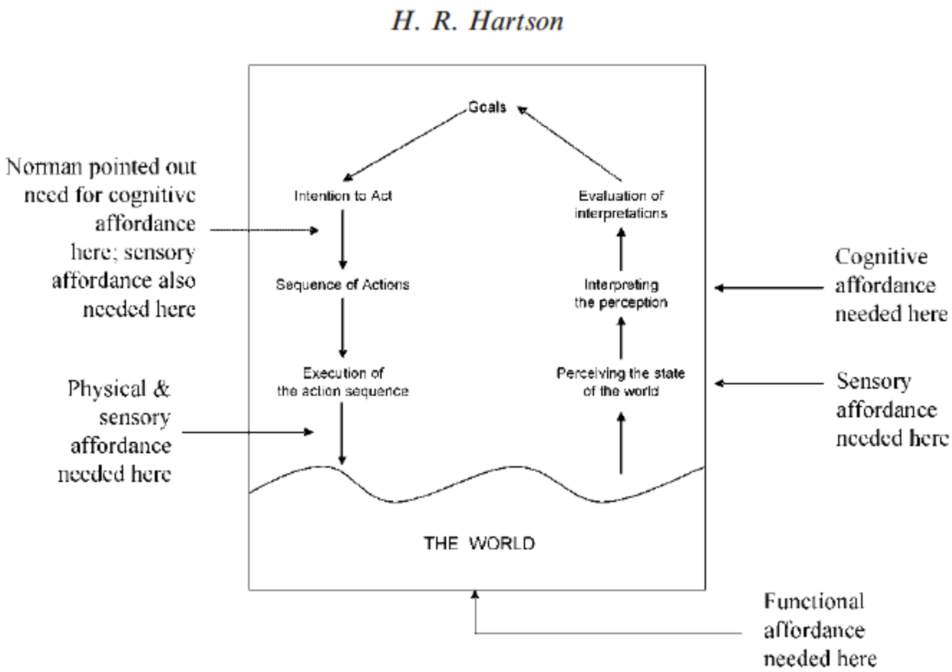

Figure 12: Hartson's review of Norman's stages of Action (Hartson et al., 2003: 328).

The user then executes the physical actions, causing a state change in the physical world, which is then sensed by the user via feedback, interpreted, and evaluated by comparing the outcome to the original goals. The interaction is successful if the actions in the cycle so far have brought the user closer to the goals.

The right-hand side of the model is where users evaluate their actions by comparing system feedback describing outcomes against their goals and intentions. This is the point where users need the most help in knowing about outcomes.

Although cognitive affordances can be used to help the user with mental activities anywhere in the top part of Norman's diagram, Hartson highlights the essential role cognitive affordance (e.g. cues given by labels, icons, and prompt messages) plays on the left-hand side of the model. This is the point where users map intentions into an action sequence of specific actions prior to making the corresponding physical actions, and is the point where users need the most help in knowing how to do things with a machine, an object or a computer system.

Hartson (2003: 328) recommends inserting a 'Functional' affordance as a bridge between the two gulfs to aid users anticipating the effect of their actions.

2.4.3 Vermeulen's Feedforward and Norman's Gulfs

Vermeulen et al. (2013) in their review of Norman's Theory of Action (1988:45-53) place feedforward, in their model, within the 'Execution' gulf, as a bridge between 'Intention to act' and 'Sequence of actions' (see Figure 13).

In addition, Vermeulen et al. place perceived affordances within the 'Execution of the action sequence' and feedback within the 'Evaluation' gulf as a bridge between 'Perceiving the state of the world' and 'Interpreting the perception'.

Vermeulen et al. (2013) present feedforward as a powerful design principle that can bridge Norman's gulf of execution and evaluation, "…in the sense that it signifies to the user what they can expect *when performing* a certain action" and "feedforward can help users in performing the correct gesture by telling them what will happen *when* a certain gesture is invoked".

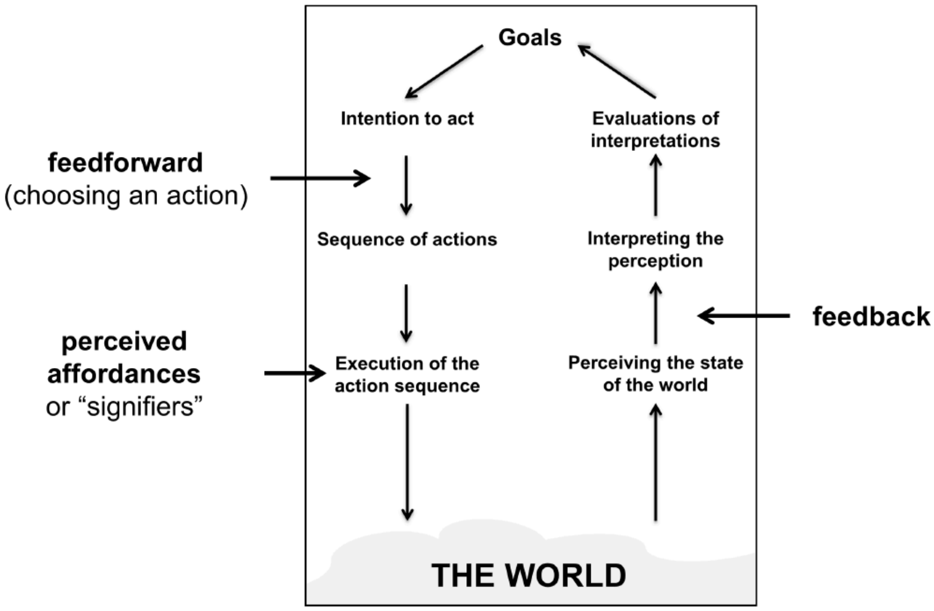

Figure 13: The position of perceived affordances (or signifiers), Feedforward and feedback in Norman's Stages of Action model (Vermeulen et al., 2013: 1931).

2.4.4 Wu's Registration, Relaxation, and Reuse for Touch Surfaces

Wu et al.'s (2006) *Gesture Registration, Relaxation, and Reuse for Multi-Point Direct-Touch Surfaces* paper was written before the first iPhone was released (Block, 2007) and gestural interactions became extremely popular. Wu aimed to develop design principles to enable designers to construct new freehand, multi-point and multi-shape gestural interaction techniques.

This paper describes how although "interesting gestural interaction techniques have been proposed at the time, their design has been mostly ad-hoc and has not been presented within a constructive design framework". The authors contend that "at the current state of development of tabletop interfaces, there is yet to emerge any semblance of standard interface elements that would serve as a baseline comparison for current designs".

Wu et al.'s (2006) research omits any direct reference to Norman's Theory of Action, and as a result lacks the theoretical insight, which is one of the main goals of this thesis. This leaves the opportunity for connecting the problems in execution with problems in understanding. There is also the potential to use the three phases as diagnostic tools to compare different affordances or designs and how well they assist the user in grasping the actions available as well as how to execute them. Given Wu et al.'s focus strictly on execution, this approach on its own will not assist a researcher to understand potential interactions if the user takes no risk in trying out potential actions.

2.4.4.1 The RCT Design Concept

Wu et al. (2006) introduce the concepts of gesture that were termed "registration", "relaxation", and "reuse". This permitted the explicit discussion of gesture performance through a consistent interaction vocabulary. A short definition of the original nomenclature follows:

- Gesture Registration: "The registration phase is entered by a distinctive posture that, once recognized, sets the context for the dynamic and end phases. The registration phase clearly delineates one context from another, enabling gesture reuse in various phases of the entire compound gesture." Later in their paper Wu et al. (2006) explain, "A more sophisticated approach to registration considers both the hand posture and dynamic actions that occur immediately after the posture is recognized, within a predefined time window." This approach was explored thoroughly in the description of the *Continuation* phase within Freeman's (2009) work.
- Gesture Relaxation: "We propose the principle of gesture relaxation to allow a gesture to be performed with minimal constraints after it is registered. Relaxing the shape and dynamics of gestures after registration allows someone to more comfortably perform a gesture, as tension would only be required in the gesture registration phase".
- Gesture and Tool Reuse: "Gesture and tool reuse refers to employing the same gesture, including hand postures, finger touches or stylus, to accomplish different tasks." Wu et al. (2006), and Wobbrock et al. (2009) explain that the "reuse of primitives" enables larger sets of gestures to be constructed without requiring additional primitive gestures to be defined.

Their three phases were later adapted and renamed into the now commonplace "registration", "continuation" and "termination", or RCT, by other researchers. This is seen in the works of Freeman (2009), Wobbrock (2009) and Wigdor (2011), and this thesis retains the same modified terminology.

According to Wu and his co-authors "a gesture consists of three stages. The user *registers* (Registration) the gesture with an initial posture when they first touch the device, then *continues* (Continuation) by performing some actions (possibly further disambiguating the gesture) while maintaining contact, and then *terminates* (Termination) by lifting their hand from the device.

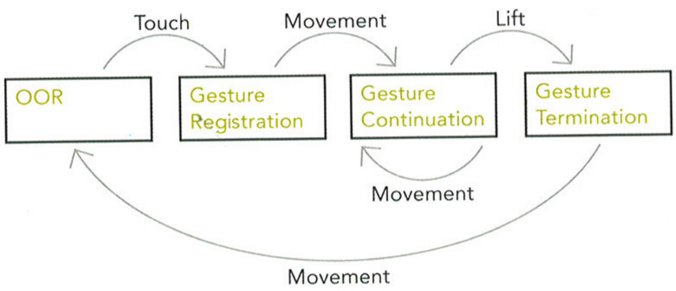

Figure 14: Wu's the three stages of gestural input on a touch system. OOR stands for "Out of Range" (Wigdor and Wixton, 2011: 127).

This was an early example of separating different aspects of a gesture. Their three phases emphasise the execution of the gesture by the user, rather than the understanding of the user regarding the action to be performed. As a result of this emphasis, the insight into user comprehension through the model is relatively limited, but it is a strong diagnostic tool for separating different problems users have in executing a gesture.

2.4.4.2 Wu's Methodology

Wu et al. (2006) stress the importance when designing direct-touch surfaces of making evident to users "the style of interaction and the available tools since these factors can significantly influence design". They conducted a user evaluation with the following tasks: annotate, wipe, moving images, copy-n-paste, pile-n-browse.

In their approach, each user-test session started with instructions on how to gesture to perform actions on the tabletop. These instructions took the form of watch and repeat, with the experimenter performing a gesture and the participant immediately imitating it. They primarily investigated visual feedback for the continuous actions. This differs from the approach taken in this thesis, which in empirical studies showed participants a system that would automatically 'self-preview' affordances for touch and multi-touch, before users attempted to interact.

2.4.4.3 Key Insights from Wu's et al. work

1. Understanding the concepts of gesture "registration", "relaxation", and "reuse" and its later adaptation to RCT helped the dissection of the anatomy of gestural interactions, therefore influencing design choices of trade-offs.

The following point is less central to the research, but provides some general observations that are still germane to gestural interactions.

2. Even though this research does not approach issues brought up by Wu et al., such as occlusion or touch angle/system recognition and fatigue from continuous use of arm stances, it is considered that such characteristics can undeniably impact the design of touch-based systems.

2.4.5 Marshall's Decision Making Analysis

Marshall et al. (2007) conducted extensive investigations with eye-tracking and measurements of pupil diameter in response to mental effort for decision making.

Marshall introduced the 'Schema Model for Problem Solving', which is a method for assessing cognitive strategies and cognitive workload based on eye measurements, which they claim can be adapted to evaluate interfaces in general.

2.4.5.1 The Schema Model for Problem Solving

In a study that analysed the activity of tactical team decision-making during a military exercise with naval officers, Marshall (2007) introduced a schema model (Figure 15) for the domain of problem solving. She explained that communication within teams takes the form of specific statements that convey the necessary Identification (1), Elaboration (2), Planning (3) and Execution Knowledge (4).

The steps pertaining to Marshall's model could resemble both Norman's (1988) stages of evaluation and execution. From the establishment of a goal, towards the execution itself, a person needs to identify control features available, in order to elaborate a plan ("specify an action sequence" in Norman's model) before any action takes place. Interestingly enough, Marshall introduced different variables, such as time (when?), agents (who?), their roles (doing what?) and prioritising a specific action (why?) in addition to cause (what is happening now?) and effect (the output itself).

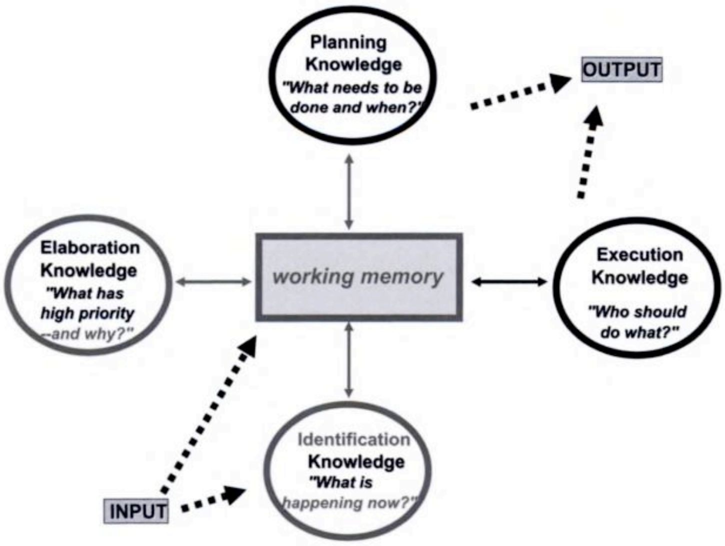

Figure 15: The schema model of decision-making (Marshall, 1995).

In the empirical study reported, Marshall recognises the importance of the context as well, by placing agents in a dynamic scenario where they should adapt to different events in a set of time constraints. By asking short-term questions, Marshall et al. was able to elicit participants' perception of context and on-going adaptation of plans in a dynamic scenario.

2.5 Building on Frameworks for a Gestural Interface Design

This section investigates existent frameworks that conceptualise design for Post-WIMP and gestural interfaces.

2.5.1 Beaudoin-Lafon Framework for Designing Post-WIMP Interfaces

Beaudoin-Lafon (2000) introduced the 'Instrumental Interaction model', which generalises and operationalizes direct manipulation. The author analysed WIMP interfaces and novel interaction techniques that were emerging at the time (e.g. two-handed input and augmented reality).

Beaudoin-Lafon applies the model to a new interface for searching and replacing text, but does not present empirical data or user feedback about the design implementation phase. The model "extends and generalises the principles of direct manipulation of higher-level user interface objects and defines a design space for new interaction techniques with a set of properties for comparing them".

2.5.1.1 The Interaction Model

Beaudoin-Lafon starts his rationale on the *Interaction Model* by explaining 'Instrumental Interactions' and 'Types of Activation'.

According to the author, 'Instrumental Interactions' is the paradigm that defines GUI. It is subdivided into 'Domain Object' and 'Interaction Instruments'. Domain objects are the users' primary focus of attention within a given application, such as the information they seek, the text they want to read or the picture they want to manipulate. Interaction instruments are mediators between the user and domain objects: the user acts on the instrument, which transforms the user's actions into *commands* affecting relevant target domain objects. An instrument is activated when it is under the user's control, or in other words when the physical part (e.g. mouse click) has been associated with the logical part (e.g. button on an interface).

The activation of *domain objects* has different costs, which is defined by 'Types of Activation.' Activations are subdivided into 'Spatial' and 'Temporal'. The author explains: "Spatial activation requires the instrument to be visible on the screen, taking up screen real-estate and requiring the user to point at it and potentially dividing the user's attention. Temporal activation requires an explicit action to trigger the activation, making it slower and less direct."

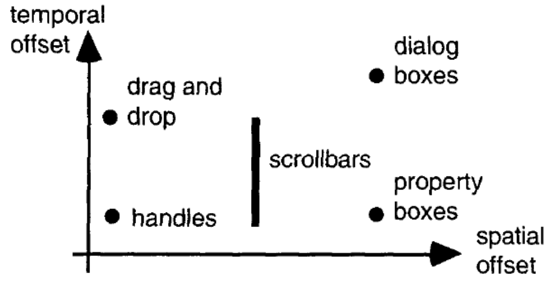

Figure 16: Degree of indirection (Beaudoin-Lafon, 2000: 450).

Beaudoin-Lafon's (2000) main contribution to this thesis is the model itself and the properties of *instrumental interactions*, described next. The author's reasoning is clarified with a comparison between WIMP-GUI and a gestural interface.

2.5.1.2 Relevance of Beaudoin-Lafon' work

Beaudoin-Lafon describes the properties of 'Instrumental Interactions' with the purpose of analysing existing interaction techniques. The properties are described as follows:

- Degree of Indirection: combines the temporal and spatial offsets. For comparison purposes, the degree of interaction of a WIMP-GUI has a larger temporal and spatial cost in comparison with a gestural interface (e.g. Apple iOS). The first requires identification of the pointer position in relation to a target object, manipulation of the mouse and moving the pointer towards the object. In a gestural interface, the temporal cost relies only on the user being able to spot the target object on the screen and touching a finger onto that object.
- Degree of Integration: It explains that some controls can be activated in different forms; for instance, panning over a document can be achieved with two scrollbars in a conventional UI or touch and drag in a gestural interface. The latter has a degree of integration of one interaction point and is therefore more efficient than two scrollbars, which incur additional activation costs.
- Degree of Compatibility: The degree of compatibility measures the similarity between the physical actions of the users on the instrument and the response of the object. "Dragging an object has a high degree of compatibility since the object follows the movements of the mouse. Scrolling with a scrollbar has a low degree of compatibility because moving the scrollbar downwards moves the document upwards". In gestural interfaces the manipulation of digital objects directly follows the touch movement.

The author goes on to recognise that further work is needed to develop the model. This requires "a more thorough analysis of graphical interfaces and interaction techniques, the definition and evaluation of new properties, a taxonomy of interaction instruments, and an exploration of the design space defined by the model".

2.5.2 Jacob's Framework for Designing RBI

Jacob et al. (2008) propose the notion of Reality-Based Interaction (RBI) as a unifying concept that ties together a large subset of emerging interaction styles, such as "virtual, augmented reality, tangible interaction (TUI), ubiquitous and affective computing, and mobile and tacit interactions."

The authors provide a framework that can be used to understand, compare, and relate current paths of recent HCI research as well as to analyse specific interaction designs.

Jacob et al. (2008) state:

> "Physical technologies attempt to make computer interaction more like interacting with the real, non-digital world. By drawing upon these themes of reality, emerging interaction styles often reduce the gulf of execution (Norman, 1988), in other words the gap between a user's goals for action and the means to execute those goals".

The 'Framework for Designing Post-WIMP Interfaces based on RBI' combines four themes of human experience with the real world with six UI design aspects. Each theme is exemplified in turn, with affordances and feedforward currently available in gestural UI.

• Naïve Physics: People have common sense knowledge about the physical world, e.g. gravity, inertia and "thus iterate with the world conjecturally."

By knowing the world, people can predict specific behaviours in the case of physical acts being applied over *digital* objects, which resemble familiar objects. As an example, if you swipe a finger from left to right over an icon, it or its properties will move from left to right. Figure 17 exemplifies this action, where the pictorial content *suggests* the movement the user is supposed to perform, with the appropriate touch-based activation (use of one finger only).

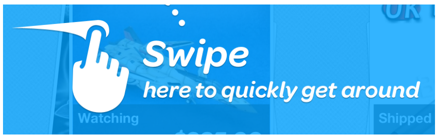

Figure 17: eBay for Apple iOS: detail of instruction (London, May 2012). The Berne Convention allows the non-profitable use of software print screens.

• Body Awareness & Skills: People have awareness of their own physical bodies and possess skills for controlling and coordinating their bodies.

Jacob et al. (2008) explain "the expressiveness or intensity with which ones perform a gesture can generate different results over an object, e.g. the harder one performs a brush stroke gesture, the harder the brush stroke will appear on the screen". Figure 18 displays an example within this category, but an arbitrary one.

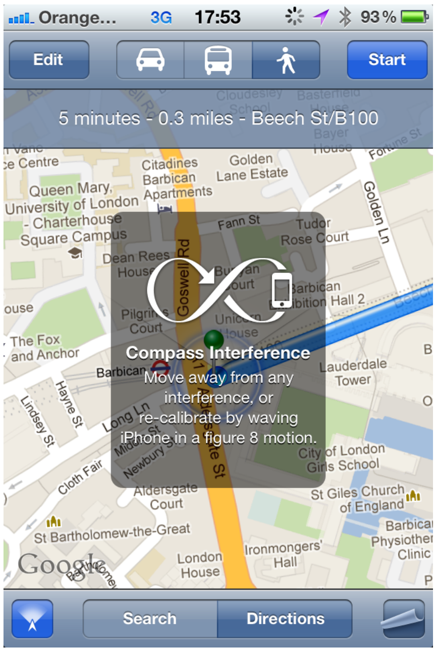

Figure 18: Google Maps in Apple iOS iPhone: compass interference and 'figure-of-eight' motion to recalibrate (London, July 2012). The Berne Convention allows the non-profitable use of software print screens.

It is possible to see in Figure 18 a visual cue that appears when iPhone presents compass interference during maps application use. The user is supposed to perform a figure-of-eight gesture with their iPhone in order to remove any source of interference and re-calibrate the in-built compass – which relies on physical awareness and skill to perform the appropriate gesture. It is possible to speculate though, whether a user would be tempted to draw the figure-of-eight gesture indicated with his finger over the screen instead of correctly moving the device itself.

• Environment Awareness & Skills: People have a sense of their surroundings and possess skills for negotiating, manipulating, and navigating within their environment.

• Social Awareness & Skills: People are generally aware of others in their environment and have skills for interacting with them.

2.5.2.1 Implications for Design

Jacob proposes that the goal of the RBI framework (Figure 19) is to "make design trade-offs by giving up reality only explicitly and only in return for other desired qualities."

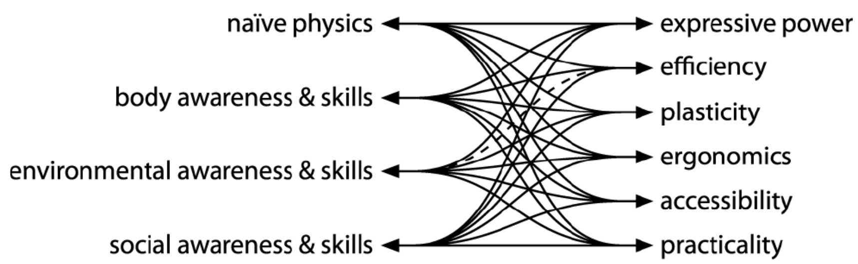

Figure 19: RBI design trade-offs (Jacob et al., 2008).

These are:

• Expressive Power: If visual perception aspects of interactive objects were strongly considered, e.g. colours, contrast, etc. users will be able to grasp the *phenomena* of a visual entity making itself present.

• Efficiency: Users can perform a task rapidly.

• Versatility: Users can perform many tasks from different application domains.

• Ergonomics: Users can perform a task without physical injury or fatigue.

• Accessibility: Users with a variety of abilities can perform a task.

• Practicality: The system is practical to develop and produce.

It is possible to see in Figure 19 the design trade-offs between the four real world themes and desired qualities of RBI:

2.5.2.2 Relevance of Jacob et al. work

Note that while the RBI framework explicitly highlights design trade-offs, it does not provide a structured methodology for discussing these trade-offs. According to Jacob et al. (2008) “the reality-based interaction (RBI) framework is primarily a descriptive one”:

> “Viewing the emerging generation of interfaces through the lens of reality-based interaction provides researchers with explanatory power. It enables researchers to analyse and compare alternative designs, bridge gaps between seemingly unrelated research areas, and apply lessons learned from the development of one interaction style to another. It can also have a generative role by suggesting new directions for research, such as incorporating RBI themes in the design of interfaces for different user populations (e.g. children or expert users) or studying the effects of different degrees of RBI themes in an interface”.

2.5.3 Golod et al.’s Design Principles on Hand Gesture Interfaces

Golod et al. (2013: 11) claim that despite the drastic increase in post-desktop input devices and interaction techniques, the industry still “lacks in specific and applicable design principles for these systems”.

The authors provide design principles, based on the fusion of different concepts from related literature and projects, e.g. Schmidt et al. (2002), Sato et al. (2012) and Wilson (2010). Similar to Freitag (2012), Golod et al. (2013) designed an unobtrusive ubiquitous system for hand gesture for *microinteractions*, which relies on data collected from depth-cameras situated over a surface table. The system and interface were created to test the overall evaluation success and the applicability of the proposed design principles.

Golod et al. (2013) explain ‘microinteractions’ with reference to Ashbrook (2010), as “interactions with a device that take less than four seconds to initiate and complete”. These are non-main task interactions that are performed on the go “without distraction from the main task, e.g., controlling the music while driving a car”. The authors also introduce the concept of 'gesture phrase' and explain how this contributes to a more intuitive as well as more precise definition of interaction periods concerning hand tension and feedforward/feedback continuity.

2.5.3.1 Golod et al.'s Design Principles

Golod et al. (2013: 13) explain that multiple HCI design principles have been assessed in the form of heuristics produced by different authors (e.g. Norman, 1998; Shneiderman, 1998; Bellotti et al. 2002).

On the one hand these heuristics can be helpful in WIMP-GUI projects. On the other hand they lack specialization while being applied to a specific project, especially the emerging Post-WIMP interfaces. In response to the shortage of methods to design and evaluate emerging surface and gestural interfaces, the authors proposed the 'design phrase', depicted in Figure 20. The phrase demonstrates that hand gesture interactions can be divided into *microinteractions* (2013: 17).

Golod et al. explain the applicability of microinteractions supported by the use of a self-revealing pie menu within a gestural UI. This menu appears around a user's hand as soon as an activation gesture is performed. The gesture described consists of placing the hand on a touch screen and making a crumple-like gesture.

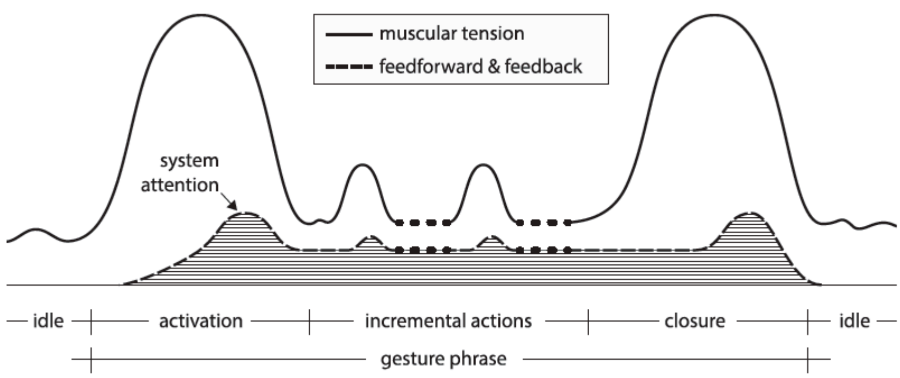

Figure 20: Schematic representation of a gesture phrase (Golod et al., 2013).

The 'Gesture Phrase' unites a sequence of single gestures and the system's reactions into one segment and defines one command. It depicts the segmentation of that gesture, which is subdivided into system feedforward and feedback (dotted lines) and the execution of the gesture itself (straights lines). The activation is described as an unconventional gesture, which ensures that the system does not start accidentally. Feedforward and Feedback provide continuous feedforward and feedback, e.g., system attention, as described by Baudel & Beaudouin-Lafon (1993) in Charade's system. The feedforward in this example is provided by animations of sectors moving to the hand menu as well as an appropriate sound support the pulling metaphor of the gesture. Incremental Actions support (additional) different single gestures within the same gesture phrase (e.g., next/previous song). Closure is the last phase that provides feedback, hence helping the user to identify the end of the gesture phrase.

The authors explain that pre-studies revealed that this gesture had good characteristics concerning the robustness–learnability trade-off. However, no design process was enlightened in their paper, neither was data supplied of how participants acquired the gesture (e.g. were they left to discover or instructed in advance).

2.5.3.2 Relevance of Golod et al.'s work

Golod segmented the physical execution of the gesture itself (termed 'muscular tension'), which was broken down into the 'activation', 'incremental actions' and 'closure' *microinteractions*. The authors emphasised the importance of a system that provides continuous feedforward and feedback.

The thesis also envisions feedforward embedded in a system that displays the available interactions before the "discrete execution of a command" occurs. However, Golod et al. cautions (2013: 15) that if the feedforward threshold is not enough, frequent appearing feedforward might be quite disturbing for the user. Therefore, system designers have to "trade-off between continuity and calmness of feedforward/feedback".

2.6 Summary

The first part of the literature review reported on the differences between Graphical User Interfaces (GUI) and Natural User Interfaces (NUI). This approach was made to clarify the emerging challenges with the introduction of new interaction techniques and unfamiliar GUI representations that were different from the mouse-based desktop-metaphor (regarded as post-WIMP).

The second part reviewed the theory of perceptible affordances (Norman, 1988; Gaver, 1991; St. Amant, 1999; McGrenere, 2000; Kaptelinin and Nardi, 2012) and feedforward (Djajadiningrat et al., 2002; Wensveen et al., 2004; Vermeulen et al., 2013), which were introduced to complement perceptible affordances. The feedforward technique is responsive to a user interacting with a digital interface and can help users anticipate the results of their actions. This aspect of feedforward demonstrated great potential for the development of a new design concept presented in this thesis that aims at making gestural interfaces more evident.

The third part of this review aimed at substantiating the creation of an analytical model for gestural interfaces. It reports on Norman's Theory of Action (Norman, 1988:45-53) and offers a selection of reviews for the purpose of updating its gulfs to apply to novel interfaces. It covered the work of Marshall et al. (2007), Vermeulen et al. (2013), Chow et al. (2011, Baerentsen (2002). Wu et al.'s (2006) description of the Registration, Relaxation, and Reuse phases for 'Multi-Point Direct-Touch Surfaces' demonstrated potential to update Norman's execution cycle to the gestural model introduced in this thesis (later described in Chapter 6).

The fourth part of the literature review drew upon a selection of authors' design processes for gestural interfaces. This was done to support actual design activity, planned for two empirical studies presented in this thesis. The review encompasses the work of Beaudoin-Lafon (2000) on an 'Instrumental Interaction model' for designing post-WIMP, Jacob's (2008) framework for designing post-WIMP interfaces based on reality-based interaction (RBI) and Golod et al. (2013) 'Design Principles on Hand Gesture Interfaces for Microinteractions'.

The next chapter continues the literature review, though with a different emphasis. It reviews design practices in industry in designing novel gestures to users, for instance, 'help systems', 'self-revealing menus', 'gesture-completion paths' and 'self-revealing' gestures.

CHAPTER 3 - A SELECTION OF APPROACHES TO DESIGN GESTURAL INTERFACES

3.1 Introduction

This chapter presents a survey of existing design approaches for communicating the available gestures in a touch interface to its users.

It further investigates the *first* 'problem statement' (Section 1.3), which describes the 'lack of awareness' users have of how to *initiate* touch for a gestural interaction and the lack of *supporting designs* for that interaction. This has previously been investigated by research on 'help systems' (Chow, 2011; Grossman et al., 2010) and 'self-revealing menus' (Kurtenbach and Buxton, 1991; Guimbretiere, 2012; Vermeulen, 2013). Previous research has introduced 'gesture-completion path' techniques for gestural interfaces: Bau & Mackay (2008) with 'OctoPocus', Freeman et al. (2009) with 'ShadowGuides' and Bennett et al. (2011) with 'SimpleFlow'. Each of these approaches intended to mitigate users' unfamiliarity with gestures by training them through visual prompts that the system displays in response to a user's touch on the screen.

Despite the progress made as a result of these different designs, and the useful evidence that they bring for more effective designs than were previously used in industrial practice, the baseline interface design practice for touch devices still lacks evident visible cues or perceptible affordances to support a user in identifying what gestural commands are available.

The *second* 'problem statement' described a 'lack of visual designs *before* interaction' in standard research in gestural interfaces. None of the techniques in this review show users how they are supposed to initiate a gesture within the context of an interaction. Rather, each responds to a user in order to guide them in the completion of a gestural command that they have already started. Freeman et al. (2009) goes further than others and gives visual indications on how to touch the screen. However, this critical cue is displayed in a training window separated from the main view of the application, and may well be overlooked by users if their attention is focussed on the main view.

The *third* 'problem statement' identifies the issue that there is 'no systematic understanding of which parts of identifying and performing gestures most contribute most to the errors that users make'. To further set a foundation for studying this area, we review previous work that aimed to dissect or distinguish types of gestural actions. Freeman et al. (2009) investigate multi-touch, gestural and hand-shape interactions on surface technology. They make a distinction between static and dynamic gestures: static gestures involve no movement after a user's first touch, while dynamic gestures require the user to move their finger away from the first point of contact. Wobbrock et al. (2009) identify factors such as which fingers or body parts make contact with the screen, and the physical scale of the gesture. However, none of these authors operationalize their taxonomies into a practical tool to assess gestural interactions, nor do they try to empirically demonstrate which parts of gestures users most commonly fail to perform, such as the number of touch points or the direction of a gesture.

The review in this chapter acknowledges, but does not cover, research that describes gestures performed with a hovering mechanism (Cheung et al., 2012), tangible feedback (Lefebvre et al., 2012), pressure (Heo and Lee, 2013; Rendl et al., 2014; Pedersen and Hornbaek, 2014), 3D posture, or multi-user configuration and the implications of social context (Hinrichs and Carpendale, 2011). It also does not cover the design of large interactive displays which enable the use of both hands and more than 5 touch points (Wu and Balakrishnan, 2003; Wigdor and Benko et al., 2011), nor does it cover mid-air gestures (Nancel et al. 2011; Aigner et al. 2012; Sodhi et al. 2012).

3.2 A Selection of Gestural Interface Issues

Many applications that support gestural interactions make use of metaphor-based GUIs. However, there is generally insufficient 'affordable' information about how to execute the gestures and what their effects will be. The user often ends up adapting to a system without ever knowing its full potential, which leads to inefficient use and failure.

Three major gaps were therefore identified, which point to missed opportunities in the design of gestural interfaces. These are:

1. No consistent representation of touch points has been displayed by gestural interfaces so far.

The *first* gap pertains to gesture 'representation'. No consistent representation of touch points has been displayed by gestural interfaces so far. The *continuation* (the movement) and *termination* (the effects of) a gestural interaction are demonstrated to users (according to Wu et al.'s terminology, 2006), but not how to *register* it (the initial touch configuration and the number of touch points).

There are three problems in triggering a command by gesture (Wu, 2006; Freeman, 2009; Wigdor and Wixton, 2011): the first is the problem of 'registering' the correct number of touch points; the second is making the right gesture (e.g. swipe, touch and hold, pinch) in the right direction; and the third is knowing the command that will be triggered. There is in general a lack of affordances to indicate gestural opportunities for interaction.

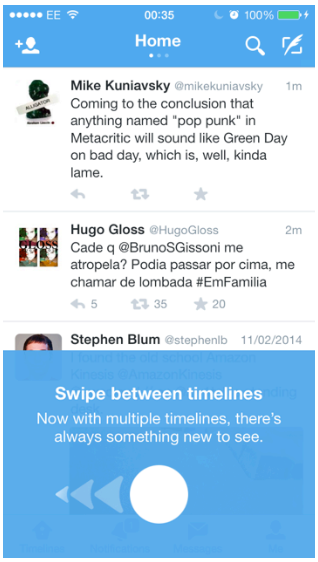

Figure 21: Swipe screen tutorial for Twitter for Apple iOS (London, March 2014). The Berne Convention allows the non-profitable use of software print screens.

As previously reported (Chapter 2), Feedforward may help clarify to the user what manipulation is required when utilised in interface design to preview to users which interaction to perform and its effects. In the example in Figure 21, the application shows the availability of a horizontal swipe gesture to reveal hidden content. A static representation of a touch-point and a directional arrow, together with an additional text, are used for this purpose. However, if the user misses this instruction after touching the cue once, he/she will not find any other control to bring it back. More importantly, the use of feedforward in an animated form may have been more efficient at demonstrating this gesture to users.

In an example of an efficient use of feedforward in a touch-based device, Figure 22 demonstrates the different stages displayed by a control present on a Microsoft Surface 2 table home screen. The first frame shows the icon that a user is supposed to press (the perceptible affordance). In the second frame it is possible to see that touching the screen reveals the movement the user is supposed to perform and where the icon should be moved (the feedforward component). The third and fourth frames display the user performing the gesture and the icon changing state and fading.

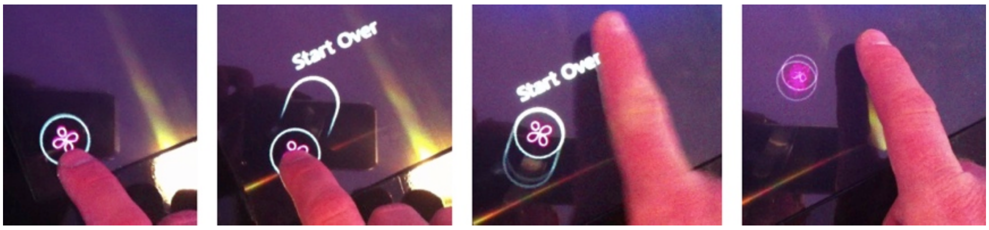

Figure 22: Microsoft Surface 2 (detail): control to unlock home screen and appropriate gesture (picture taken by the main researcher - London, March 2012). The Berne Convention allows the non-profitable use of software print screens.

Figure 23 shows a playback video screen in YouTube for the iPad. In order to minimise the video playback area (a), users have to perform a very unfamiliar gesture and there are no affordances or feedforward to demonstrate this gesture. A diagonal swipe towards the right hand bottom of the screen (b) can be used to minimise a playback video (c). The sequence also demonstrates that placing the finger over the minimised video and swiping across the screen towards the left will result in closing it completely (d). The use of feedforward could have helped mitigate this issue by providing visual cues to aid users in becoming acquainted with such unfamiliar gestures and anticipating their effects.

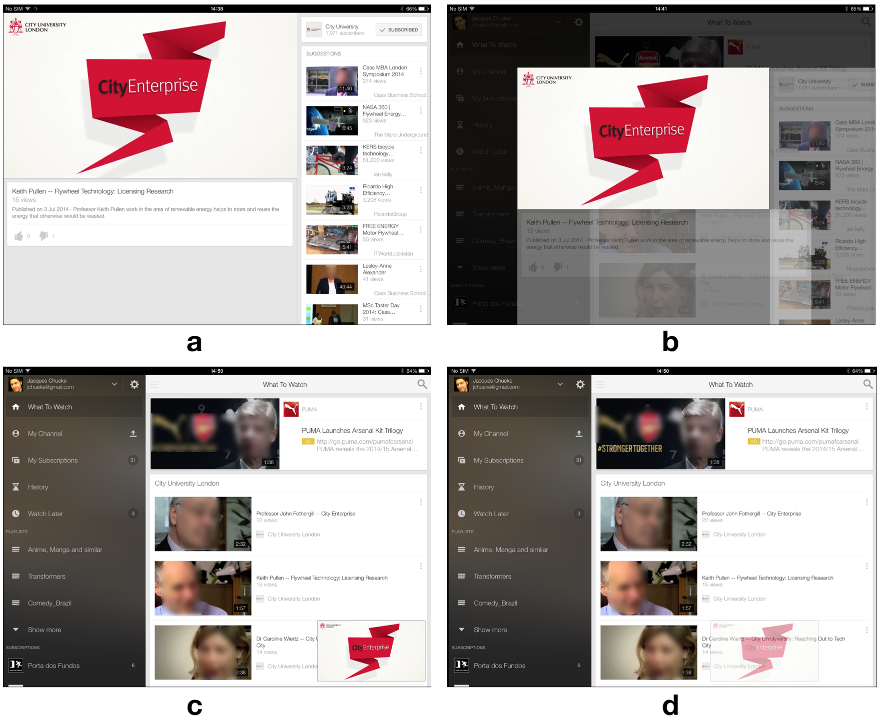

Figure 23: YouTube for iPad - unfamiliar minimise video gesture (London, July 2014).

In another example, an efficient use of feedforward for touch interaction is given. Figure 24 shows Facebook for the iPad (iOS 7) while a user touches and holds a specific chat icon (flagged with an arrow). The system in response displays the target zone necessary to close or 'hide' that chat. Even though users were initially unaware of this particular feature, the interface was designed to consistently inform them about this feature every time they initiate a dragging action with a chat icon.

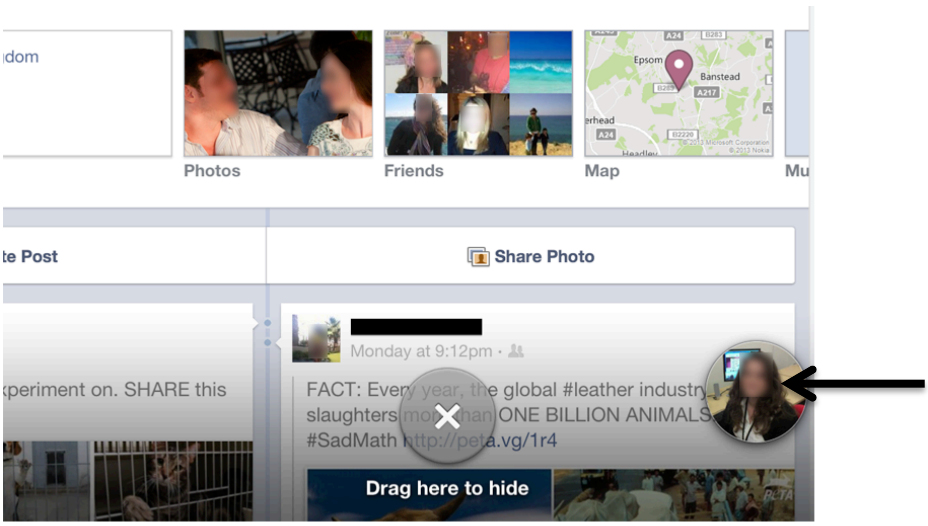

Figure 24: Facebook for iPad, iOS 7 during drag and hold a chat 'icon' (London, July 2014).

2. No automatic presentation of visual prompts to communicate to the user the available multi-touch gestures and hidden UI menus and tools.

Directly related to the previous gap, the *second* gap pertains to gesture 'discoverability'. We have established that perceptible affordances for touch are marginally visible.

For instance, several researchers introduced gesture-completion path techniques to train users in gestures and used feedforward *in response* to their participants' attempts to execute gestures. Examples are Bau and Mackay's Octopocus (2008), Freeman et al.'s Shadowguides (2009), Wigdor et al.'s Ripples (2009), Bennett et al.'s SimpleFlow (2011), and Gutwin et al.'s FastTap (2014). These prompts are presented by the interface only in response to interactions users have already started. This approach to interaction is viable and lower error rates in the execution of gestures were observed in comparison to baseline solutions. However, this approach does not aid gesture discoverability and hence does not demonstrate the appropriate fashion to initiate gestures (registration, according to Wu et al., 2006).

It has been observed that various mobile applications and desktop programs conceal menus and toolbars in literally every corner of the screen (some interactions start from the bezel e.g. Jain & Balakrishnan, 2012). This represents yet another unfamiliar way to interact, because in most cases there are no affordances to indicate the existence of such UI elements. For instance, *Microsoft's* 'Metro dashboard' (Whitney, 2014) interface, which allows for pointer device and gestural interaction, displays a general lack of proper signage for its hidden menus and toolbars (used in MS Windows phone, X-Box 360, Surface tablet and Windows 8 desktop). These interfaces support touch commands that start off-screen without any visual indicator. For example, in Windows 8 the user can reveal menus (Figure 25) and trigger mode changes with swipe gestures from different bezel sides towards the screen (Figure 26).

Figure 25: Microsoft Windows 8 OS Metro dashboard screen. Swiping from the right edge displays a context sensitive menu (picture taken by the main researcher - London, March 2012). The Berne Convention allows the non-profitable use of software print screens.

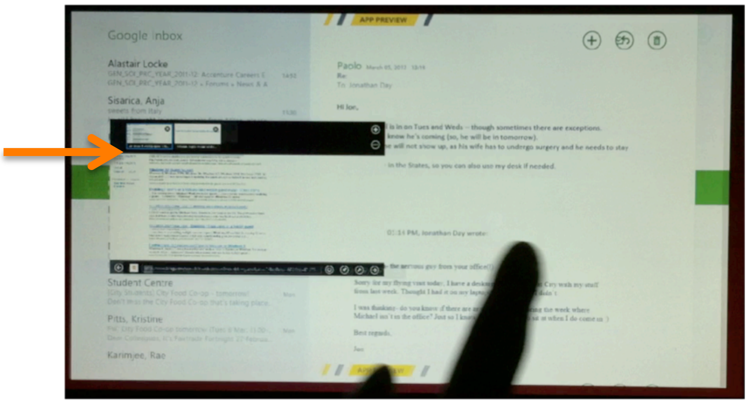

Figure 26: Microsoft Windows 8 OS Metro dashboard screen. Swiping from the left edge displays running applications (picture taken by the main researcher - London, March 2012). The Berne Convention allows the non-profitable use of software print screens.

In another example, Apple's iOS 7 conceals a *notification centre* tab (Figure 27) that gathers all updates available from the system, such as email messages, application warnings, alarms, calendar, etc. There is an affordance that should indicate something hidden on the top of the screen (a), which is the notification tab. The user should perform a swipe downward starting from the top bezel to reveal the tab (b). This visual cue is rather discrete and not very informative: it does not embed a clear representation of the available gesture to perform, nor the correct direction, nor its effect.

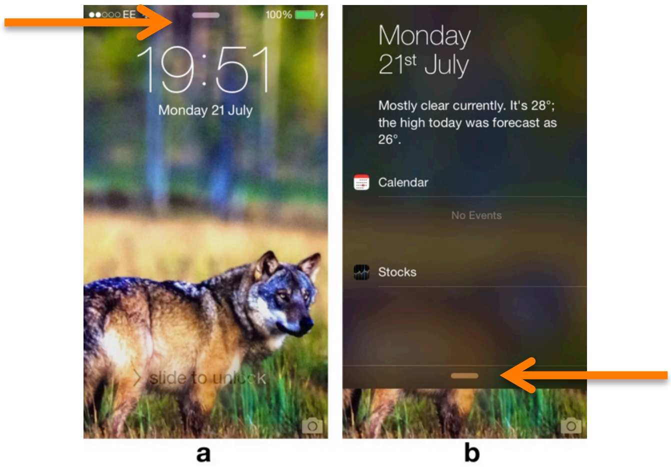

Figure 27: Apple iPhone iOS. Hidden notification tab (London, July 2014). The Berne Convention allows the non-profitable use of software print screens.

3. The 'static nature' of tips and tutorial screens is insufficient to communicate gesture undertaking.

The *third* shortcoming, or gap, is that the 'static nature' of tips and tutorial screens is insufficient to communicate gesture undertaking. In many cases, visual representations of gestures, if present, are usually displayed when an application is first launched. These are generally static and rely on textual labels to express the potential action (Figure 28).

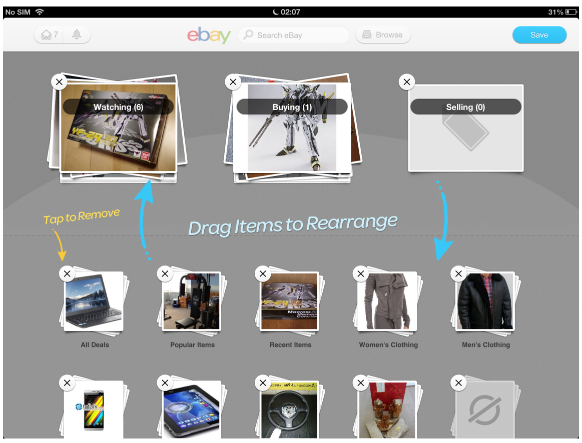

Figure 28: eBay for Apple iPad iOS: Introductory screen (London, January 2014). The Berne Convention allows the non-profitable use of software print screens.

This limits the communication of movement required for the gesture. As a result, even if users are aware of the existence of a 'command', they may be unaware of the exact gesture that triggers that effect. Yet again feedforward – but in animated form – would provide the additional information to aid users in understanding the required movement to successfully complete a gesture.

As observed in mainstream devices, there is no persistent cue to indicate the existence of gestures, the set of available gestures or their effect. Some gestures completely rely on textual messages, as can be observed in Figure 29. The screen demonstrates one of the first messages a user receives after updating to iOS 7 on iPad & iPhone: "Spotlight Has Moved".

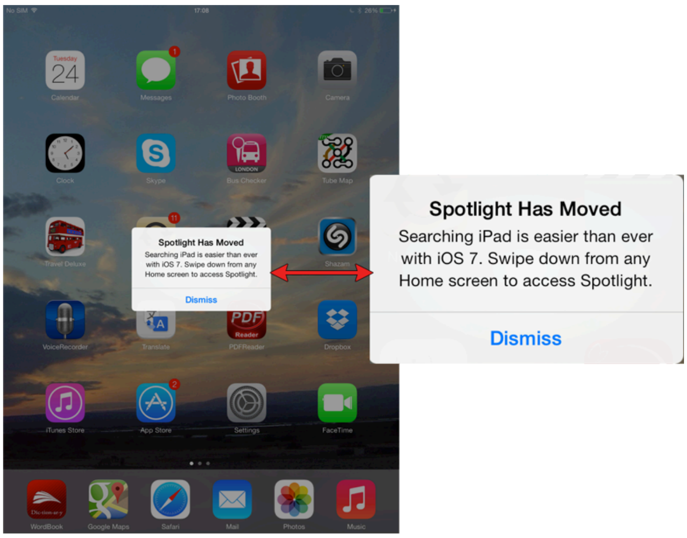

Figure 29: Apple iPhone iOS 7 warning message on how to find Spotlight (London, Sept 2013). The Berne Convention allows the non-profitable use of software print screens.

However, the example above does not inform the user that only a vertical downward swipe gesture specifically from the centre of the screen will reveal the 'spotlight' tab. An attempt from the top bezel brings a notification tab and hence does not deliver the desired effect. Indeed, because many iOS users did not notice the prompt message, complaints were made as can be observed by the following remark in a Tweet (@serversideup, 11 Jun 2013): "It took way too long to figure this out… Here is where Apple hid Spotlight Search in iOS 7" (Serversideup, 2013).

Apple iOS has recently introduced textual descriptions of gestural interactions in the 'update screen' of several applications in order to circumvent users' lack of awareness about gestural interactions (Figure 30). The instructions describe 'touch-and-hold' interactions to edit conversations and messages. This kind of interaction is still rather unfamiliar to users and presently lacks affordances to indicate its presence or opportunity.

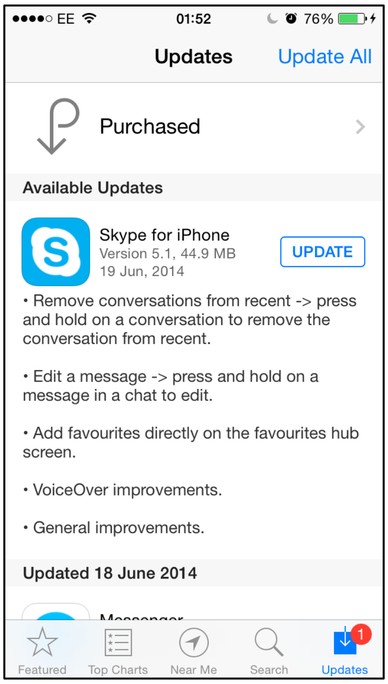

Figure 30: Apple iPhone iOS 7 update screen for Skype V. 5.1. (London, Sept 2014). The Berne Convention allows the non-profitable use of software print screens.

Another interaction feature by which a number of iPad application interfaces attempt to circumvent this issue is by presenting 'tutorial' screens (Figure 31) upon the first run of an application or program. These multi-step tutorials are designed to inform the user about the multitude of gestures, hidden menus and toolbars.

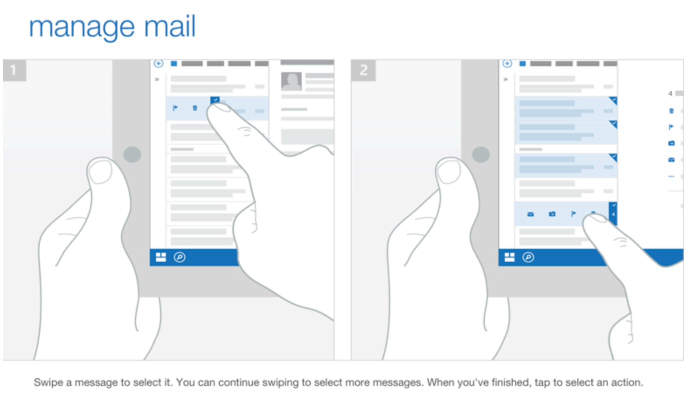

Figure 31: OWA for Apple iPad tutorial screen (London, Sept 2013). The Berne Convention allows the non-profitable use of software print screens.

Humans, however, are teleological (Rasmussen, 1983). Hence, they are driven by objectives and not instructions necessarily. Therefore, this sort of step-by-step tutorial can represent a sub-optimal solution and users consistently avoid them. This can happen for many reasons particularly when users are multi-tasking under a high cognitive load or time constraints to achieve their goals. Should the user decide to ignore the tutorial, he/she is likely to be unaware of the best use of the software and part of its interactive potential can be lost, especially because, as observed, in many cases there is no link or button to summon the tutorial screen back.

The Blackberry Playbook tablet uses a different approach whereby a specific 'help' application 'teaches' the user the many different sorts of swipe gestures available and informs the user about the 'sensitive' bezel from where hidden menus can be pulled out. The interface makes use of animated arrows and text descriptions to demonstrate different multi-touch and swipe gestures (Figure 32).

Figure 32: Blackberry Playbook tutorial application (London, Aug 2012). The Berne Convention allows the non-profitable use of software print screens.

However, the interface does not demonstrate the interactions within their context because the program runs only as a stand-alone help application. Knabe (1995) and Kang, Plaisant & Shneiderman (2004) reported on issues of non-integrated documentation and help and the importance of integrating initial guidance within the context of the applications in a seamless fashion.

This thesis, in order to mitigate the aforementioned gaps, introduces a new design concept. It is termed 'self-previewing' gestures (SPG), and this technique combines perceptible affordances and feedforward to embed in the interface visual prompts that '*preview*' to users how to initiate and perform a gesture (e.g. one finger swipe from canvas), as well as the effects from a particular gesture (e.g. to reveal a hidden menu). The SPG is displayed *before* users even touch the screen and animation shows their movement and implied effect (see Chapter 5).

3.3 Building on Taxonomies and Interface Techniques

A number of authors have reported taxonomies for gestures (Karam, 2005; Wu et al., 2005), or undertaken research in multi-touch table devices (Dietz et al., 2001; McNaughton, 2001; Han, J., 2005; Benko, H., 2009a and b; Bailly, G., 2010; Annett et al., 2011) and produced guidelines and techniques to support different aspects of the design process and the creation of new models of interaction for gestural interfaces (Benford et al., 2005; Freeman et al., 2009; Wobbrock et al., 2009).

As reported by Bennett et al. (2011), various styles of visual feedback have been proposed for gesture entry, such as Kurtenbach & Buxton's Gedit (1991), Bau and Mackay's Octopocus (2008), Freeman et al.'s Shadowguides (2009), Wigdor et al.'s Ripples (2009), Bennett et al.'s SimpleFlow (2011), Gutwin et al.'s FastTap (2014).

Often the feedback styles are for enhancing pre- and post-gesture entry. Research on pre-gesture feedback aims to help users know and remember what set of gestures are available, while post-gesture feedback helps users understand whether they successfully entered a gesture, and if not, what went wrong during gesture entry. As previously reported, the feedforward technique effectively enhances the during-gesture execution.

The next section reports a selection of research into prototypes that required adaptations to the UI, to 'afford' touch input and gestural techniques.

3.3.1 Help Systems

Traditional help systems normally deliver out-of-context general help information and it falls to the user to relate this information to the problem at hand (Sukaviriya, 1990).

Several authors have tried a different approach to help within systems, by providing contextual help that allows users to invoke some form of aid during interaction in case they get stuck. This can be seen in the work of Palmiter et al. (1991), Halsted et al.

(2002) and more recently Chow (2011). Furthermore, these help systems provide animation as a supportive media in an attempt to enhance system messages and improve user understanding of instructions (Vanacken, 2008).

Another well-known approach to teaching users about how to use the controls available in a system is the use of tutorials (Harms et al., 2011). Tutorial systems can help to reduce errors (Huang et al., 2007) or support transfer of learning. Ramachandran et al. (2005) and Kelleher et al. (2005) used Artificial Intelligence planning methods to offer contextual help to users in step-by-step tutorials and Grossman et al. (2010) embedded video in their instructions. The contextual help is generally displayed in certain parts of the interface, either overlapping content or splitting the screen into portions. Interestingly, this interface solution resembles 1998 Apple iOS ‘Coach marks' (Quinn, 1988).

The step-by-step approach to providing help information has been adapted in some gestural interfaces. Many Apple iOS applications use this approach on an application’s first run (e.g. Figure 33). However, it is often the case that the tutorial disappears after the user finishes going through its steps and links or other controls to bring it back are seldom to be found. In some cases, these tutorials are mandatory and there is no option to skip them, which can represent another form of frustration to users.

Figure 33: The Guardian tutorial in Apple iPad iOS (London, April 2012). The Berne Convention allows the non-profitable use of software print screens.

Myers et al. (2006) contend that help systems for interactive applications have been studied extensively and that many help systems are designed to “help with the gulf of execution (Norman, 1988): teaching users how to perform actions, primarily to learn about a command they already know the name of, or learn how to perform tasks”. Myers et al. designed an application named ‘Crystal’ for Windows, which consists of a pop-up window (named ‘Why’) that can be invoked by users to provide an “automatically-created explanation” of possible issues and interaction opportunities related to the active window or mode. The application also ‘flags’ the control or widget referent by linking it to the explanation with a red stroke line. The authors claim that this approach can aid users whilst in the gulf of evaluation.

A number of systems have allowed the user to go into a special mode and click on controls in the interface to get help on them. For instance, LabView (National Instruments, 2005) provides a question mark (?) icon that works in a similar way to some Windows dialog boxes. Interestingly, a similar approach has been adopted in software for mobile devices. In several iOS applications (iOS version of 2012) the interface displays a ‘help’ layer with tags and sticky notes (similar to Kang et al., 2004) at first run. The user can tap anywhere to disengage the help mode and some applications offer a question mark icon (?) or, in the example given (Figure 33), an information icon (i) to summon these visual cues back. Customarily, this approach does not display ‘animated’ events.

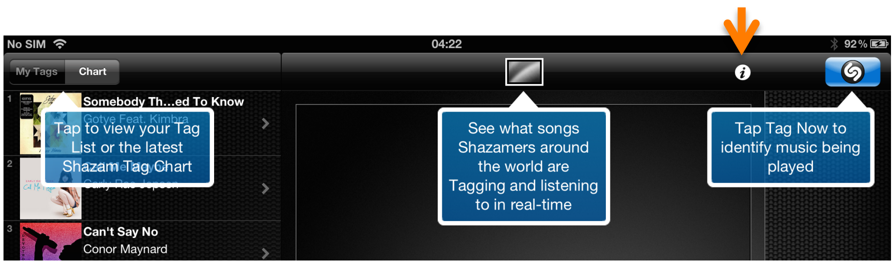

Figure 34: Detail of Shazam V2.7.0 help mode in an Apple iPad iOS, (London, April 2012). The Berne Convention allows the non-profitable use of software print screens.

3.3.2 Self-Revealing Menus

Some researchers have tried to update interface designs to accommodate emerging input technologies such as stylus and gestural interactions (Vermeulen, 2013; Golod, 2013).

Initial developments occurred in the field of self-revealing menus and gestural shortcuts, whereby users could use a stylus or touch gestures to trigger unfolding menus of different shapes and sizes (e.g. radial, unconstrained, or rectangular) and perform interaction shortcuts with pre-set gestures. Examples are Wiseman (1969), Callahan (1988), Kurtenbach & Buxton (1991), Kurtenbach (1993), Lenman (2002), Harrison (2008), Bragdon et al. (2009), Bailly et al. (2010), Lepinsky (2010), Guimbretiere (2012), Seto et al. (2012) and Samp et al. (2013). These menus in turn would guide the user in the selection of possible options stemming from their original selection, providing a form of 'path-driven' shortcut similar to the extinct 'symbol' commander (Internet Archive, 2002).

In a different approach, Gutwin et al. (2014) report on a thumb-and-finger shortcut technique (FastTap) for menu selection in a touch tablet as an alternative to marking menus (Kurtenbach & Buxton, 1991; Kurtenbach, 1993; Agarawala and Balakrishnan, 2006; Bau et al. 2008). This interaction consists of a radial menu triggered by a simple stroke or any other specific gesture command. The user then can choose a command with a simple pre-determined gesture (Figure 35). Kurtenbach (1993) explains the important point is that the physical movement involved in selecting a command is identical to the physical movement required to make the mark corresponding to that command.

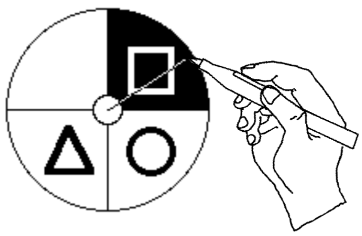

Figure 35: A radial (or "pie") menu is displayed when a user keeps the pen pressed. An object can then be selected from the menu (Kurtenbach, 1993).

The next section reports on Kurtenbach & Buxton's (1991) paper, which raised fundamental questions with regards to the design of an interface that would 'self-reveal' novel interaction technique for a stylus-based prototype graphical editor.

3.3.2.1 Kurtenbach & Buxton's Issues in Combining Marking and Direct Manipulation Techniques

Kurtenbach & Buxton (1991) reported a prototype graphical editor named 'GEdit'. GEdit permitted a user to create and directly manipulate objects (squares, circles and triangles) using shorthand and proof-reader style markings using a stylus as the input device. The authors ask fundamental questions regarding how to present the available interactions of a system more efficiently: "What do users expect? How do they know what to write and when? When and how do they use direct manipulation?" Kurtenbach & Buxton highlighted two key aspects, which may perhaps even be requirements, of a well-designed, touch-based device: these were firstly, *modeless* interfaces and secondly, the benefits of previewing potential interactions to users. In terms of modeless interfaces, they highlight that the need to select tools and functions from a menu palette is an undesirable step that causes "overhead in both the time and actions required to switch modes" which could result in errors. What they term direct manipulation techniques (Shneiderman, 1982) combine both command and object in a single interaction, resulting in a modeless interface.

The authors also coined the term 'self-revealing' many years before Wigdor and Wixton (2011) and Hofmeester (2012) adapted it to gestural interactions. The term is introduced when explaining the need for a system that in "itself supplies information on what commands are available and how to invoke them through the mechanism used to invoke commands". They explained that gestures are not intrinsically 'self-revealing' as the user needs to touch the surface by holding the stylus steady for a few moments before a menu of options is displayed.

The paper focuses on the design choices for gestures that permit the user to move, copy, delete and group objects. However, a drawback of the paper is that it does not provide empirical data from real users regarding actual use. The authors regarded GEdit as a 'test bed' for investigating direct manipulation in an interface. They articulate their interest in further studies that would explore ways of making other gestures in GEdit self-revealing. One approach they suggest would be to supply an 'on-line' graphical catalogue of gestures and they note the potential value of using animation to convey the available gestures more effectively to the user.

3.3.3 Gesture-completion paths

As described by Bau & Mackay (2008), Bennett et al. (2011), Sodhi (2012), Anderson (2013) and Roy et al. (2013), the myriad of paths to complete a gesture is revealed in response to a user moving their finger or a stylus in a particular direction. Nancel et al. (2011) term this form of responsive system 'passive haptic feedback.'

In the example of *SimpleFlow* (Bennett et al., 2011) the gestures were tested in a mouse-based desktop interface. A participant starts the gestural interaction by moving the finger diagonally (Figure 36a) and a small triangle is automatically displayed. The only possible gesture to be produced is a triangular one, as portrayed by the red triangle (b). This image represents the feedforward. The user makes an educated choice and executes the gesture appropriately (c). However, no 'explicit' effect or consequence of this gesture was displayed by the system – the purpose was solely to make the gesture evident.

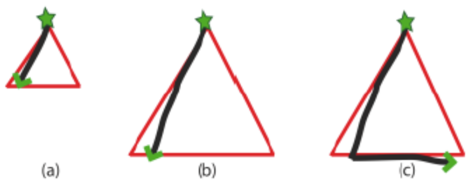

Figure 36: SimpleFlow, a gesture prediction and auto-completion path (Bennett et al., 2011: 592).

However, this technique lacks any form of perceptible affordance. The user does not know the required gesture at the outset, although the gesture has the opportunity to make 'itself' visible. Furthermore, the myriad of possible 'continuations' for finger movement (e.g. hold the gesture, contract, expand, swipe fingers in all sorts of directions, etc.) seem to require additional information to aid users in understanding the implied action.

In similar fashion, Bau & Mackay (2008) introduced *OctoPocus,* a prototype application that displays gesture-completion paths – or dynamic guides (Figure 37). The authors explain that these guides combine on-screen feedforward and feedback to help users learn, execute and remember gesture sets. The technique was applied to single-stroke gestures only.

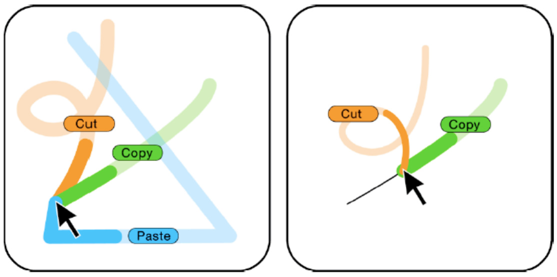

Figure 37: OctoPocus, displays three gestures and commands. Following the 'copy' path causes the other commands to disappear (Bau & Mackay, 2008).

The authors explain that "like marking menus, OctoPocus appears after a 'press and wait gesture' of approximately 250ms. However, for OctoPocus, both feedforward and feedback are continuously updated as the gesture progresses". The application reveals each gesture's ideal future path as well as how the recogniser has interpreted the current gesture. Additionally, it displays a textual label (prefix) that serves as feedforward to the intended command.

The dynamic guides appear only if the user hesitates. Empirical studies showed that expert users could execute commands very efficiently and were aware that by slowing down at any time during the interaction, the system would display the potential gestures and commands.

The next section reports on the work of Freeman et al. (2009). The authors describe a gestural prototype system termed ShadowGuides, which teaches users how to perform unfamiliar gestures. Freeman et al. conducted an empirical study and assessed participants' performances by classifying gestures according to fixed criteria.

3.3.3.1 Freeman's ShadowGuides

Freeman et al. (2009) created ShadowGuides (SG), which is a system that enables users to acquire the touch interactions required for completion of unfamiliar pre-defined multi-touch gestures.

The focus of the authors' study is on the use of large-scale surface devices, rather than hand-held or personal devices. They follow Wu's (2006) taxonomy of registration, continuation and termination (RCT) of a gesture and explain that the concept of ShadowGuides was intended to support all three phases. Feedforward mechanisms are used to "guide novice users, provide help in-situ to reduce the need for task switching, to provide a modeless gesture system so that novices and experts perform the same gestures, and to teach expert style in performance of gestures".

Freeman et al. (2009) have chosen to display visual cues in an offset from the user's touch points (Figure 38), to avoid occlusion of the main interface (similar to the work reported by Shen et al., 2006 and Vogel, 2012). This approach does not match the design of SPG, which are displayed *in situ* and overlaying the interactive object. These visual cues are categorised in the *registration pose guide*, which provides other alternative registration poses and the *user shadow annotation*, which is a gesture completion from the current hand pose. ShadowGuides were only displayed as a feedback response (labelled as shadow annotations) when a user initiated a gesture and they show where the user is supposed to follow a path along the surface. They labelled this mode a *dynamic continuation pose*.

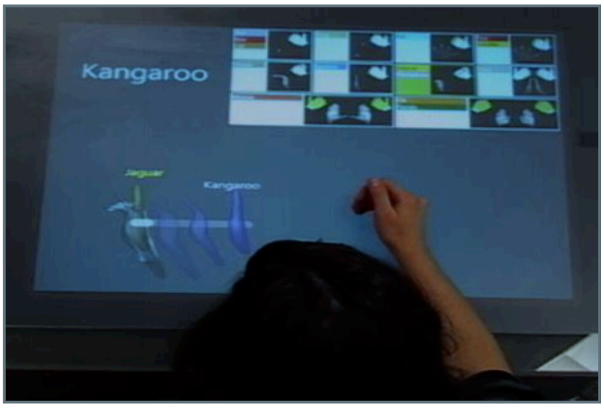

Figure 38: A user learning multi-touch gestures with ShadowGuides. The Registration Pose Guide is seen above the user's hand, and the User Shadow Annotations are to the left (Freeman et al., 2009).

3.3.3.1.1 Freeman's Gesture Taxonomy

Freeman et al. introduce a taxonomy of multi-touch and whole-hand gestures, which makes a distinction between static and dynamic gestures for the continuation phase. As with Hofmeester (2012), animation is used to help articulate the motion of a gesture. As can be observed in Figure 39 and in similar fashion described by Wu's (2006) RCT, the taxonomy distinguishes registration, continuation and movement of single and multi-finger gestures.

Freeman et al. (2009) contend that the use of multiple fingers and whole-hand shapes increases bandwidth relative to single-touch and pen gestures, "However, there is little convergence in user expectation in the mapping of multi-touch gestures to system actions, except for simple gestures (i.e. one finger, one hand)". The authors describe the issue of unfamiliarity with multi-touch gestures and emphasise that "teaching multi-touch and whole-hand gestures is a larger problem than single-touch gestures, primarily because the hand pose and the number of contacts can vary, both in the initial contact posture and throughout performance of the gesture".

Registration Pose	*Single Finger*	Initial touch with a single finger
	Multi-Finger	Initial touch with multiple fingers
	Single Shape	Initial touch with a single hand shape ('blob') (e.g., a palm down)
	Multi-Shape	Initial touch with multiple hand shapes (typically bimanual)
Continuation Pose	*Static*	Hand pose remains the same after registration; no relative movement
	Dynamic	Hand pose changes after registration (e.g., new fingers come in contact with the surface)
Movement	*No path*	Hand stays in place
	Path	Hand moves along a surface path

Figure 39: Taxonomy of multi-touch and whole-hand surface gestures (Freeman et al., 2009: 3).

The next section describes the work of several researchers who have explored the possibilities of end-users defining gestures on surface computing interfaces, instead of adapting and memorising pre-defined gestures.

3.3.4 User-Defined Gestures

It is useful to consider how gestures are defined. While some researchers appear to design gestures based on their own intuitions, others argue that gestures should be designed through engagement with users in order to develop an understanding of the potential rudiments or foundations for relevant gesture actions. Yet others believe that users should be able to 'program' the system to recognise gestures of their choosing.

Wobbrock & Wilson (2009) comment that gestures created by system designers do not necessarily reflect user behaviour. Furthermore, Rekik et al. (2013), Nacenta et al. (2013) and Oh & Findlater (2013) all report empirical studies with participants in order to explore the benefits of user defined gestures versus pre-defined arbitrary gestures. Rekik et al. (2013: 246) contend that multi-touch gestures "are often thought by application designers for a one-to-one mapping between gestures and commands", which does not take into account the high variability of user gestures for actions in the physical world. Instead they render a limited set of arbitrary gestures and sometimes simplistic interaction choices.

Nacenta et al. (2013) studied the recollection of free-form gesture sets for invoking actions by comparing three types of gesture sets: user-defined gesture sets, gesture sets designed by the authors and random gesture sets, in three studies. Oh & Findlater (2013) present a mixed-initiative approach. To understand the end-user gesture creation process, the authors conducted a study where "participants were asked to: (1) exhaustively create new gestures for an open ended use case; (2) exhaustively create new gestures for 12 specific use cases; and (3) judge the saliency of different touchscreen gesture features.

The next section reports on Wobbrock et al.'s (2009) user-defined gestures. The authors conducted a study on a Microsoft Surface prototype and drew on their user data to construct a four-dimensional *taxonomy for surface gestures*.

3.3.4.1 Wobbrock et al.'s User-Defined Gestures for Surface Computing

Wobbrock et al. (2009) explain that one of the major challenges in the design of gestures is to define the physical actions that should be used to trigger a specific effect or command (e.g. the deletion of a file).

The authors conducted an empirical study to elicit gestures from 20 non-technical users, with the eventual goal of informing designer's selection of effective gestures. In the study, users were first told the effect of a gesture and then were asked to perform the gesture that would trigger it. Through this approach, the researchers aimed to obtain an insight into user's anticipation of, or perhaps even model of, the potential gesture for a specific command.

Wobbrock et al. (2009) did not approach the design of gestures by drawing on the principles of perceptible affordances or feedforward. However, they mention that “Feedback, or lack thereof, either endorses or deters a user’s action, causing the user to revise his or her mental model and possibly take a new action”. Their user-centred focus together with their awareness of the importance of user expectations and interpretations, nonetheless echoes in part the chosen approach for the research conducted for this thesis and further emphasises the value of a directly user-centred approach to gesture design.

From their results, the authors underline the importance of the number of fingers in characterising a gesture, distinguishing between 1, 2, 3 and 5-finger gestures. The last of these proved difficult for users to distinguish. Wobbrock et al. drew on their user data to construct a four-dimensional *taxonomy for surface gestures*.

3.3.4.1.1 Taxonomy of Surface Gestures

The main contribution made by Wobbrock et al. is a surface gesture taxonomy, which comprises four dimensions: form, nature, binding and flow (Figure 40). The ‘form’ and ‘binding’ dimensions usefully identify the different components of a gesture, such as pose, static and dynamic instances, touch points, object-centric or context-centric.

Taxonomy of Surface Gestures		
Form	*static pose*	Hand pose is held in one location.
	dynamic pose	Hand pose changes in one location.
	static pose and path	Hand pose is held as hand moves.
	dynamic pose and path	Hand pose changes as hand moves.
	one-point touch	Static pose with one finger.
	one-point path	Static pose & path with one finger.
Nature	*symbolic*	Gesture visually depicts a symbol.
	physical	Gesture acts physically on objects.
	metaphorical	Gesture indicates a metaphor.
	abstract	Gesture-referent mapping is arbitrary.
Binding	*object-centric*	Location defined w.r.t. object features.
	world-dependent	Location defined w.r.t. world features.
	world-independent	Location can ignore world features.
	mixed dependencies	World-independent plus another.
Flow	*discrete*	Response occurs *after* the user acts.
	continuous	Response occurs *while* the user acts.

Figure 40: Taxonomy of surface gestures based on 1080 user gestures. The abbreviation ‘w.r.t’ means “with respect to” (Wobbrock et al., 2009: 4).

Wobbrock et al. (2009) elaborate on factors such as which fingers or body parts to use, the scale of the gesture and an indication of the pressure to apply, all of which can benefit the design of a gesture.

3.3.4.1.2 Relevance of Wobbrock et al.'s work

1. User perception of number of fingers: According to the authors, the user-defined gestures emerging from their study differ from sets proposed in the literature, because they allow flexibility on the number of touch points that can be used, rather than binding a specific number of fingers to specific actions.
2. Preference for number of hands: Wobbrock et al. observed that participants preferred 1-handed gestures for 25 of the 27 referents (action consequences).
3. Physics of digital objects: Unlike interactions with desktop interfaces, the laws of physics can be used to suggest specific gestures with different purposes, for example increasing speed to toss an unneeded object away, or applying pressure with one or more fingers to 'fix' another object in a particular corner of the screen. Wu et al. (2006) add: "(…) the physical affordances of the display and interaction surface, such as height or angle of incline, can affect the contact shape and dynamics of a gesture".
4. Bias from desktop paradigm: Wobbrock et al. also discovered that about 72% of gestures were mouse-like, one-point touches or paths. In addition, some participants tapped an object first to select it, then gestured on top of the same object thereby negating a key benefit of gestures, which is the coupling of selection and action.

The next section reports on Lao et al.'s (2009) gestural interaction design model for multi-touch displays. The authors conducted a study with a hand-held device and a multi-user surface table in order to elicit user motivation and preferences for specific gestures to manipulate pictures. Lao et al.'s computational system captured similar gestures for different purposes to acquire the most natural way users found to interact in both handheld and tabletop platforms.

3.3.4.2 Lao et al.'s (2009) Gestural Interaction Design Model for Multi-Touch

Lao et al. (2009) created a 'Gestural Interaction Design model', which offers a mapping between users' interpretation of gestures and software that captures their actual performance of gestures.

Lao et al. explain that their motivation for this endeavour was the lack of "a conventional comprehension of gestures, and the algorithms of gesture recognition vary from different software platforms". As a result, interaction designers create gestural interactions for each specific platform with the consequence that gestures cannot be reused across different platforms.

Lao et al. strongly defend the use of an 'intelligent' "gestural recognition middleware for all platforms" to capture users' natural preferences for gestural input as an approach to design a more intuitive system, rather than retrofit as has been done heretofore (2009: 445)". Lao et al. (2009) undertook a case study of two different platforms: iPad Touch, which is a PDA for personal computing and DiamondTouch, which is a surface tabletop system for multi-user interaction. They explain that users of the PDA usually have one hand holding the device so that only the thumb can move and this means that two-handed gestures (commonly used in tabletop applications) are limited. Thus the possible gestures for a PDA are a subset of those for a tabletop.

The authors used task analysis to define mapping rules between actions, motivation and computing levels. Lao et al. discovered that the same gesture could serve different purposes and emphasise the importance of identifying the most common denominator between users' preferences in order to design gestures.

3.3.4.2.1 Relevance of Lao et al.'s work

Lao et al. (2009: 441) make a distinction between gestures pertaining to specific applications and gestures that make sense when used to control the OS or the underlying platform.

This indeed is still one of the major design and computational issues when defining the interaction rules of a gestural system. Users still struggle to understand whether a gesture will affect the application only (for example a swipe will flag an email message for deletion) or if it will change some overall system configuration (for example the same swipe gesture closer to the screen bezel will reveal a hidden menu pertaining to the OS).

The authors also recommend the definition of gestures for specific tasks or 'sub-motivations'. Lao et al. (2009: 441) contend: "When we divide motivations into sub-motivations, the sub-motivations are usually exploring specific WIMP elements. We should try to reduce the WIMP elements to make the interaction and interface simple and clear (2009: 444)". In addition they stress the importance of capturing events such as speed, time per gesture and pressure over screen to obtain a wider understanding of users' preferences.

The next section reports on Wigdor and Wixton (2011) and Hofmeester's (2012) concept of Self-Revealing Gestures (SRGs). SRGs consist of visual cues that are displayed by the system in response to users touching the screen. These visual cues have the purpose of teaching users how to perform gestures.

3.3.5 Self-Revealing Gestures

A novel approach to teaching users how to use gestures while interacting with a system is the concept of 'Self-Revealing Gestures' (SRG) introduced by Wigdor and Wixton, (2011: 145), Hofmeester (2012) and Golod et al. (2013).

Wigdor explains that SRG are "one method of making the gestural interface self-revealing" in the context of the interaction. Wigdor continues, "objects are shown on the screen to which the user reacts, instead of somehow intuiting their performance". This is achieved through a 'meta-level interface object' (Kang, Plaisant and Shneiderman, 2004; Golod et al., 2013), that is, an object that overlays the existing visible interface content and which therefore lies 'behind' or 'beneath' it.

3.3.5.1 Wigdor and Wixton's Framework for Designing Gestures

Wigdor and Wixton (2011) present a thorough analysis of how to design gestural interfaces drawing on many example interactions with the Microsoft Surface, a project in which they were involved.

Several examples of gestures on touch-based devices are given, where the various steps are identified from the very first moment a user lays a finger or two on a screen in order to manipulate content or activate controls. The model considers the various possible system responses, including error, incorrect and false positive gestures, no feedback, and so on. In another example, Wigdor and Wixton (2011: 90-94) describe a design technique termed *tethers* touch feedback (Figure 41), which was used on Microsoft's 2007 Surface tabletop. These are a visual representation that 'feedforward' the extent to which one could stretch the target object.

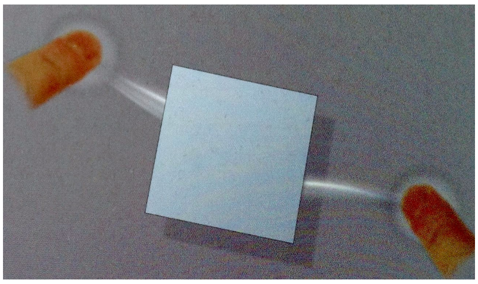

Figure 41: *Tethers* touch feedback found on Microsoft's 2007 Surface tabletop (Wigdor and Wixton, 2011: 90-94).

The authors explain – as a sensible approach in gestural interface design – that "interface control elements should not be presented if they are not needed." For instance, if a user is resizing an object in the MS Surface, he simply stretches it by touching it in two places and moving his fingers apart. However, the authors mention that they tested this interaction with dozens of users and observed, "this gesture is almost impossible to guess", except by users who have had previous experience with enlarging pictures on iPhones.

Notwithstanding the authors' thorough analysis on how to design for gestures, they do not provide experimentation and user feedback data from real usage of touch-based devices.

3.3.5.1.1 Key insights on Self-Revealing Gestures

In describing SRG, Wigdor and Wixton (2011: 145-156) write: "Objects are shown on the screen to which the user reacts, instead of somehow intuiting their performance". The "trick", as the authors contend, is to not overload the user with UI 'chrome' that overly complicates the UI, but rather to afford as many suitable gestures as possible with a minimum of extra on-screen graphics.

Wigdor and Wixton contend they do not "particularly advocate for this approach in general, (although it) is worth considering for certain applications" (2011: 154). Figure 42 shows that the visual cues for stretching, zooming in and moving a picture are displayed as a form of *enhanced feedback* (according to Wensveen, 2004 and Freitag, 2012) or even as an *enhanced feedforward* (according to Freitag, 2012) when the user touches the photo, rendering a 'just-in-time' chrome approach to gestural interfaces.

Figure 42: Just-in-time chrome is shown on tap (Wigdor and Wixton, 2011: 154).

3.3.5.1.2 Key insights on Piaget's INRC

Wigdor and Wixton (2011:137-138) acknowledge "in part any NUI presents a new world to the user. NUI's are natural, in the sense that it supports skilled and fluid practice and does not require that objects and operations be formalised into abstractions". However, the introduction of a new gestural vocabulary still requires learning from the user's side. New rules apply when inputting information through touch and new visual feedback is required to guide users. In order to provide guidelines to organise the semantics of a gestural interaction, Wigdor and Wixton report on Piaget's (1971) theory of Identity, Negation, Reciprocal and Commutative (INRC). The authors explain, "it seemed logical to apply some well-accepted concepts of developmental psychology to understanding a system". Wigdor translated the INRC into the following guidelines for how gestural systems should be represented and make interactions available:

- Identity: Primary objects (content) are "permanent unless explicitly deleted, and an action on a given object in a given context always yields the same consistent result". This concept is related to the well-known fact within HCI that users like to keep things under control and dislike events that occur without being triggered by them, such as objects or screens disappearing and users being unable to recover them.

- Negation: Any action "can be reversed midcourse, and that reversal will return the system to its previous state". This equivalent to an 'undo' command is generally unavailable in touch-based systems. As an example, dragging a picture with a finger can be undone by releasing the picture before the drop gesture reaches a target zone.
- Reciprocal: Once "an action is completed, a side effect on that action can be undone by another action. In contrast to the previous, it is a different action that returns an object to its previous state". For instance, "horizontal stretching of a graphic object will change its width and aspect ratio. A subsequent vertical stretching of the same object will not undo the change in width but will restore the aspect ratio".
- Commutative: Actions can be performed in any order and yield the same result. "Moving an object and then resizing it is the same as resizing the object and then moving it".

3.3.5.2 Hofmeester's Self-Revealing Gestures

During his time as Senior UX Lead at Microsoft, Hofmeester coordinated the design of the Windows 8 OS. Hofmeester et al. (2012) describe the concept of 'Self-Revealing' Gestures (SRG), which they aimed to implement across future Windows 8 touch platforms.

The researchers conducted a series of empirical studies with participants in order to 'fine tune' visual cues that explained to users how to perform two interactions in a gestural interface: swipe to select multiple items and touch and hold to select and rearrange items within a list. As an example, Figure 43 shows two pictures within a file manager window.

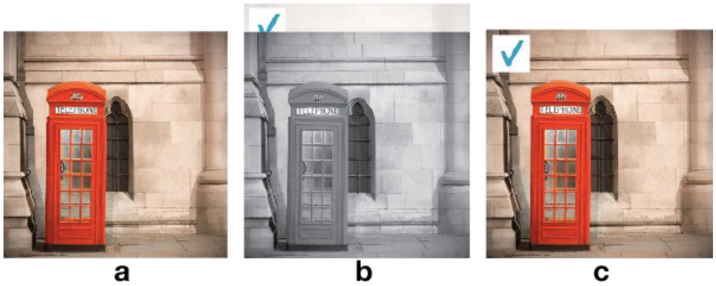

Figure 43: The three object states: Unselected, during selection gesture, and selected (Hofmeester, 2012: 823).

In an experiment, users were asked to select as many pictures as they wanted in that window. The authors explain that when a user pressed and held on a photo it would shift down slightly, revealing an arrow pointing down (a-b). The downward motion of the picture and arrow were intended to communicate, “drag the object down to select”. The interface then communicated the result of swiping by the picture appearing ‘selected’ with an active checkmark over it (c).

The authors explain that early attempts to support this animation failed because users found it obtrusive during testing and some participants confused the animation with feedback from their own touch interaction. They wondered if it might be actually happening, rather than just be a *preview*. I had anticipated this problem in my design activity before reading this paper and mitigated this issue by leaving the original object untouched and animating a ‘*ghost*’ of it instead (see Chapter 4).

3.3.5.2.1 Design Method

Hofmeester et al. wished to avoid disrupting the user’s interaction by “inserting a learning experience at a fixed point in the timeline, for instance after set-up, or when starting a new feature or application” (Hofmeester, 2012:817).

Hofmeester et al. also sought to avoid intruding on the user’s ‘flow’ by “adding laborious extra steps to the interaction, which would in turn increase the user’s cognitive burden and reduce their attention to their main task”. They were further concerned to ensure the user did not have to specifically seek out information to learn this new gesture, such as accessing a separate program in the form of a manual or help system.

Finally, Hofmeester et al. wanted to teach the new gestures without introducing new visual user interface elements or controls, further cluttering the user interface. They argued that common interactions such as opening or closing a menu, or minimising an application, should be learned through visual cues that are easy to remember, afford gesture execution and preview the system's response but without increasing the number of GUI elements.

3.3.5.2.2 Key Insights from Hofmeester's work

Hofmeester et al. do not claim that their findings can be generalised, neither do they draw on theoretical fundamentals to justify their approach. They focus on developing a design method involving an iterative process with participants (RITE method: Rapid Iterative Testing and Evaluation as described by Medlock, 2002), which helped them improve a design for self-revealing feedback from touch. Their approach, of designing a 'reactive' touch interface, is intended to teach users how to perform unfamiliar interactions. The key points, which are pertinent to this thesis, are:

1. The authors discovered that when using a new device, users with prior touch experience would experiment or see what the device could do by applying their vocabulary of known gestures. Users without touch experience would use gestures that simulate mouse interactions.
2. The natural motion of our hands, wrists and arms is an arc shape, not a straight line (Hofmeester et al., 2012: 820). This anatomical characteristic makes users drag slightly down or upward in an arc while scrolling UI elements horizontally. This also demonstrated that any object the finger was on could also be moved in the orthogonal direction. In support of this, Saffer (2009: 37) claims "designers need to be aware of the limits of the human body when creating interfaces that are controlled by it.
3. Although the teaching animation (Tverski et al., 2002) can enable the easy discovery and intended outcome of interactions it should not interfere with or distract from the primary interaction.
4. Among the desirable criteria that Hofmeester et al. propose for the design of gestural interfaces, are "reversible interactions" The authors recommend 'logical' reversibility of gestures. This resonates with Piaget's postulate of 'Negation', as reported by Wigdor and Wixton (2011: 137-138), which states

that any action "can be reversed midcourse, and that reversal will return the system to its previous state".

5. The authors warn about "limited use of touch-and-hold gestures". Hofmeester et al. (2012) cautions about the use of touch-and-hold interactions for gestural interfaces, such as touch and hold for options, because this interaction is still unfamiliar to users.

Unfortunately, Hofmeester's paper addresses issues 4 and 5 only in passing and no empirical data is reported.

3.4 Summary

This chapter has reported on applied interface design features and interaction techniques for gestural interactions. This review was undertaken with the purpose of informing the design of SPG and the interface prototypes planned for this thesis.

Example techniques that were used included the display of completion paths to guide the user's execution of a stroke (as seen in the works of Grossman et al., 2010; Freeman et al., 2009; Wobbrock et al., 2009; Bennett et al., 2011) and self-revealing menus that reveal potential actions in response to a command (Wigdor et al., 2011; Hofmeester, 2012; Bennett et al., 2014). Some systems have taught gestures in-situ, such as marking menus (Kurtenbach, 1991; Vanacken et al. 2008) and dynamic guides (Bau et al. 2008). Such systems lead the user through the continuation (Wu's, 2006) portion of gestures (see Chapter 3: 3.3).

Each of these designs used some form of the feedforward technique to demonstrate the execution of the available gesture to the user. Some compared this explicit approach with traditional trial-and-error that used no additional visual cues (Myers et al., 2006; Novick et al., 2009).

The next chapter describes the rationale to define the methods utilised to undertake two major empirical studies. It also reports on the techniques used to analyse the resulting quantitative and qualitative data.

CHAPTER 4 - METHODOLOGY

4.1 Introduction

Before commencing the main part of this chapter's content, a brief review of the key material from the previous chapters is given.

The previous chapter reported on a set of gaps (Section 3.2) found in the area of gestural user interfaces. For instance, the standard industry practice in designing interfaces for gestures does not explicitly reveal physical aspects of a gesture, such as the number of touch points required to initiate it. This is a problem investigated both in practice and in theory. Experimental work in the field has focused so far on demonstrating 'gesture-completion paths' (Bau & Mackay, 2008; Bennett et al., 2011; Sodhi, 2012; Anderson, 2013, etc.) to guide participants on how to continue a gesture with, for instance, trails that are progressively shown as a user touches the screen. Participants, however, were left to 'stumble-upon' these gestures or were trained in advance. The current omission of touch points in gestural interfaces therefore provides an opportunity for testing a new design concept, which is introduced in this thesis. The two hypotheses presented in the Chapter 1, hypotheses 'a' and 'b' (Section 1.5), stem from this realization, and propose that visual prompts depicting touch points over the screen – and displayed automatically – will aid users in discovering and performing gestures.

This chapter explains the strategy adopted to investigate this issue in order to propose a new design concept. It begins by reporting on the field of research and design referencing two key studies on design research by Frayling's (1993) 'Research in Art and Design' and Koskinen's (2011) 'Design Research Through Practice: From the Lab, Field, and Showroom', which explain various forms of research in the field of design. The strategy adopted was the use of design as intervention to investigate a specific problem.

Finally, a review of six selected papers in the field of designing and testing gestural interactions further supports the design process and method used to conduct the empirical studies. It indicates that other research has predominantly focused on gauging participants' error rates in execution. Thesis hypothesis 'c' proposes that a study focused only on errors in execution may not necessarily elicit users' subjective understanding of novel interfaces. To support this hypothesis, the method utilised to assess users' evaluation of gestural UI is reported, in addition to the execution of commands. The chapter ends by describing the statistical analysis of the data obtained from the empirical studies.

4.2 Research and Design

This section explores categories of research and design and the relationships between the two practices, in order to establish the core methodologies adopted.

Frayling (1993: 1) makes a distinction between Research with an uppercase 'R' and research with a lowercase 'r'. The first is original research, which seeks to innovate and to contribute with new knowledge, processes and artefacts. The latter is routine, driven by a personal quest, and serves as a foundation for original research work. The *Frascati Manual* (OECD, 2015) explains Research and Development (R&D) as creative and original work "undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications".

In the context of Human-Computer Interaction, however, 'research' and 'design' practices are often seen as both separate and in tension with each other (see Frayling, 1993; Zimmerman et al., 2007; Sas et al., 2014). Frayling draws attention to this tension when he writes:

> Research should be an orderly procedure, theoretically based on ontologies and constrained practices to ensure rigour in methods and therefore validity of results. Design, which is usually situated within creativity, is generally seen as the prerogative of the artist rather than the scientist as an unconstrained, hands-on, untamed praxis. (1993: 3)

He highlights a perceived separation between research as a 'scientific' pursuit with ordered and rigorous methods and results and design as an 'artistic' pursuit with unplanned outcomes at odds with research.

Frayling (1993: 5) proposes three relationships between design and research, which are listed below, followed by a brief description:

1. Research into design;
2. Research for design;
3. Research through design.

Research *into* design primarily constitutes research into the process of design, developing from work in design methods. It includes work concerned with the context of designing and research-based design practice, rather than developing domain-specific knowledge within any professional field of design. The point is made by Godin et al. (2014: 1668) that this form of research is “mainly found in universities and research centres contributing to a scientific discipline studying design. It documents objects, phenomena and history of design.”

Research *for* design, in contrast, refers to designers undertaking research to inform artefacts created by his or her design work or design process. Examples would be searching for visual inspiration for the design of a particular icon or investigating methods for developing wireframes.

Research *through* design (RTD) pursues goals that are different from the design itself. The design serves as a material with which to advance the researcher’s investigations, in order to expose principles underlying the effectiveness of artefacts or processes. Forlizzi et al. (2009) explain RTD as “a research approach that employs the design process as a method of inquiry on the near future, and that can produces theories in the area of *research for design*”. Godin et al. observe that,

> Designer/researchers who use RTD actually create new products, experimenting with new materials, processes, etc. Furthermore, it is an approach to scientific inquiry that takes advantage of the unique insights gained through design practice to provide a deeper understanding of complex and future-oriented issues in the design field. (2014: 1667)

According to Keyson et al. (2009: 4548), RTD focuses on the role of the product prototype “as an instrument of design knowledge enquiry. The prototype can evolve in degrees of granularity, from interactive mockups to fully functional prototypes, as a means to formulate, develop and validate design knowledge”. In this category design is an instrument of inquiry.

The concept of RTD has been adopted in human-computer interaction (e.g. Zimmerman et al., 2007). The approach of research through design can more specifically be detected in the method of previous research on the topic of communicating novel gestures to users, though RTD is seldom credited directly.

Research on the topic of communicating novel gestures to users was covered in Chapter 3. The typical research route – for example Bau and Mackay's Octopocus (2008) and Freeman et al.'s Shadowguides (2009) – was to create visual, interactive techniques to train users in how to execute gestures in a given interface. The creation of those techniques involved extensive design work. After creating their techniques, these researchers compared their proposed new method to an existing baseline design in laboratory studies. They expected these tests to show that their new designs had lower error rates than the existing baseline design. The goal of each exercise was to advance theoretical knowledge of how to design effective techniques for guiding the user. Thus, design work was carried out to conduct testing used to fulfil a research goal. In other words, the research covered in the previous chapter addressing ways of communicating novel gestures can be categorised as research through design.

One key decision these researchers all made was to use a laboratory-based test. This connects to a key distinction within RTD made by Koskinen et al. (2011), in their book *Design Research through Practice*. They contrast three approaches to 'constructive design research[3]':

1. Lab;
2. Field;
3. Showroom.

Laboratory (Lab) research aims to identify relationships designers "might find interesting". For example, "how the test limits of human cognitive processing capabilities affect error rates in using tablet computers". Laboratory research uses

[3] Constructive design research refers to "design research in which construction – be it product, system, space, or media – takes centre place and becomes the key means in constructing knowledge" (Koskinen et al., 2011: 5).

artefacts to deliver independent variables in a controlled study environment. It can use instruments to take measurements and record user performance (e.g. audio, video, the screen, sensors to measure heart rate). In HCI studies, in many cases, a facilitator guides participants by prompting them about tasks and asking them to think aloud about the experience. Koskinen (2011: 51) issues a warning, though: “It is impossible to study a phenomenon like design in the laboratory in its entirety; design has many faces, only some of which are appropriate for laboratory studies.” The context of a Lab is artificial. Therefore, the context is not as ‘natural’ as field research can be.

Field research in contrast is conducted in 'natural' or 'real world' contexts. As Koskinen writes, field researchers "work with context in an opposite way from researchers in a lab […] If there is one keyword to describe the field approach to design, it must be context” (2011: 69). Rather than bringing things of interest into the lab for experimental studies, field researchers go after these things in a natural setting, that is, in a place where design is being used. Taking a similar example to the previous topic, the user will take the tablet onto the street and use it without boundaries or a facilitator to guide his/her interactions.

Showroom research has roots in art and design, rather than science or the social sciences. Koskinen describes its context as in the ‘field’ or ‘real world’, but within a contrived environment not entirely of the user's making: “Research is presented in shop windows, exhibitions, and galleries rather than in books or conference papers” (Koskinen, 2011: 89). For instance, the visitor to a digital and interactive art exhibition uses a tablet to control an installation. The context is public space, the tablet is no longer a personal possession and it might focus, for example, the social and aesthetic aspects of the artefact, “turned to exploring the impact of science on society”.

The next section explores the relation of the present thesis to Frayling’s (1993) and Koskinen’s (2011) categories.

4.2.1 Research through Design and the Thesis

Firstly, as the objective of this thesis is to create new knowledge in reference to Frayling’s (1993) contrasting definitions, of ‘research’ and ‘Research’, the goal is Research with a capitalised ‘R’. The research goals of the thesis are anchored in specific research questions concerning how to design effective visual cues to help users learn unseen and unfamiliar gestures. These are design-focussed concerns. The thesis involves both research and design and relates to the three frameworks of research *through*, *into* or *for* design to different degrees.

The overall process followed is that to answer the research questions, empirical work introduces design interventions within gestural UI prototypes, which compares 'improved' design conditions with baseline UIs with the aim of reducing error rates. This process is research *through* design (RTD). As will be explained, the RTD work undertaken is closely related to Koskinen's category of laboratory-based research (2011). In addition, the goal of the research is to arrive at design knowledge or guidance that is transferrable, generalizable and reproducible. The designs and the methodology developed will inform other researchers and practitioners in the field of HCI in their own work. Thus, the thesis also contributes to research *for* design (as *per* Frayling's categories).

Turning to the categories described by Koskinen (2011), there are both advantages and limitations to each of the Lab, Field and Showroom forms of research. Fieldwork research focuses on how people and communities understand and make sense of designs, talk about them and live with them. Koskinen et al. (2011: 69) explains that "the lab decontextualizes; the field contextualizes". The first-hand experience of context gained in the field is typically more important than fact-finding or even careful theoretically informed interpretation. For instance, Gaver et al. (1999: 22-25) used the approach of 'cultural probes', which is closely related to Fieldwork research (and indeed combines it with the Showroom approach). Gaver focussed on eliciting user experience *in their own location* using instruments such as postcards, maps, camera, and a photo album. These tools were not intended to collect representative data. In looking at novel interaction techniques to enhance the voice of the elderly in their local communities, the outcome of their research was three different design scenarios such as a network of computer displays in public spaces for the local community to interact with. However, it is difficult to consistently capture small details when undertaking field observation, particularly when data may be provided by the participants (as in Gaver's example here).

Showroom research, which is rooted in art and design rather than in science, uses prototypes to provoke - unconstrained - reaction and conversation in the context of a public intervention. Koskinen et al. (2011: 94) contend the aim of this Showroom research "is to provide stories, some of which are highlighted as 'beacons' that tell about how people experience the designs and what trains of thought they elicited. These stories are food for debate; they are not meant to become facts". The research focus of this thesis is more concrete than the more general, pervasive experience that showroom studies emphasise, and thus, even more than field work, it is less directly relevant to the thesis.

Designing methods of revealing the decisions and experiences of users required a more controlled environment than either 'field' or 'showroom'. As seen in the previous chapter, consistently capturing small-level details has been important to the careful comparison of design techniques to assist users in rehearsing gestures. In addressing a similar issue, it was important to maintain the same level of control. However, every method has shortcomings. The limitations of working in a laboratory are that participants may change their habitual ways of using interfaces because they are in an unfamiliar environment. As part of the empirical work undertaken in the thesis, participants were also interviewed about their experience of participating in the test. This additional qualitative information helped provide a backdrop with which to reflect on the extent to which the artificial elements of the lab-based test affected the results.

Frayling's categories intertwine. As Yee (2010) writes, "research *into*, research *through* and research *for* are not mutually exclusive." Yee also comments that a design PhD research methodology should "innovate in the format and structure; use a pick and mix approach to research design; situate practice in the inquiry; and validate visual designs." The thesis use sources in a "pick and mix" way as part of its methodology of design through research, as it engages with the categories of research *through* design and *for* design proposed by Frayling (1993) and Lab research proposed by Koskinen. To underpin design and method choices and to understand participants, it also distils information from different sources at. The relevance of these sources to each chapter is outlined next.

This thesis starts by following the broad approach of research *for* design. To support the theories generated in the research process, and the empirical research, it looked at previous research studies, which provided useful references for the decision-making process. This can be seen in Chapter 2, which comprises a review of the theoretical foundations of HCI that supported generations of new theory. Chapter 3 provides a systematic review of previous work in creating designs and interaction techniques for improving the performance of users' gestures. For instance, *academic research* such as Wigdor et al.'s (2009) Ripples, *industrial research*, such as Wigdor and Wixton's (2011: 90–94) tethers touch feedback found on Microsoft's 2007 Surface tabletop, and *applied methods*, such as the Microsoft touch interactions guide (Windows Dev Center-b, 2014). The present chapter also undertakes research *for* design in comparing design and empirical methodologies from a selection of researchers who conducted empirical studies with gestural interfaces. This comparative analysis underpinned the choice of methods to undertake two empirical studies presented in this thesis and the techniques used to analyse the data and produce findings.

According to Cross's (1999: 5) examination of the outcome of design research, this thesis uses design artefacts or *products* to initiate an 'internal dialogue to enable research through design, with reference to Frayling's (1993) categories'. It continues by including both acts of design, such as creating new design interventions to inform users of available actions, and acts of research, such as evaluating those designs to arrive at scientific knowledge. For instance, Chapter 5 proposes a new design technique to teach gestural interfaces (the SPG) to users and a new conceptual model to assess user interaction with gestural technologies.

Zimmerman et al. (2007: 493–494) describe *design thinking* as a "process that involves grounding investigation to gain multiple perspectives on a problem; ideation-generation of many possible different solutions; iteration–cyclical process of refining concept with increasing fidelity; and reflection". Chapter 6 and Chapter 7 describe empirical work to undertake two major empirical studies, which have a strong focus on *design thinking*. Furthermore, considering Koskinen's (2011) approaches to constructive design research, the thesis has a strong focus on Lab research *through* design. The rationale to arrive at the design interventions and prototype work (Keyson et al., 2009) and the methods to explore their efficiency in informing participants of the available gestures are thoroughly described. As Zimmerman et al. contend, "The work must be documented in such a way that peers can reproduce the results".

Sas et al. (2014: 1979) refine Zimmerman's focus on the quality of the *research output*, by stating that, "in addition to framing the work within the real world, interaction design researchers must also articulate reasons the community should consider this or that state to be preferred"; for instance, one chair may be more comfortable than another, users can accomplish more in a given interface than another, and so on. The outcome of the laboratory-based RTD phase undertaken in the present research is a contribution to research *for* design - on interface design for touch devices. Chapter 8 synthesizes the *research output* from the two empirical studies, providing a list of the most common problems users experienced when confronted with unfamiliar gestural interfaces and drawing design recommendations to mitigate each problem and make visual recommendations to exemplify possible design solutions.

Chapter 9 concludes the thesis and recaps key contributions. The importance of the research outcome to be transferrable, generalizable and reproducible is highlighted. The limitations of the methodology are also discussed, along with suggested future work.

In conclusion, the research in this thesis follows the approach of laboratory research *through* design *for* design. Design work is used as a basis for supporting design through discoveries and recommendations. It uses *laboratory* work (Koskinen et al., 2011) to conduct empirical studies with design interventions and *artefacts* (Frayling, 1993; Cross, 1999; Yee, 2010) to discover with participants which designs and interaction techniques yield lower error rates. It also contributes to research *for* design in the sense that it aims at *increasing the stock of knowledge* (OECD Frascati Manual, 2015) in the field of gestural interactions, with *original findings and generalizable methods* (Zimmerman et al., 2007; Sas et al., 2014) that can benefit both the design of gestural UI and methods to assess its efficiency with users.

4.3 Methodologies in Researching Gesture Training

This section presents a comparative analysis of the methodologies used by previous research in gestural interactions. It is subdivided into:

1) Creating designs: highlights the key visual characteristics, implementation and functionalities of the UI designs from the selected work;
2) Evaluating designs: the criteria other researchers used to define the scope of their studies will be drawn out from this selection. In addition, their methodology to conduct studies is reviewed;

3) Analysing results: the analysis used by previous researchers to assess their findings (e.g. statistical methods) is reviewed here.

Throughout this section, the focus will remain on six key papers that are closely relevant to the research undertaken for this thesis. These researchers have sought to help users in learning new gestures in unfamiliar gestural interfaces, which aligns with the scope and goals of this thesis.

To provide a brief review, the first paper is about Bau and Mackay's Octopocus (2008), a system that aimed at solving single-touch gestural interactions on a table-top. The next is Freeman et al.'s Shadowguides (2009), which tested single and multi-touch interactions also on a table-top. Freeman et al. compared an in-context gesture-training guide with an offset training window and tested participants' memory of gestures in their studies. The third system is GestureBar, designed by Bragdon et al. (2009). Bragdon et al. tested single-touch gestures on a desktop, which also used a training window. Bragdon aimed at finding out if participants would discover gesture-completion paths during interactions. The fourth, Wigdor et al.'s Ripples (2009) also tested a gesture-training guide, which demonstrated a gesture-completion path. In addition, Ripples also demonstrated the effect of a gesture. The fifth system is Bennett et al.'s SimpleFlow (2011). Bennett et al. tested single-point interactions on a desktop system. Similar to Bau and Mackay, and Freeman, Bennett trained participants in a new vocabulary of gestures before asking them to execute any actions. The last system analysed is Gutwin et al.'s FastTap (2014). In contrast to the others, who tested their design concepts in table-tops, Gutwin et al. tested single-touch and multi-touch gestures on a hand-held tablet. As a further difference, they also tested iconic gesture shortcuts and not completion-paths.

4.4 Creating Designs

An important stage in Lab RTD is creating the design intervention. Different visual qualities such as textual support, paths with specific colours or animation to indicate movement, context of use, etc. were used to represent the design concepts deployed in the selected papers. Many of the research methodologies used for designing and studying multi-touch interaction include user observation (Derboven et al, 2010;

Peltonen et al, 2008), collaborative usability analysis (Pinelle and Gutwin, 2008), and co-design (Mazalek et al, 2009). The users and their task are central to the design process in such approaches. For instance, Hofmeester (2012) constantly redesigns study prototypes taking into account feedback from participants. Others have sought to elicit potential gestures for a particular command from the user (Wobbrock et al, 2009; Nacenta et al, 2013; Oh & Findlater, 2013). For instance, Hofmeester, among others, use designs as interventions – to discover underlying principles of successful approaches to UI prototypes.

This section explores various solutions, to support (or not) interactions such as single and multi touch gestures, or the visual position of guidance for gestures within the interface. Note that the approach taken by the authors reviewed in this chapter was similar: visual prompts were displayed *during* execution. As will be seen, the technique introduced in the empirical studies for this thesis is defined by the display of prompts *before* users attempt to execute gestures. Even though this technique pursues a different path, it is sufficiently close to previous work to draw relevant insights.

4.4.1 Previous Work in Designing Gestural UI

An overview of the design aspects is given in Table 1. These aspects were drawn from the review of existing work (see Chapter 3).

Six distinct aspects that illuminate differences in the design approaches used in each of the studies are examined in turn:

1) The choice of device targeted in the design work.
2) The consideration of supporting either single- or multi-touch gestures, or both.
3) The visual position, or context, in which directions are shown to the user as to how to complete or make a gesture.
4) Visual prompts provided to the user and what these communicate about the available gestures (from touch points used, to final effect).
5) The moment during the interaction when the visual cues are presented;
6) Movement: whether static or dynamic visual cues are used.

To facilitate an analysis and comparison of existing research, the aspects listed in the left-most column of Table 1 will be referred to throughout this chapter as '[aspect x]' (e.g. [Table-top] or [Single-touch]).

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**
Device: Hand-held						X
Device: Table-top	X	X		X		
Device: Desktop			X		X	
Touch points: Single-touch	X	X	X	X	X	
Touch points: Multi-touch		X		X		X
Position: In context	X	X		X	X	X
Position: Training window		X	X			
Visual prompts: Touch		X				
Visual prompts: Path	X	X	X	X	X	
Visual prompts: Shortcut						X
Visual prompts: Effect				X		
Time relative: During execution	X	X	X	X	X	X
Movement: Static						X
Movement: Animated	X	X	X	X	X	

Table 1: Comparison of different design features for analysing gesture training.

Device Choices: Four of the studies use table-top PCs [Table-top], Gutwin et al. use hand-held devices [Hand-held] and Bennett et al.'s SimpleFlow, was tested using a standard desktop PC and mouse [Desktop].

Although table-top, hand-held and touch-based devices vary in terms of dimensions, single versus multi-user and other factors, these have not been reported as creating profound differences in design principles. Differences may emerge in detailed study, but there is a lack of even informal reporting of any significant difference. This theme is explored next together with a rationale for the selection of the device in Section 4.5.2.

Touch points: In the specific design space for gesture training, Bau & Mackay (2008), Bragdon et al. (2009) and Bennett et al. (2011) focused their studies on gestures performed with one touch-point [Single-touch].

The other studies combined single and multi-touch interaction techniques [Multi-touch] across different tasks. Wigdor and Wixton (2011) explain that earlier devices used single-touch points, but that with the advances in the touch and surface technologies, multi-touch became mainstream and was adopted by the industry.

Visual Position: Shifting to the contextual presentation of visual prompts for gesture training, the 'in-context' visual support appears over the visual workspace, at or very close to the location of the user where they are performing the gesture at hand (e.g. Bau & Mackay's OctoPocus). Every study except Freeman et al.'s (2009) Shadowguides and Bragdon's (2009) GestureBar, test visual support for performing gestures in the context of the interface [In-context]. In summary, Bragdon uses a fixed-location display only [Training-window], four teams use an in-context display only and Freeman's ShadowGuides uses both approaches.

Visual Prompts: One common feature of the designs tested across five of the six existing studies has been the use of gesture-completion paths [Path] (Section 3.3.3). In this design technique, when a user starts a gesture, a visual cue is displayed to guide the path to follow in order to correctly complete the gesture. However, no consistent representation of touch points [Touch] was verified in the selection of gestural interfaces technologies. According to Wu's (2006) terminology, users are being shown the continuation of a gestural interaction, but not how to register it with the appropriate number of touch points and/or configuration. Freeman et al (2009) is an exception to this rule and present a unique model for the design of the registration position.

Gutwin et al.'s FastTap, on the other hand, enables the user to reveal a local grid-like menu of different commands available at the current location. However, in contrast to marking menus it does not demonstrate the gesture itself but only the position of an invoked target button location over the screen [Shortcut], in order for participants to execute a command. Most gestural interfaces display (or *feed-forward*) gesture movement, pathways or direction of the gesture. Wigdor et al.'s (2009, 2011) and

Hofmeester's (2012) self-revealing concept is an exception to this rule, by previewing the effect [Effect] of a specific gesture whilst participants interact.

In conclusion to the design analysis, temporal features such as 'time relative to execution' (to display self-completing paths) and 'static' and 'animated' aspects are addressed next.

Time Relative to Execution: Across all six studies, the visual cues, commands or pathways, are shown in response to the user performing a gesture – that is after their touch first registers on the screen [During execution].

Movement: The review indicates that most experimental work in the field uses animated [Animated] events in some capacity. For instance, both feedforward and feedback are continuously updated as the gesture progresses in Bau & Mackay's (2008) OctoPocus. Pathways over the screen are displayed progressively and fade away when the hand is lifted. After the user selects and begins to make a gesture, less likely gesture guide paths become thinner and disappear.

Bragdon's (2009) 'GestureBar' trains participants how to perform gestures in a toolbar-like layout across the top of the screen. This toolbar is located out of the document practice area and therefore away from the users' contact point with the screen. Bennett et al's (2011) SimpleFlow continuously updates gesture predictions as soon as a user begins entering a gesture. Wigdor et al's (2009) Ripples enable visualizations around each contact point on a touch display and, through these visualizations, provides feedback to the user about successes and errors of their touch interactions.

In contrast, Gutwin et al.'s (2014) 'FastTap' uses thumb-and-finger touches to show and choose from a spatially stable grid-based overlay interface [Static]. Icons that represent a command are provided and the grid only fades in when the user initiates the touch and out when the hand is lifted. No animations for gesture performance are provided in Gutwin's concept.

4.4.2 Foundations for Design work

Following the review of existing work above, the next section reflects on the six aspects highlighted and outlines the design work done for the two empirical studies conducted. For comparison purposes the empirical studies 1 and 2, named 'Chueke, 2014 study 1/2' are now included in the far right column of the following tables.

Device Choices: Two aspects determined the choice of device for the empirical studies. The *first* being access to equipment, the *second* aspect relates to interaction techniques. The review of existing work in the field demonstrated that experiments were mostly undertaken using surface tables (table-tops) and desktop as that was the available equipment from 2008 to 2010. Indeed, Bau and Mackay (2008), Freeman et al (2009) and Wigdor et al (2009) used a multi-touch table-top.

Table 2 shows in the first column the three aspects that describe device choice.

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Device: Hand-held						X	X
Device: Table-top	X	X		X			
Device: Desktop			X		X		

Table 2: Comparison of different device choices for analysing gesture training.

Only recently have handheld touch-sensitive devices become readily available and as a result ubiquitous with the release for instance, of Apple iPad (Apple Press Info, 2010). Gutwin et al (2014) is the only study from the selection that uses a tablet device. However since 2010, the majority of people adopted hand-held mobile devices and not large and clunky surface tables, hence the decision to use a hand-held device. According to Statista (access in March 2015), smartphone shipments reached 1.3 billion units in 2014. Tablet shipments worldwide are expected to reach 276 million units in 2017. Table-top devices did not become an accessible form of equipment.

The *second* aspect relates to interaction techniques. While desktop computers using a mouse and pointer are still widely used, the empirical studies focussed on issues users encounter when there are two or more contact points on the screen, fundamentally because they are more complex to acquire. The analysis shows that Bragdon et al and Bennet et al have used a regular desktop OS to test their concept, using a pointer - which lies beyond this thesis scope.

Even though most table-tops afford multi-touch, they do not target a broader public. Therefore, to organise prototype tests within a surface table would have created an additional unfamiliar aspect to the interaction: people are not used to manipulating this kind of device. In addition, table-top technology allows two or more users to interact at the same time, which is also not within the scope of the thesis study.

Finally, the technology embedded in smartphones generally affords interactions limited to two touch-points at any time and therefore was excluded from this research scope. Tablet technologies afford interactions that permit two or more touch-points; therefore tablets were the appropriate choice.

Touch points: Saffer (2009: 17) claims that single-touch is more natural to humans as it "reflects real-life point-and-select interactions with the world". However, even single-touch gestures require unfamiliar commands such as touch-and-hold and swipe gestures from the device's bezel. In addition, the adoption of multi-touch technologies by the industry is unquestionable. As can be seen on Table 3, three studies from the review included multi-touch in their research.

	Bau & Mackay (2008) OctoPocus	Freeman et al. (2009) Shadow guides	Bragdon et al. (2009) GestureBar	Wigdor et al. (2009) Ripples	Bennett et al. (2011) SimpleFlow	Gutwin et al. (2014) FastTap	Chueke (2014) study 1/2
Touch points: Single-touch	X	X	X	X	X		X
Touch points: Multi-touch		X		X		X	X

Table 3: Comparison of different touch-point numbers for gesture execution.

Therefore, the thesis study adopted both single- and multi-touch gestural interactions as variables within task performance.

Visual Position: Five of the previous studies displayed their guidance to the user close to the point of interaction (see Table 4). The exception was Bragdon et al. (2009). Bragdon used an out-of-context separate window, set aside from the place of contact. Freeman's study was also different from most, using a combined approach that displayed guidance in-context and in addition used a separate, remote area with additional information.

HCI research has proven that in the design of user interfaces, displaying visual cues within the user's focus-point on the screen can maximise task efficiency. For instance, Tarling (2009) explains that when items are positioned close together, information from multiple items is available from a single location. Wensveen et al. (2004) explains, "The reaction of the product and the action of the user should occur in the same location" (Section 2.3.8).

	Bau & Mackay (2008) OctoPocus	Freeman et al. (2009) Shadow guides	Bragdon et al. (2009) GestureBar	Wigdor et al. (2009) Ripples	Bennett et al. (2011) SimpleFlow	Gutwin et al. (2014) FastTap	Chueke (2014) study 1/2
Position: In context	X	X		X	X	X	X
Position: Training window		X	X				

Table 4: Comparison of different visual positions for displaying visual prompts.

Therefore, the approach taken by Bragdon et al. (2009) of providing a separate window for gestures training was avoided, because it would have been more time-consuming for users, to acquire the relevant information for interaction.

Visual Prompts: Of the six previous papers, Freeman et al. (2009) includes the direct representation of the number and position of touch [Touch] points. Bennett et al.'s (2011) SimpleFlow technique used a black point as the starting point for drawing the gestures representation of touch over the screen – in response to a user initiating the gesture (see Table 5). Others show only movement paths, sometimes embedding text labels.

	Bau & Mackay (2008) OctoPocus	Freeman et al. (2009) Shadow guides	Bragdon et al. (2009) GestureBar	Wigdor et al. (2009) Ripples	Bennett et al. (2011) SimpleFlow	Gutwin et al. (2014) FastTap	Chueke (2014) study 1/2
Visual prompts: Touch		X					X
Visual prompts: Path	X	X	X	X	X		
Visual prompts: Shortcut						X	
Visual prompts: Effect				X			X

Table 5: Comparison of different visual characteristics to aid gesture training.

This simple measure gives the user straightforward guidance as to the desired pose. Therefore, this particular choice, shared by Freeman and Bennett, is one that was adopted for the empirical studies.

In addition, Wigdor et al.'s (2009, 2011) technique also previews the effect of a specific gesture whilst participants interact, by for instance showing the extension an object can be stretched. This choice of design provides a complete feed-forward cycle of registration-continuation-termination (see Wu's RCT, Section 2.4.4) and was therefore adopted in the designs for the empirical studies.

Time Relative to Execution: Norman (1988: 45-56) uses the term 'Execution' to mean to perform or do something. Goals have to be translated into intentions, which in turn have to be made into an action sequence that can be performed to satisfy the intentions. However, according to Norman's model, people execute first and then assess the results of their actions afterwards. The six projects outlined all displayed guidance after the moment of registration (see Table 6). This eliminates the possibility of the user identifying potential interactions before they act. In contrast to existing research, the thesis hypothesises proposes that displaying visual cues before interaction will improve discovery of new gestures as well as reduce errors in execution (see thesis hypothesis 'b' Section 1.5, and Section 5.3).

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Time relative: Before execution							X
Time relative: During execution	X	X	X	X	X	X	X

Table 6: Comparison of different times to display visual prompts for gesture training.

The empirical work undertaken compared interaction techniques that display visual guidance for gestures during the execution of gestures with UI that shows guidance before user action (the condition proposed in this thesis).

Movement: Table 7 shows that five of the six previous design techniques use animation to demonstrate gesture performance. For instance Bau and Mackay's Octopocus and

Freeman et al.'s Shadowguides reveal animated gesture-completion paths during user execution of commands. No animations for gesture performance are provided in Gutwin's FastTap concept – only static iconic depictions of the gesture and effect with additional textual support in the form of labels.

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Movement: Static						X	
Movement: Animated	X	X	X	X	X		X

Table 7: Comparison of design techniques for gesture training that use static or animated visual prompts.

As described in Section 1.3 and further elaborated in Section 3.2, many applications designed for contemporary gestural operating systems (e.g. Apple iOS and Android), display static visual cues to indicate potential user action. For instance, textual tags or step-by-step tutorials, might explain a gesture or a function of the program. The key operating system creators – Apple (Apple Developer, 2014), Microsoft (Windows Dev Center, 2014) and Google (Google Design, 2014) – all recommend the use of animations in their design guidelines. They advise that this can improve the rate at which users learn about potential interaction with an app. Academic research has also demonstrated that animated cues are more effective, as seen in the work of Tversky (2002), Kang et al. (2004) and Bedford (2014).

Given this consistent advice from researchers and developers on the use of animation the empirical studies follow the same approach.

4.5 Evaluating Designs

Turning from a consideration of design ideas and reviewing previous designs, this section now turn to considering how to evaluate designs. A good evaluation method will carefully connect the research goal with the research method, allowing the evaluation of designs and the creation of fundamental knowledge.

4.5.1 Previous Work in Evaluating Gestural UIs

This section describes the different methods used by each research team from the selected studies. As we shall see, the predominant approach has been to use empirical studies, typically conducted in a laboratory setting.

User studies and user evaluation are two common parts of the assessment of an interactive system. These two practices have served for the evaluation of predominant web-based and desktop OS software (Perlman, 2011), new interaction techniques (Spindler et al., 2009; Weiss et al., 2011), new visualisations (Wigdor et al., 2009), and the new use of existing technology to create novel applications (Apted et al., 2006; Piper et al., 2009). Preece (2011: 435) further explains that, in terms of evaluation that is undertaken to reveal user needs, the scope of evaluation "ranges from low-tech prototypes to complete systems; a particular screen function to the whole workflow; and from aesthetic design to safety features".

We will examine in turn seven distinct issues that illuminate differences in the methodological approaches used in each of the studies:

1) The criteria for participant selection and their numbers.
2) The number of gestures, which affects the complexity of tasks and participants' memory.
3) The 'moment of learning' set describes strategies that train participants before the execution of tasks or leave them to discover the gestures without any guidance.
4) The effects report on the focus of each study, hence the actual material results each investigation aimed to measure.
5) The use of a probe or instrument to collect responses, e.g. Likert-scale based questionnaire, NASA TLX, QUIS methods.
6) Rating reports on studies that used a classification method defined by the researcher and his team, e.g. effort or success.
7) The statistical test describes the selected method to analyse quantitative data.

To facilitate an analysis and comparison of existent research, the aspects listed in the left-most column of Table 8 will be referred to throughout this chapter as '[aspect x]' (e.g. [Trained before exec.] or [Discover during exec.]).

Table 8 lists in the left-most column the methodological aspects considered relevant for further analysis and which ultimately underpin the choice of methods for the thesis study.

	Bau & Mackay (2008) OctoPocus	Freeman et al. (2009) Shadow guides	Bragdon et al. (2009) GestureBar	Wigdor et al. (2009) Ripples	Bennett et al. (2011) SimpleFlow	Gutwin et al. (2014) FastTap
Selection: No. of participants	16+12	22	24+44	14	18	16
Gestures: No. of gestures	8	15	16	3	16	16
Learning: Trained before exec.	X	X			X	
Learning: Discover during exec.			X	X		X
Effects: Memory		X				
Effects: Evaluation			X			
Effects: Execution	X	X	X	X	X	X
Elicitation method	Post-task debrief: preference	Post-task 7-point Likert: preference	Post-task 5-point Likert: preference	Post-task debrief: preference	Post-task 3-point Likert: preference	Post-task NASA-TLX and 5-point Likert: preference
Rating: Attempts		X	X			X
Statistical Test: Analysis	ANOVA	T-test	ANOVA	T-test	ANOVA, LR	ANOVA

Table 8: Comparison of different methods for analysing gesture training.

Participant selection is a critical part of designing a Lab RTD experiment. Choosing too few participants may lead to a failure to achieve a statistically significant difference between systems' or participants' performance. In addition, choosing expert participants when researching novice performance, or vice versa, will lead to invalid results.

Across the six studies, the number of participants [No. of participants] varies from 12 to 44. None of the research teams gives an explicit explanation of their choice of number of participants, age or gender selection, nor do they make recommendations for future researchers. However, they provide explanations of criteria used to choose participants. Bau & Mackay (2008) tested participants with medium to expert-level computer experience. All were right-handed. Freeman et al. (2009) conducted a between-subjects experiment with participants who had limited experience with gestural interfaces (nothing more advanced than the iPhone) and had not previously used a Microsoft Surface.

Bragdon et al. (2009) selected participants who were able to operate a Tablet PC, also with diverse backgrounds and levels of experience in using computers. Wigdor et al. (2009) recruited from the local community. Education levels varied between undergraduate and postgraduate degree level students. None had used a multi-touch tabletop before and none had experience with touch devices (excluding automated tellers and self-checkouts). Bennett et al. (2011) briefly mention that participants' average age was of 26.5 years and all participants naturally used their right hand to control the mouse. Gutwin et al. (2014) compared the two interfaces in a controlled experiment in which participants selected a set of commands over several repeated blocks, allowing examining both novice and more expert selection behaviour.

Number of Gestures: A second concern, which itself influences the decision about the number of participants, is the complexity of the number of designs or number of tasks (achieved by gestures) that are to be studied in the experiment.

The number of gestures [No. of gestures] tested varies from 3 to 16 with no specific rule described by the authors, with the exception of Bau & Mackay (2009). The authors explain that in both experiments they chose to use 16-item gesture sets. A 16-item set is relatively difficult to learn because its size exceeds the limits of short-term memory (as seen in Sternberg, 2006). Their intention was in saturating the participants' short-term memory; they could discern any learning as being via changes in long-term memory, rather than simply a recent recollection in short-term memory.

Moment of Learning: Now shifting to strategies to introduce visual aid to support gesture training, Bau & Mackay (2008), Freeman et al. (2009) and Bennett et al. (2011) trained [Trained before exec.] their participants on the gestures to be executed, in order to test their memory/learning in a later stage.

In contrast, Bragdon et al. (2009), Wigdor et al. (2009) and Gutwin et al. (2014) did not train their users before the experiment, because they wished to elicit the experience of users who were unfamiliar with their interfaces, at the first moments of use [Discover during exec.].

Effects Measured: There are three different measures that have been used to assess the effectiveness of the proposed designs: Memory, Evaluation and Execution.

Recall [Memory], how well users are able to produce previously encountered gestures, is one key factor. Freeman et al.'s (2009) Shadowguides focused their studies on the ability of users to recall a previously encountered gesture. As noted in the previous paragraph, these studies isolated recall from learning by training users before the experiment.

The user's ability to perform a gesture, either during learning or during later recall, relies on the correct evaluation [Evaluation] of available gestures and, in contrast, the ability to successfully execute each gesture. Bragdon et al. (2009) explain, "evaluations were conducted by observing the complete open-ended process by which users approach an unknown interface, including forming goals, searching for commands, performing gestures, and assessing results". However, Bragdon did not present empirical data on participants' subjective assessments of their gestural interface. The researcher investigated the execution of gestures and only presented data from a Likert-scale questionnaire on participants' assessment on finding commands.

The main approach that has been followed in assessing gesture-based systems is to analyse execution [Execution] only. In the six studies, researchers typically analyse the frequency with which the gestures are used, the rate of gesture input, or user preference with the gesture system (Callahan et al. 1988; Li et al. 2005), which yields an error rate. The authors did not distinguish between evaluation and execution of gestural interactions. A successful interaction is then determined by the error rate yielded by participants' interactions.

Finkelstein (2008) explains error rate as "the total number of failures within an item population, divided by the total time expended by that population, during a particular measurement interval under stated conditions". Traditionally, error rate gauges how many participants failed after first or last execution to assess the efficiency of an interface, e.g. out of a 100 executions by any user how many succeeded and failed in a population. With a similar approach, Bennett et al. (2011) determine error by the time measurement of speed to execute gestures.

Questionnaire: This comparison of methods assesses the different approaches to post-hoc data analysis. As can be seen in Table 8, the majority of researchers utilized Likert-scale based questionnaires to gauge extra information from participants.

Their common goal was to reveal a participant's preference for specific features of their specific implementation versus a baseline one. For instance, Freeman introduced four questions with a 7-point Likert measure to ascertain user's subjective ratings in more detail. Gutwin et al. (2014), besides introducing a 5-point Likert questionnaire to gauge participants' preference for specific aspects within the interfaces presented, also utilised Hart and Staveland's (1988) NASA Task Load Index (TLX) questionnaire. NASA-TLX assesses workload on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales. In contrast to the majority, Bau & Mackay (2008) only asked for an overall preference for the interfaces utilised. Wigdor et al. (2009) briefly inform about the preferences of a few participants without producing an organised analysis of it.

Rating: Another measure of the difficulty that users experience with an interface is the number of attempts [Attempts] required to successfully execute a gesture. Three studies: Freeman et al. (2009), Bragdon et al. (2009) and Gutwin et al. (2009) count the number of attempts made by each participant until they succeed or fail to execute a gesture.

Gutwin et al. did not use any classification method, but divided the number of errors in a trial by the number of commands in that trial. Errors were counted as any incorrect selection (note that multiple-command trials could be carried out in any order).

Two studies have used a rating scheme to further analyse user behaviour. Freeman et al. (2009) gave 2 minutes for participants to perform each gesture with no restriction on number of attempts. Freeman then classified the first four attempts of a gesture in the memory phase as either (1) correct, (2) errors in performance – correct mental model but clumsy performance, or, (3) errors in memory – completely incorrect gesture.

Bragdon et al. (2009) explain that handling failed gesture attempts is an important usability aspect of any gestural system, and so "coping with failed gesture attempts was left to the participants". As the purpose of their experiment was to collect qualitative feedback, the authors "believe that this added significantly to the realism of using a variety of gesture disclosure interfaces".

Bragdon, in similar fashion to the approach of Freeman et al., classified gesture performance for each participant, by assigning one of five categories: (1) successful on first attempt, (2) successful within three attempts, (3) successful in more than three attempts, (4) attempted but all attempts were unsuccessful, and (5) did not discover a correct gesture. In their experiment, participants received no training in gestures and had to discover it by themselves, simulating an end-user approach.

Statistical Test: As can be seen in Table 8, the majority of researchers utilised ANOVA (analysis of variance) as their main statistical analysis [Analysis].

In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal and therefore generalizes the t-test to more than two groups. ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance. The analysis of variance has been studied from several approaches, the most common of which uses a linear model that relates the response to the treatments and blocks.

Bau and Mckay (2008) are typical of many of the studies in focussing their statistical tests on the number of errors made by users when using two different designs. To assess the reliability of the difference, they used ANOVA on the number of errors made. They reported low overall rates of error and did not identify any statistically significant difference between their designs. Wigdor et al. (2009) adopted a similar approach by testing user errors with two interfaces and assessed the difference using a t-test. Both papers in fact only ever compared two designs and hence both ANOVA and t-test methods are valid (Press, 1992).

Bragdon used ANOVA to assess the number of errors made, but also extended their method to consider the total number of attempts made as an additional method. Gutwin et al. (2014) again used error counts, tested by ANOVA, but added the execution time rather than the number of attempts. Bennet et al. (2011) used a variety of different tests, but did not use any direct assessment of error rate. Instead, they focussed on how well or closely users reproduced exact paths specified for a gesture.

4.5.2 Foundations for a Method

Having established the general principles of a method, the next step is to reconsider the same set of aspects in terms of how they informed the method designed for the thesis empirical studies. For comparison purposes, the thesis studies and their characteristics are included in the far right column of the tables presented in this section.

Participant Selection: The first column of Table 9 shows the initial aspects that determine participant selection, three of which aspects were regarded as highly influential in the choice: age, the desired number of participants and expertise with touch devices.

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1**	**Chueke (2014) study 2**
Selection: No. of partic.	16+12	22	24+44	14	18	16	34	45

Table 9: Comparison of different methods for analysing gesture training.

The review of selected work (Section 4.5.1) demonstrated that other researchers did not explicitly describe criteria for age. All participants in the thesis's studies were within the age range of 19 to 64, to avoid ethical issues (participants under the age of 18 or over 65 would require special protection consent, as described by the university's ethical regulations).

Ideally, the number of participants should be arrived at from knowledge of the variance between participants likely to be seen in the chosen task and also of the prospective effect of any conditions to which they are to be exposed. Lower degrees of variation typically require higher numbers of participants, whereas lower numbers are often reliable in situations where the power of effect is extremely high. A further factor is the number of conditions to be tested, in which multi-factor tests such as ANOVA are to be used. The previous research successfully proved most of their hypotheses, while some were clearly rejected. This indicates that the numbers of participants previously used were appropriate for testing similar systems on a closely related task.

As can be seen from Table 9, previous researchers recruited from 12 to 44 participants. Bennett tested two novel interfaces against one benchmark interface, while the others tested one new interface against an existing benchmark. Three research teams, Bennett et al., Gutwin et al. and Bragdon et al., each tested 16 gestures. Two research groups tested a small number, Bau and MacKay testing eight gestures and Wigdor et al. only three. Bau and MacKay used the fewest participants (12), while Bragdon et al. used the most, with 24 in their initial, formative study and 44 in their second, summative study.

The first empirical study contrasted two separate designs, in line with most of the preceding work. This study included eight gestures, at the lower end of the range of numbers tested in earlier studies. The closest comparison was with Bau and MacKay, who also involved eight gestures and included only 12 participants. The study was also formative, in line with the smaller of Bragdon et al.'s two studies (with 22 participants) and Bau and McKay's (2008) first study.

Most of the related research was on a similar, but not identical interaction. The present researchers therefore erred on the side of caution, seeking a larger number of participants to mitigate the risk that the variations between either visual cues or users might be less than seen in the case of guidance provided during the performance of a gesture. In terms of within – versus between – subjects, the majority of the prior work and all the formative studies were followed, using a within-subjects design. Given the unknown impact of effects of individual variation, a within-subjects design was also adopted, in line with the strategy recommended by prior researchers taking initial steps in their research.

For the first thesis study, a total of 34 participants were recruited, more than the largest number of participants used previously for formative research and exceeded only by those doing between-participant comparisons in a summative context. The variation between users seen in the first study was in line with that observed by earlier researchers. In the second study, the number of participants was increased to 45. This was done in response to the larger number of interfaces – five versions in total – albeit with fewer gestures (see Section 7.4.1, Table 35 for all possible variations). This (just) exceeded the number of participants in previous summative work and was also a product of the number of conditions tested in the study.

Previous work tested participants who were not experts in gestural interactions. The knowledge with computers varied from novices to experts. Education levels were diverse and irrelevant to the tests. The criteria to participate in the empirical studies conducted during the thesis study, dictated that only people without any known cognitive or physical impairment were to be recruited. Acquaintances, canteen staff, front desk receptionists, graduates and MA students from different departments were unfamiliar with the research and therefore eligible. Colleagues from the Centre for HCI Design were not invited because of their proximity to the researcher (which could have made them prone to issue cautious responses), which could also compromise adequacy of the test.

Number of Gestures: The number of gestures [No. of gestures] tested varies from 3 to 16 with no specific rule described by the authors, with the exception of Bau & Mackay (2009). The authors used 8-item gesture sets in two different experiments making a total of 16 gestures because this number exceeds the limits of short-term memory.

	Bau & Mackay (2008) OctoPocus	Freeman et al. (2009) Shadow guides	Bragdon et al. (2009) GestureBar	Wigdor et al. (2009) Ripples	Bennett et al. (2011) SimpleFlow	Gutwin et al. (2014) FastTap	Chueke (2014) study 1	Chueke (2014) study 2
Gestures: No. of gestures	8	15	16	3	16	16	8	3

Table 10: Comparison of different methods for analysing gesture training.

Compared to the studies of Bau & Mackay (2008) and Wigdor et al. (2009), the number of interactions in the thesis studies was chosen to give variety (respectively 8 and 3). For instance, in the first study, the eight interactions mimicked known iOS gestures. The second study used three gestures that were completely unfamiliar or used in a different context than a user of touch devices would expect. Again, this is a matter of finding a balance between too few and too easy to perform against too many and too hard to comprehend, which can compromise the results.

Moment of Learning: As the aim of this thesis is to improve the discoverability of unfamiliar gestures, the empirical studies that tested the thesis hypotheses did not gauge memory [Trained before exec.]; however this was included in the future work session (Section 9.2) as a topic of interest.

As can be seen on Table 11, Bragdon et al. (2009), Wigdor et al. (2009) and Gutwin et al. (2014) also did not instruct the participants to memorize the gestures and did not inform in advance that there would be a memory test at the end of the study. The authors wanted to test how well they would learn simply by using each system [Discover during exec.].

As we want to capture the novice experience of users when they first encounter a gesture, we also did not train the participants before testing began. The research was rather about the impact of designs and their communicative power – in the form of automatic visual prompts – to indicate available gestures. To facilitate discovery, these prompts were displayed automatically and before [Discover before exec.] participants engaged in the traditional trial-and-error approach.

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Learning: Trained before exec.	X	X			X		
Learning: Discover during exec.			X	X		X	X
Learning: Discover before exec.							X

Table 11: Comparison of different learning methods to train participants in gestures.

For comparison purposes, Derboven (2012: 720), for instance, used a similar approach to the one utilised for the final empirical study, by also creating a set of unfamiliar finger-combinations gestures. Derboven then tested participants to trace a semiotic profiling of user interpretation of such interactions.

Effects Measured: Before explaining the measurement of effects, we should make a distinction between summative and formative evaluations in HCI.

Preece et al. (2007: 309) reflect on different approaches to measure the effectiveness of interactions. Preece et al. state that both direct observations in the field, and indirect observations (e.g. diary studies) most readily provide qualitative information, and are very time-consuming to conduct and analyse. This also requires a working prototype to exist. Preece et al. (2007: 589-590) also explain that summative evaluation refers to the assessment of participants where the focus is on the outcome of the software program. This contrasts with formative assessment, which evaluates a design in order to improve it or, in the case of Lab RTD, to improve the underlying theory. This type of study has in general a qualitative step to analyse data. The first study was entirely formative, while the second was primarily summative, as will be seen in later chapters.

The previous studies reviewed in this chapter undertook summative evaluations focused on participants' executions of gestural commands, such as precision in hitting targets (Wigdor, 2009), time for task completion and error rates in task performance (Bennett et al., 2011), etc. For instance, Freeman et al. (2009) focused their studies on the ability of users to recall previously encountered gestures. Anderson (2013: 1109), on that matter, contends: "many methods for learning gestures have been proposed, but they are often evaluated with short-term recall tests that measure user performance, rather than learning."

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Effects: Memory		X					
Effects: Evaluation							X
Effects: Execution	X	X	X	X	X	X	X

Table 12: Comparison of different measurements for analysing gesture training.

As the research aim was not to evaluate recall, this aspect is not directly useful for informing the design of the empirical studies 1 and 2. As can be seen on Table 12, our two studies rather aimed at gauging participants' [Evaluation] of the UI and then the [Execution].

Cairns et al. (2008:138), on this matter, recognised that the focus on tasks is not enough to assess how effective a system is and suggests, "A growing need to understand how usability issues are subjectively and collectively experienced and perceived by different user groups". Cairns' statement resonates with the goal of this thesis to construct an effective and readily understood gestural user interface that could seamlessly reveal the available gestures in a given touch system.

To pursue that goal, the next section reviews different elicitation methods that could help in assessing how accurately users might acquire new gestures with the new interface design.

4.6 Elicitation Method

The approaches of previous studies in assessing participants' learning of new gestures can be seen in Table 13.

Previous research in designing and evaluating gestural interaction, such as that by Wigdor et al. (2009, 2011) and Freeman et al. (2009), gave users fixed, simple tasks to perform with a proposed 'improved' design, often contrasted with a baseline design, in order to evaluate their recommended design. Error rates and time to perform tasks were common measurements, an approach that was found perfectly effective for assessing performance alone. To supplement the objective performance data, all researchers used paper-based post-task questionnaires to debrief participants.

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Elicitation method	Informal debrief	7-point Likert	5-point Likert	Informal debrief	3-point Likert	NASA-TLX and 5-point Likert	Oral structured interview

Table 13: Comparison of different methods for analysing gesture training.

In these questionnaires, participants rated their preference for specific features of each design concept, on a Likert scale with 3 to 7 points. The number of questions varied. For instance, in terms of user preference and experience, Wigdor et al. asked for a simple general preference between two alternatives, while Freeman and colleagues introduced four questions with a 7-point Likert scale to ascertain users' subjective ratings in more detail.

As the research goal was not strictly to measure completion times to gauge success or failure in execution but to capture the experience of users when they first encountered a gesture, time-sensitive data were of no concern. As described in Section 4.5.1, other researchers used statistical analysis to assess questionnaire responses and error rates to assess participants' performance. However, according to Kowalczykiewicz and Weiss

(2002), ‘statistical analysis on its own is not well suited for evaluating users’ subjective opinions. Numbers can reveal quantity but of themselves are poor at revealing meaning.’ Thus, a twofold method was deemed necessary to enable this research to glean the two different perspectives. Two different data sets were considered, as follows.

First, the users’ subjective feedback. It was considered that the key to train users in gestural UI lies in how effectively affordances can convey gestural interaction opportunities to users. Hypotheses ‘a’ and ‘b’ (see Section 1.5) express the aim of investigating this aspect of user interaction.

A method was required to assess participants’ interpretation of the UI, such as its aesthetics, its visual qualities and the meaning the affordances and feedforward metaphors seek to convey. The participants’ user experience (UX) and how they articulated their thoughts was then subject to the researcher’s interpretation.

Second, their performance. The users’ performance is evidence that cannot lie: either participants executed a target gesture correctly or they did not. However, as will be further reported, the research was interested in ‘success at what cost’ and the finer detail of ‘where’ precisely people were making more mistakes (e.g. in understanding the number of fingers to initiate the gesture or to perform a swipe across the screen). Hypothesis ‘c’ (see Section 1.5) is based on the expectation that a rating system that segments users’ gestural interactions into smaller phases will help reveal issues.

4.6.1 Proposed Methods: Pros and Cons

As reported in Section 4.2.1, the research takes the approach of laboratory-based RTD. It requires a controlled lab environment and structured study. To meet the research goals, a data collection method is required that captures how people think and what they have to say about the design interventions.

There are a number of approaches available to the researcher, including focusing on obtaining users’ free and unconstrained responses or focusing on a number of set criteria. For instance, questionnaires are one standard method that more often matches the latter, while, for unconstrained responses, talk-aloud techniques during the study and interviews following it are more common. Interviews are recommended to elicit unanticipated issues, which pre-set Likert scale responses, for example, would be unlikely to reveal.

The next step is to narrow down on how to capture such data on effectiveness by reviewing work that can support the construction of a method. In this section we discuss: 'Interaction logs', 'talk aloud', 'contextual inquiry', and 'oral structured interview'.

4.6.1.1 Interaction Logs

Interaction logs are commonly used to capture what participants do, in fine detail and without disturbing their activity. The interaction log is an indirect observation technique that provides a realistic experience to participants. It is used, for instance, in UX with mobile technology, by capturing participants' interactions 'touch by touch' on a screen device. Special software runs on the prototype background to capture such data.

This can lead to producing a large amount of quantitative data that demands tool support for analysis. Furthermore, these methods are not easily adapted for use early in the design process, as they require commitment to developing a sophisticated prototype. Gerken et al. (2008) observe that there are limitations in this method: '…it may also be necessary to record situational variables like the amount of information presented to, and required by the user. In addition to these factual measurements, developers may also be interested in their users' individual preferences and satisfaction with the system.'

Therefore, this method can provide a large amount of data on what people do, but not much insight into what they think. The next method comes closer to solving this issue.

4.6.1.2 Talk aloud

Talk-aloud methods require participants to describe, for example, what they see, what they think, what they presume is the best action to take next and what they are doing while taking that action. It is usually task-driven and commonly used in testing software (e.g. desktop software or mobile application). Participants are instructed to undertake tasks and describe their thinking as they do so (Preece et al., 2007). Generally, a camera and microphone are used to record the test sessions, along with screen-capture software in a controlled lab environment.

Thus, in addition to focus on performance, which logging and observation can capture, talk-aloud also captures users' attitudes and experiences. Therefore, this method well matches the research interests, by letting participants articulate in such a way as to give an insight into their thinking. Being an open-ended elicitation method, it is less likely to generate premature assumptions about the user's understandings.

However, the very openness of the 'open-ended' talk-aloud method could lead participants to stray off course. The research goals require fundamental questions to be asked – questions intended to glean further insight into specific design features and the interaction techniques used. The talk-aloud protocol could benefit from additional structure and systematic reasoning that could reel the participant back in to provide answers that are closer to the research interests. The next method could provide such structure.

4.6.1.3 Contextual inquiry

Beyer and Holtzblatt (1995) introduced 'contextual inquiry' as an efficient method of gaining unconstrained information from participants. In this sense, it has similarities to talk-aloud protocols, adopting an open-ended approach. However, it differs in having a semi-structured approach to interviewing participants. It is generally used to obtain information about the person's context of use, participants being first asked a set of standard questions and then observed and questioned while they work in their own environment, such as the workplace or home.

There are limitations to this method, however. Following a contextual inquiry field interview, interpretation sessions are needed to analyse the data. Preece et al. (2007: 498) explain that it is resource-intensive, 'as it requires a 3-8-team members interpretation session, gathered to hear the researcher re-tell the story of the interview in order. As the interview is re-told, the team add individual insights and facts as notes.' They also may capture representations of the users' activities as work models. It requires travel to the informant's site, a few hours with each user and then a few more hours to interpret the results of the interview along with other researchers.

4.6.2 Choice of Method (1): Oral Structured Interview

Another, more generic approach to interviewing participants is the ‘oral structured interview’ (Geiwitz et al., 1990; Hudlicka, 1997). This method synthesizes the characteristics suitable for referring back to the research goals. The oral structured interview method combines situational and behavioural question types and, in contrast to ‘contextual inquiry’, can also be used in a controlled laboratory environment. Furthermore, in contrast to conventional, post-task, long interviews (such as used in ‘contextual inquiries’), this method takes the form of short questions to elicit micro-responses, rather than a time-consuming addition at the end of the test.

Marshall et al.’s (2007) approach is an example of such a method, and is highly relevant to the research goal in understanding how users make sense of what they are doing while they are doing it. Marshall introduced the ‘schema model for the domain of problem solving’ (described in Section 2.4.5), which consists of an interview containing several short questions. In their empirical studies, Marshall et al. introduced different questions within their model, such as time (when?), agents (who?), their roles (doing what?) and prioritizing a specific action (why?), in addition to cause (what is happening now?) and effect (the output itself). This strategy covers a user's mental model, from the formation of meaning (when, who, doing what and why) of available interactions, followed by system feedback (what is happening now), to anticipation of the consequences of executing such interactions (the effect).

By asking short questions at the time of the interaction, problems caused by users’ naturally short time-span of working memory are also much reduced and a more complete picture of the user’s experience can be obtained. Therefore, to ensure the systematic capture of users’ impressions and understandings, an oral structured interview with open-ended questions was adopted in the present study to elicit participants’ responses. This approach employed a talk-aloud protocol, cued by scripted short questions.

Next section describes the methodology used to analyse the data acquired from the interview process.

4.7 Data Analysis

As described in Section 4.6, the research sought to validate the participants' reported experiences against real behaviour (i.e. whether what they say can be trusted). Thus, the method selected must permit analysis of a user's expressed intentions against her or her success or failure in executing a gesture. It must also allow a broader view to be gleaned of problems users have, objectively and subjectively. The use of different methods in combination to tackle different usability problems is one form of 'triangulation[4]'. As will be reported, it was decided to use more than one data source, of qualitative and quantitative sets to answer the research questions.

4.7.1 Proposed Methods: Pros and Cons

This section compares alternative approaches to data analysis before making a final selection for the research done in the thesis. Throughout, the goals in assessing user success and understanding user interpretations of the interface are considered. The methods reviewed are: 'Grounded theory', 'General inductive coding', 'Semiotic analysis', and a non-traditional method termed 'Rating scheme'.

4.7.1.1 Grounded theory

Many established methods are used in qualitative analysis. None of the papers reviewed in this chapter used such a method.

Grounded theory, for instance, is a well-accepted approach to discourse analysis in all forms of research. However, according to Grbich (2007), grounded theory places much emphasis on hypotheses, variables, reliability and replicability, which makes for a complex method that uses 'confusing, overlapping terminologies rather than the data'. Taking into account the observation data likely to emerge during the laboratory studies

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[4] Preece et al. (2007: 293) explain triangulation as a strategy that "entails using more than one data gathering technique to tackle a goal, or using more than one data analysis approach on the same set of data. It provides different perspectives and corroboration of findings across techniques, thus leading to more rigorous and defensible findings".

and a lack of familiarity with the powerful, if complex, method of grounded theory, an alternative approach was sought. The unfamiliar stimulus – visual prompts for unfamiliar gestures – further added to the caution concerning the use of a complex technique.

Discourse analysis – which presumes longer, discursive text – would furthermore be challenging to apply to small instances of observed behaviour or to snippets of participant utterances. This would compound the high demands on researcher expertise that Grbich and others have noted stem from using grounded theory. In addition, the user's language to describe his or her task would very likely be limited and informal, such that forming and assigning codes would be particularly challenging.

There are other methods that provide different trade-offs in researcher expertise, complexity of use and other factors.

4.7.2 Choice of Method (2): General Inductive Coding

Gibbs' (2007) general inductive approach is a readily adopted method for data analysis, which is, from the outset, to be inductive with generative bottom-up coding.

The coding method combines qualitative data (e.g. participants' responses in free-form speech) into smaller categories, nodes and larger themes. The method also considers similar passages of text with category labels that can be easily retrieved at a later stage for further comparison and analysis. Therefore, general inductive was deemed the right fit for analysing the participants' utterances. By letting codes and themes emerge from the data it was possible to obtain a wider view of unanticipated problems participants experienced during the study sessions.

The video and audio recordings were analysed in order to capture any utterances made by the participants. The analysis of verbalisations was undertaken *a posteriori* to the study sessions. No non-verbal sounds were transcribed, neither were digressions unrelated to the study at hand. The coding criteria also included the facilitator's notes, which covered any relevant gestures made by participants that indicated difficulties in comprehending and performing the interactions. In the coding criteria (see Appendix J for an example of a control spreadsheet), the observer's notes were added, which covered any relevant gestures made by participants that could reveal effort or difficulty in performing the interactions.

The procedure outlined by Gibbs was followed:

1. Initially, participants were given a unique identifier, followed by gender and age, e.g. (P1, F, 39).

2. Data cleaning was carried out, this included transcribing the video audio files verbatim, in which keywords were highlighted within responses. Key quotations were extracted manually from participants' responses.

3. Keywords were organised into high-level codes, or non-hierarchical coding. These were checked and accepted throughout all responses where similar coding was found, and every new remark that could yield a new code was considered. Smaller sub-codes derived from high-level codes to specify topics.

4. Multiple categories were mapped within quotations. These were checked and accepted throughout all responses where similar coding was found, and every new remark that could have yielded a new code category was considered.

5. Revisions to the category list were carried out to ensure all data was treated consistently. Larger themes emerged, which by comparison allowed a wider understanding of category lists.

Taking an example from the final empirical study, a participant (P3, M, 22) answered the following when asked what the visual prompt was for: "Need to use two fingers to open the little icon. It said in the little animation the little 'open' (P36, F, 24)". This response was annotated with the following codes:

1. "Need to use two fingers to open the little icon (…)" was labelled as '1. Correct understanding of affordance'. This code gathered any comment from participants that demonstrate comprehension of the prompt that implies a gesture and effect of a gesture.
2. "It said in the little animation the little *open*" was labelled as '1.1. Textual aid'. This sub-code is related to the text label provided with some visual prompts.

Some participants regarded the text as the determinant factor that helped them understanding the meaning of the visual prompt and implied interaction.

3. The emerging theme from the described code and sub-code was termed 'Design feature'. This theme would gather any verbalisations that described the design technique as effective.

Table 14 shows the resulting coding scheme. The first column shows the code itself (1.) and the specific sub-code (1.1.), followed by the sum of comments, the emerging theme, a description of the code, and on the far right examples of verbalisations.

Code	Sum	Theme	Definition	Examples
1. Correct understanding of affordance: 1.1. Textual aid	7	Design feature	It was observed across the 3 interactions participants describing the text label as a fundamental aid to relay function or purpose of visual cue.	"This time it said 'hold', that's easier". (P4, F, 23)
				"Ah, that's better. Much easier when you have a little command as well as the image". (P34, F, 35)
				"Need to use two fingers to open the little icon. It said in the little animation the little 'open'" (P36, F, 24)
				"But wasn't written 'hold' beforehand". (P40, M, 42)

Table 14: Example of coding scheme.

Therefore, the qualitative part was already addressed in this section, with an inductive approach to coding. As reported in Section 4.6, the research goals also aim at both assessing participants' interpretation of the UI, along with their performance across the gestures presented. The generic assessment of error rates, which simplify interactions into 'succeeded' or 'failed' at the end of the task did not seem suitable in providing the 'finer grain' approach to assess *where* and *when* participants are succeeding or failing.

The next section looks into prior work that uses such approach.

4.7.2.1 Semiotic Analysis

The first method considered closely related to the research goals in assessing participants' interpretation of the UI is Derboven's semiotic analysis. Derboven et al.'s (2012) used the De Souza's (De Souza & Leitão, 2009) Communicability Evaluation Method (CEM) to arrive at an in-depth semiotic analysis of a touch table. The CEM method constitutes a verbal-protocol driven framework and is both qualitative and interpretive method. Derboven transcribed participants' verbalisations and then associated the most common expressions in reaction to the interface to pre-defined tags, constituting a top-down or deductive[5] approach.

Derboven demonstrated in advance a set of gestures, which, as previously reported, would not be suitable to encode participants' discoverability of gestures by themselves, with the aid of a responsive interface. Rather, they solely reported on participants' interpretations of the UI before and after the facilitator gave an explanation for the available gestures.

However, the *a priori* tagging approach to code interactions seemed relevant to the analysis of participants' performance. It could be used to distinguish the moments within user's evaluation of the interface and execution of commands participants are making more mistakes.

Next section looks into previous work that used *a priori* coding that is relevant to the research goals.

4.7.3 Choice of Method (3): Rating Scheme

As reported in Section 4.5.1, Freeman et al. (2009) and Bragdon et al. (2009) defined their *a priori* rating criteria to judge success or failure in participants' attempts to perform gestures.

Freeman et al. (2009) classified the first four attempts of a gesture in the memory phase as (1) correct, (2) errors in performance – correct mental model but clumsy performance, or (3) errors in memory – completely incorrect gesture. Freeman's approach to quantifying data focuses on participants' recall of the visual prompts that did not align with the research interests.

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[5] Research in HCI, as explained by Lewis (2013: 76) "often refer to two broad methods of reasoning: deductive and inductive. Deductive approaches refer to reasoning that goes from generic to specific i.e. a top-down approach. Inductive reasoning works the other way, observations towards generalizations and theories and is often referred to as a bottom-up approach.

In Bragdon et al.'s (2009) rating scheme, the authors counted the number of attempts participants undertook until they succeeded or failed in executing a gesture. Bragdon et al. assigned gesture performance for each participant to one of five categories: (1) successful on first attempt, (2) successful within three attempts, (3) successful in more than three attempts, (4) attempted but all attempts were unsuccessful, and (5) did not discover a correct gesture.

The research goals are to discriminate between participants' 'quick success' versus success obtained at great cost (e.g. how many attempts to get it right) in a prototype design with untaught gestures. Bragdon et al.'s criteria seemed directly relevant to the research interests. The next section describes the rationale for adapting Bragdon et al.'s rating scheme to the research goals.

4.7.3.1 Criteria for Rating

In light of Bragdon et al.'s (2009) rating scheme at a more strategic level, counting the number of attempts could be used to determine nominal coding. For instance, up to six attempts could indicate success, but more than six could indicate a greater effort to understand a visual prompt or execute an action. However, the present research sought to discover, empirically, if such an approach would serve to meet the research goals. Thus, a pilot study was organized to verify the rating criteria.

Pilot study

A pilot study (n=10, 6F, 4M, age 22 to 54) was conducted in order to validate the pre-set criteria. There was no intention to produce a formal coding or statistical analysis. A preliminary set of two designs and the eight interactions from the first study were used to, *first*, validate the designs and, *second*, validate the number of attempts necessary for the participants to succeed or fail in understanding and executing gestures.

The participants comprised a variety of people, including staff and students from City University (including colleagues from the Centre for HCI Design). There was no preference for participants who had previous experience with touch-based devices, e.g. smartphones or tablets. They were informed that, while the main researcher (and facilitator) would take notes during the sessions, the study was informal in character, with no voice or video recordings. As such, there was no need for a consent form. Little guidance was given and participants were left to discover the gestures through automatic on-screen visual prompts run on a Keynote application.

No verbalisations indicated a need to change in the initial set of designs. With regard to the rating criteria, it was observed that most participants who fully understood the visual prompt produced an acceptable description and executed the gesture in the first three to six attempts. Participants who struggled to comprehend the prompt managed to describe and perform it in up to seven attempts, rarely more; but some failed to describe or execute the gesture. The realization that some participants struggled to execute the gestures showed that a 'partial' rating would provide the finer grain mentioned in Section 4.6. Note that the partial rate of assessment, although stemming from a successful description, was defined in such a way as to differentiate it from full success.

Final rating scheme

Therefore, in the final rating scheme, a 'success' (1) was measured by the clarity of the user's description of the meaning of what he or she saw before a successful execution. Both the precision of the description and the number of attempts taken to arrive at the final assessment were considered. An accurate description was considered to contain the number of touch points required, the motion to be performed and, at the most rudimentary level, the basic opportunity for a gesture to be performed within the first six attempts. A 'failure' (2) was considered to be a complete inability to describe the visual cue or to execute the gesture. A 'partial success' (3) was considered to be a correct assessment from the seventh attempt onwards up to a successful execution.

Participants' evaluations and executions were assessed separately, which meant that a participant might succeed at one phase but fail at another. For instance, a user might correctly identify a gesture that requires two touch points but fail to identify the movement that he or she should follow. This would result in a 'correct' assessment for the number of fingers, but 'physically' executing it might present different issues that could lead to failure, such as swiping in the wrong direction.

Thus, the approach adopted by the thesis to rate interactions continues an established thread of model-based rating systems to identify problems encountered by users in touch-based gestures and in interpreting the user interface.

The next section consolidates the strategy to assess the results from the empirical studies. It explains how the numbers obtained from the rating scheme were statistically analysed.

4.8 Statistical Analysis

The majority of researchers from previous work utilized ANOVA (analysis of variance) as their main statistical technique (Table 15).

All previous work has used Likert-style questionnaires or analysed factors such as time or number of attempts. Thus, the analysis undertaken by previous researchers considered a normal distribution and was defined by their choice of dependent variables (DV) and independent variables (IV). When up to two IVs are considered, a t-test is recommended. An IV with more than two factors requires an ANOVA test. These tests are part of a large group of statistical tests called generalized linear models (GLM; Carey, 2013: 129).

	Bau & Mackay (2008) OctoPocus	**Freeman et al. (2009) Shadow guides**	**Bragdon et al. (2009) GestureBar**	**Wigdor et al. (2009) Ripples**	**Bennett et al. (2011) SimpleFlow**	**Gutwin et al. (2014) FastTap**	**Chueke (2014) study 1/2**
Statistical Test: Analysis	ANOVA	T-test	ANOVA	T-test	ANOVA, LR	ANOVA	GLM, G^2, Kruskal-Wallis, Mann-Whitney

Table 15: Comparison of different methods for analysing gesture training.

The statistical analysis for this thesis was intended primarily to assess the early success or failure of the user in attempting a new gesture. Given the focus on users' understanding, time data were less valuable and, as described in Section 4.6, with the use of talk-aloud within the studies, the timing data would in fact not be valid for statistical analysis.

As reported in Section 4.7.2, the video and audio recordings from the studies undertaken in this research were analysed after the study sessions. Participants' verbalisations were transcribed and the emerging categories inductively coded. The *a priori* rating scheme was then applied to rate the gestural interactions, according to the 'correct', 'partial' or 'incorrect' categorical ratings6. The outcome of the rating phase is a nominal rate of success across different stages of participants' evaluation and execution of gestures.

Therefore, and in contrast to previous work, the rates adopted for the present research did not follow a normal distribution (such as time measures). Hence, ANOVA was not the most suitable method to analyse the ratings. Instead, the GLM was used in the data analysis, though in its non-parametric versions.

4.8.1 Choice of method: Non-parametric GLM set of tests

Ultimately, the key question was in what proportion users succeeded or failed at any point in their interaction. For testing proportions of populations – or, in this case, proportions of a group of users – the normal statistical test is Chi-squared. However, this method allows for only two factors in an experiment, which is a major limitation. As will be seen in the chapters on empirical studies, three factors had to be taken into account (i.e. different interactions, different designs and different phases of user action) and so a more sophisticated technique was needed.

As previously mentioned, these different factors were not normally distributed across the population tested. Therefore it was necessary to employ a non-parametric measurement so that inferences could be made. In other words, the emerging data from the studies are of a nominal nature and are linearly associated with one or more DVs. Thus, the GLM set of tests, in its non-parametric versions, was deemed suitable for the data set in all analysis.

Bonferroni post-hoc corrections were applied to correct any unbalanced factors within the IVs. Furthermore, regardless of any differences in stimuli conditions, the tables were organized by modal results to assess the effect of any specific condition, i.e. designs across interactions and the rating scheme.

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[6] In statistics, a categorical variable is a variable that can take on one of a limited, and usually fixed, number of possible values, assigning each individual or other unit of observation to a particular group or nominal category on the basis of some qualitative property.

The statistical analysis therefore followed four steps, which assessed the micro-phases within evaluation and execution of gestures: the Log-linear, Chi-square, Mann-Whitney, and the Kruskal-Wallis technique. The steps are now described:

1. Log-linear analysis: Two empirical studies were organised and utilised three separate dimensions in their set up, which characterised a 3-way contingency table (A x B x C). The two studies used different sets of independent variables (IV), however with identical dependent variables (DV: the threefold rating system). To verify significance of the whole set, the first step of the Log-linear is a global analysis. Log-linear is a more advanced form of the Chi-squared test, but denotes its result with the term G^2 rather than χ^2. The use of the method is almost identical when applied to an entire data set. However, like ANOVA, when used with multiple factors, further tests are taken to analyse individual factors and their interaction with each other. Whereas ANOVA uses Tukey's Honest Significant Difference (HSD) test for this later, more detailed analysis, Log-linear analysis produces a detailed analysis as part of its main calculation. Following the global test (A x B x C), pairs of factors are tested in turn (e.g. A x B, A x C, B x C and so on), without performing counter-balancing for the third factor. The third and final step examined the same pairs of interactions while counter-balancing for the effects that have been isolated for the factors in the second phase (e.g. A x B (C), A x C (B) and so on).

2. Chi-square: this second step assesses the evaluation and execution phases separately. It utilises simple frequency tables to describe all versions by the frequency of success of the participants. The measurement was therefore nominal and a Chi-square (χ^2) was used for each micro-phase, to assess each design(s) or version(s) within the study. The Yates' correction was used in all cases to avoid type '1' (false positive) errors, where numbers were too low for a simple probabilistic comparison.

3. Mann-Whitney (non parametric / non normally distributed T-test): The Mann–Whitney U test (or Wilcoxon–Mann–Whitney test) is a nonparametric test of the null hypothesis that two samples come from the same population against an alternative hypothesis, especially that a particular population tends to have larger values than the other. It can be applied on unknown distributions contrary to t-test, which has to be applied only on normal distributions.

4. Kruskal-Wallis (non parametric / non normally distributed ANOVA): in the final step the categorical data was organised in way of measuring significance of each independent variable in relation to the rating criteria. Each rating was associated with a discrete value and then converted to a nominal scale ('Correct' with higher value, followed by 'Partial', and 'Incorrect' with the lowest value) for further statistical analysis. Again, simple frequency tables and percentages were utilised. The data was revealed to be non-normally distributed by a Shapiro-Wilk test. Therefore, we rejected the use of a parametric test (e.g. simple ANOVA), and used the Kruskal-Wallis test. To further increase the cautious handling of the data, we increased robustness of the result by bootstrapping by a value of 10.000 - increasing resistance to noise and reducing again the likelihood of a type-1 false positive. Finally, a simple linear regression was made to assess variability for both the evaluation and execution phases of the model. All analysis was made with nominal 'α' value of .05, using SPSS v.22.

4.8.1.1 Additional analysis

An additional analysis was required for the first empirical study. To check the reliability of the rules for applying the rating system, a second independent researcher also assessed the scores of randomly selected participants. Both the independent and the main researcher assessed the same participants and a comparison was made of their ratings for 'correct', 'partial' and 'incorrect'.

A Pearson product-moment correlation coefficient was used to compare the results from both researchers. This is a measure of the linear correlation between two variables, X and Y, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation and −1 is total negative correlation. It is widely used in the sciences as a measure of the degree of linear dependence between two variables. Correlation coefficients whose magnitude is between 0.7 and 0.9 indicate variables that can be considered highly correlated.

4.9 Summary

This chapter has summarized the methods used in this thesis. It started by situating this thesis within laboratory research *through* design *for* design and research and practice in HCI. It continued by comparing design and empirical methods from a selection of authors who have researched the design of effective gestural interfaces. This comparative analysis supported the choice of designs and methods employed to undertake the two studies found in Chapter 6 and Chapter 7.

An ‘oral structured interview’ (based on Geiwitz et al., 1990; Hudlicka, 1997, method), cued by short questions (based on Marshall et al., 2007, method) was used to elicit participants’ interpretations of the UI.

The data analysis followed a twofold approach: *first*, an inductive approach to qualitative analysis (Gibbs, 2007) was used to form categories that stemmed from participants’ experiences with prototype gestural UI; *second*, a deductive and *a priori* nominal coding was used to rate participants’ interpretation and physical execution of gestures in given gestural systems (based on Bragdon et al., 2009, method).

Statistical data analysis followed, consisting of mixed, non-normally distributed techniques (within GLM).

CHAPTER 5 - INTRODUCING SELF-PREVIEWING GESTURES AND THE GESTURE-AND-EFFECT MODEL

5.1 Introduction

Three key research problems were presented in Chapter 1 regarding the support of user learning of gestural interactions. The initial two problems are fundamentally ones of design: the *first* concerns the lack of any consistent representation of touch points in gestural interfaces to date; the *second* claims that ideally any depiction should be displayed to users before they start touching the screen. The *third* problem is, in contrast, methodological: how to analyse the strengths and weaknesses of different design and interaction techniques in communicating available gestures to users.

This chapter introduces two major contributions of the thesis.

The *first contribution* is the interface design concept, which is termed here 'self-previewing' gestures (SPG). Thesis hypotheses 'a' and 'b' claim that user interfaces that automatically show the registration points should reduce error rates in the execution of gestures. To support these hypotheses, the SPG was designed with these characteristics. This chapter articulates the relationship between SPG and the existing concepts of perceptible affordances, feedforward and self-revealing gestures (as seen in the work of Wigdor and Wixton, 2011; Hofmeester, 2012) and the rationale for its ideation.

The *second contribution* supports thesis hypothesis 'c'. This hypothesis claims that a framework that segments users' gestural interactions into smaller phases will help reveal issues with users' evaluation and execution of gestures. To verify this hypothesis a new model of 'gesture-and-effect' is introduced. The model is rooted in Norman's Theory of Action (Norman, 1988: 45-53; Preece et al., 2007: 120-124), Wu et al.'s (2006) RCT theory, and Golod et al.'s (2013) 'gesture phrase'. This model provided the structure for a rating system (Section 4.7.3) that was used to assess participants' performance in two empirical studies.

This chapter will now address the rationale that led to the concept of the self-previewing gestures.

5.2 From Perceptible to Gestural Affordances

This section describes, in four steps, the rationale for adapting the two principles of perceptible affordances and feedforward to communicating unknown gestures to users:

The *first* step is the adaptation of the concept of perceptible affordances in the context of gestural interfaces. The *second* step focuses on feedforward in isolation and its known advantages including how feedforward is, potentially, relevant to addressing the learning of unfamiliar gestures. The *third* step reviews 'self-revealing gestures' (Wigdor and Wixton, 2011; Hofmeester, 2012), which use feedforward, feedback, and perceptible affordances *during* the execution of a discovered or known gesture. In the *fourth* step, the new design technique of 'self-previewing' gestures is defined, which applies the concept of self-revealing gestures to indicate the presence and execution of unfamiliar gestures, *before*, rather than *during* a user's interaction. This technique exploits both perceptible affordance and feedforward, and furthermore uses animation to ensure the full range of information that a user might need to successfully choose and execute a new gesture.

5.2.1 An Adaptation of Perceptible Affordances to Gestural Interfaces

As previously described in Chapter 2, interfaces using the prevalent desktop metaphor articulated information on available system or software commands to the user through perceptible affordances (Norman, 1988; Gaver, 1991; St. Amant, 1999; Mcgrenere, 2000; Hartson, 2003; Turner, 2005 and Kaptelinin, 2012). Examples include menu items, visual cues for interactive 'hot-points', such as hyperlinks on a webpage, and visual signs to indicate moveable items, such as scrollbars.

An affordance *implies* an action possibility. It is something that 'affords' an interaction of some kind, for example a button 'affords' being pressed. Figure 44 shows how a perceptible affordance is divided into 'potential action', which is the available interaction for a user to perform, and 'potential effect', which is the anticipated consequence of that action.

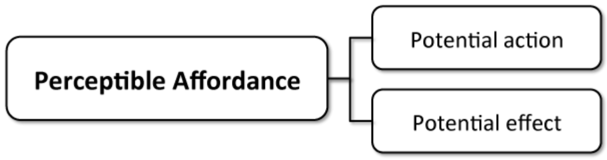

Figure 44: Perceptible Affordance components.

Perceptible affordances are long established as an effective foundation for the design of easy-to-use interactions in a conventional WIMP or GUI interface. However, as seen in Section 2.2, a number of leading researchers have recently argued that this approach has limitations when attempting to articulate the full range of available actions in a gestural interface (Sorensen, 2009; Schneiderman et al., 2010; Norman and Nielsen, 2010; Wigdor and Wixton, 2011). Standard gestural interfaces, with very few exceptions, do not display any form of perceptible affordances for gestural interaction for many of the gestures that control them (Sections 3.3 and 4.4.1). Many contemporary gestural interfaces lack a pointer, visible menus and accelerator keystrokes. This means that gestures are often invisible and evade the user's sensory 'radar' when compared to predominant WIMP-GUI controls such as a button, which is normally visible and static.

In order to demonstrate to users how to initiate a gestural interaction the system could display what is termed here a 'gestural affordance' (Figure 45). This form of affordance involves a visual representation of the gesture, which suggests to the user the number of touch points, their spatial configuration, and the subsequent effect on the system. For instance, the user might be invited to touch an object with two fingers (represented by the 'potential touch') in order to scale it (the 'potential effect'). Note that the terms 'potential touch' and 'potential effect' are introduced in the thesis.

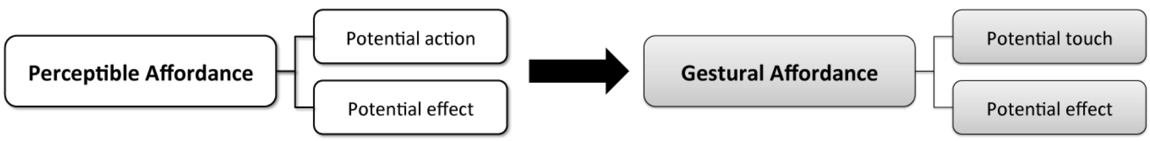

Figure 45: Adaptation of Perceptible to Gestural Affordance.

In this stage, movement is often not represented or is poorly portrayed. The user does not yet know how to perform the gesture. However, feedforward is a powerful technique to demonstrate the performance of a gesture.

5.2.2 The Feedforward Component

Feedforward (Djajadiningrat: 2002, Wensveen: 2004, Freitag: 2012, Vermeulen: 2013) is an HCI technique that aims at making 'explicit' the action – most often the *movement* – that is required to perform an interaction and its effect (Figure 46). In feedfoward, the potential movement is demonstrated to the user to guide their control of the interface. Golod (2013: 15), for instance, recommends continuous use of feedback and feedforward in gestural interfaces.

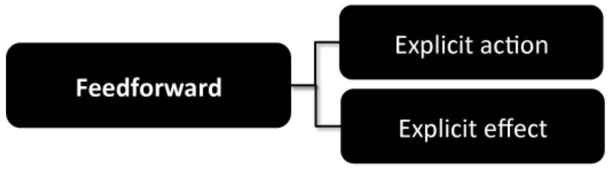

Figure 46: Feedforward components.

Wobbrock (2009) further analyses the feedforward pairing of action and effect into an analogous pair of sign (action) and referent (effect). The sign communicates to the user potential action, while the referent element communicates the effect of the action.

One way feedforward has been used is to indicate gesture completion pathways during interaction (Bau, 2008; Freeman et al., 2009; Wobbrock et al., 2009; Bennett et al., 2011; Roy et al., 2013), but it rarely implies gesture initiation or effect (Section 4.4.1). In the past, only 'enhanced' feedforward (as described by Freitag, 2012) or 'enhanced' feedback (as described by Wensveen, 2004) have been used to indicate interface response from a user initiating a touch interaction.

Wigdor et al.'s (2009, 2011) 'self-revealing technique' is the exception to this general rule, as will be reported later in this chapter.

The principle of feedforward can disambiguate what the user should do during the continuation phase (Wu, 2006) of the gesture, when the user moves from their initial touch on the screen. Feedforward can communicate information that shows users how to continue the gesture and demonstrates an 'explicit' action and effect. For instance, a system could show that a double tap will maximize the application window view by actually previewing the zoom. This interaction was termed a 'gestural' feedforward (Figure 47). The definition of 'inherent feedforward' by Wensveen et al. (2004) further supports this thesis concept: “it offers information related to the action possibilities of the product and appeals primarily to the perceptual motor skills of the person (e.g., pushing, sliding, rolling)”.

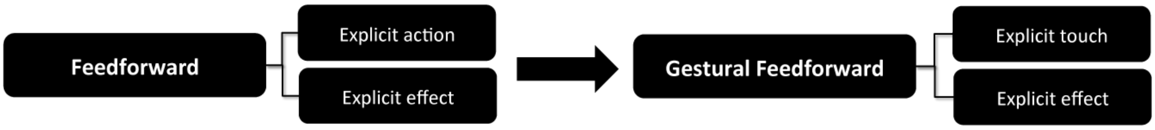

Figure 47: Adaptation of feedforward to gestural feedforward.

5.2.3 Self-Revealing Gestures

This section elaborates on ‘self-revealing’ gestures (SRG). This technique was already described in Chapter 3 (Section 3.3.5); however, a few additional examples of its implementation are brought here to underpin the rationale that led to the construction of SPG.

Figure 48 shows an example pf SRG through a ‘just-in-time chrome’[7], as described by Wigdor and Wixton (2011: 153).

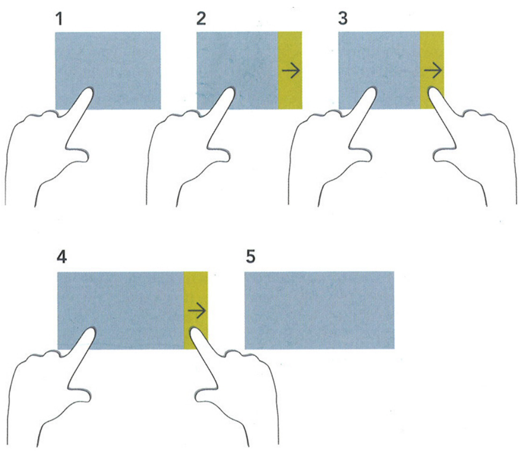

Figure 48: Just-in-time chrome (Wigdor et al., 2011: 153).

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[7] Just-in-time chrome is “just one method of making your gestural interface self-revealing. The key is to consider affording registration actions as well as continuation actions” (Wigdor and Wixton, 2209: 154).

The visual cues for stretching a picture are displayed when the user touches the photo (Figure 48-1). Once the touch is recognised (2) by the interface, an overlay (a meta-level interface object) is displayed. This overlay contains an arrow to indicate the potential direction of movement and the corner available for a dragging interaction is highlighted (3). This indication of gesture and effect is the feedforward. The user would then perform the interaction by holding the left-hand side of the picture and stretching the right-hand side (4). The picture displays its updated status (5).

The ‘chrome’ is only triggered in the specific case where the user both touches and holds the left-hand side *and* initiates a second touch on the screen. This means that the user must have initiated the gesture for the animation to help them perform the gesture displayed. This leaves open the possibility of providing some indication of potential action without the user having already embarked upon that specific gesture. Through such an approach, a new or unknown gesture could be revealed to the user.

Analysing Wigdor’s SRG ‘chrome’ through the principles of feedforward (touch and effect) led to the structure presented in Figure 49. This technique displays an ‘explicit’ depiction of the required touch and the ‘effect’ shown in the form of a visual cue that highlights the ‘stretchable’ border (1-2).

Figure 49: Composition of self-revealing gestures in Wigdor’s ‘just-in-time’ chrome approach.

Hofmeester (2012), on the other hand, has provided a more sophisticated approach to SRG. He introduced a ‘teaching gesture’ with which the user could tap on the screen to learn through animated events how to perform gestures. An example (Figure 50) is given in which a user has the goal of opening an application through a horizontal menu.

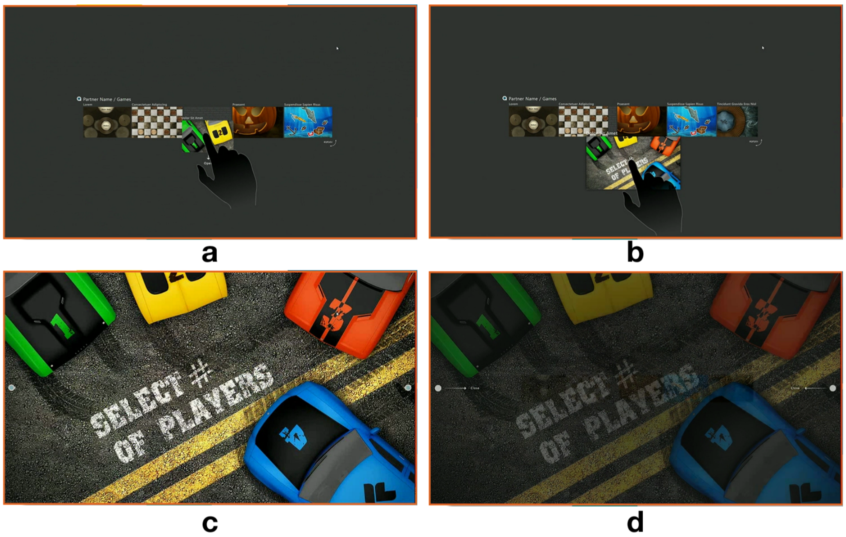

Figure 50: Hofmeester's concept for Microsoft Surface. Adapted from video (Channel 9, 2012). The Berne Convention allows the non-profitable use of software print screens.

The horizontal menu consisted of square buttons (a) and the interface appears in the context of a tabletop PC. The moment the application is loaded, the central button enlarges and an arrow is animated downwards to demonstrate the potential movement. If the user touches the button (a), the system introduces an element of feedforward suggesting further interaction that the buttons provide: the button temporarily moves downwards (b). In Figure 50 the illustration of the hand shows the position of a user's physical hand, but this part of the figure would not appear on the real interface – it is simply there to show the position of the touch on the screen and to communicate the system's response to a particular touch. When the user actually performs the gesture suggested by Hofmeester's cue, and pulls down the menu item all the way to the bottom of the screen, the application opens (c). Furthermore, after the application is opened, small arrows accompanied by text labels provide a basic indication of the gesture required to close the app (d), but there is no depiction of touch points.

The author's approach to SRG rendered the configuration represented in Figure 51:

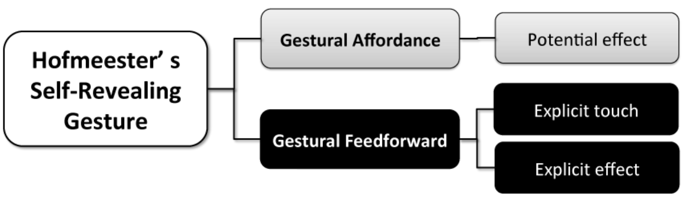

Figure 51: Composition of self-revealing gestures in Hofmeester's approach.

Had Hofmeester added some form of visual representation that indicated the number of touch points, or any textual label informing the purpose of the gesture (to 'open' an application) he would have indicated the 'potential action' of that gesture. Nevertheless, the concept described by Hofmeester (2012) served as the main inspiration to develop the 'self-previewing' gestures concept introduced in this thesis.

5.2.4 Self-Previewing Gestures

Self-previewing gestures synthesise the ideas presented in this section, and directly expand on self-revealing gestures. In contrast to self-revealing gestures (as seen in Figure 49 for example), an additional component within 'gestural' affordance is added to create self-previewing gestures: a visual representation that shows to the user the gesture that can be made. This was termed in the thesis the 'potential touch' (Figure 52, also at Section 5.2.1), and may reveal details such as the number of touch points that constitute the gesture, or the direction of movement. The 'gestural' affordance and feedforward are displayed *automatically* and *before* the user starts an interaction.

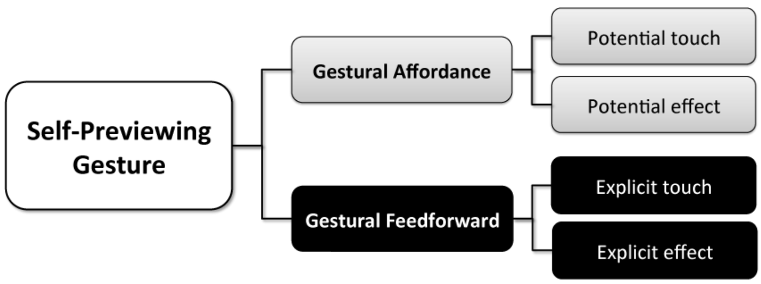

Figure 52: Components of a self-previewing gesture.

One could argue that this approach contradicts Nielsen's (1995) principle of 'control and freedom', which claims "users should experience perceived control as they interact with the system". Automatic events could possibly indicate loss of control because users did not trigger that specific event. However, there is a trade-off between that loss of control on one hand, and the loss of performance that arises from a failure to acquire a key gesture that might help achieve the user's goal. This thesis therefore hypothesises that automatic revelation of gestures may prove a necessity when a user is exposed to an unfamiliar gestural interface.

The concept of self-previewing gestures is now demonstrated, taking an example from later in the thesis (Section 7.2.2). Figure 53 shows a sequence of images that illustrate

SPG in action. It depicts a hypothetical home-screen for a gesture-based user interface, with four buttons.

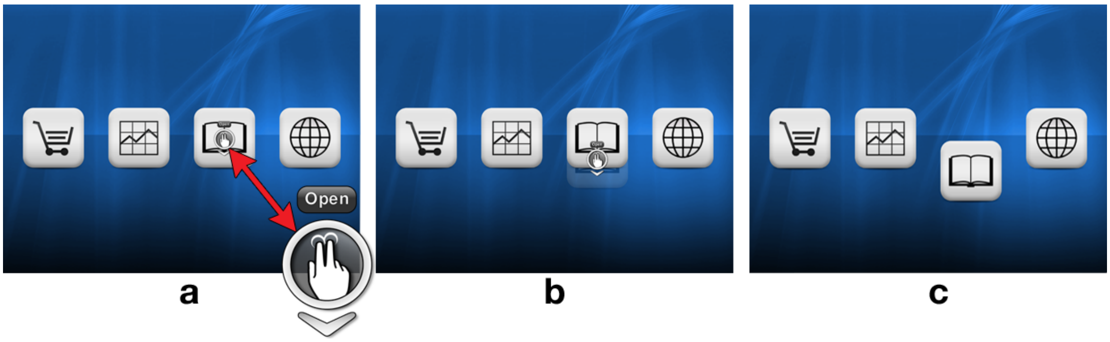

Figure 53: Example of 'self-previewing' gesture.

The first frame depicts a gestural affordance being displayed automatically and before the user touches the screen. The 'Potential touch' is depicted by a visual cue that represents the registration of a two-finger touch over the button (showed in zoom in Figure 53-a). The label 'Open' and the directional arrow pointing down indicate the 'Potential effect'. The 'gestural' feedforward demonstrates a 'ghost' of the button moving down (the 'Explicit' Touch) along with the button (b) and recoils back to its place. This shows the 'Explicit' effect or the preview of the gesture itself. The user should move the button in the appointed fashion to open the application (c).

5.2.4.1 Feedback on SPG

Across the development of SPG, the main researcher sought feedback on the concept. This section gives a brief report on design critiques provided by experts in the field, of the more formal testing that is found in the following chapters.

Dan Wigdor, who wrote *Brave NUI World* (Wigdor and Wixton, 2011), provided a detailed critique of the SPG concept in a conversation at CHI 2013. Wigdor contended that there was one overwhelming concern when the user is provided with guidance. For all systems, subtlety is key for an interface design that invokes automatic visual prompts to educate the user about the use of gestural interfaces. Wigdor said that the visual cues should be introduced seamlessly and in context. This confirmed an approach that the design work had adopted from the very beginning, of always providing the content of the cues *in situ*, close to or in the relevant visual context.

To underline his point, Wigdor also took a similar example from his own work. His team tried a similar approach with the first MS Surface table interface. When the surface remained idle for a given time, the interface would go into 'screen-saver' mode (displaying an aquarium) but would still display a visual cue on each corner of the screen to cue users on how to activate the interface. Wigdor believed this demonstrated in similar fashion the principles that both his work and SPG were consistent with.

Ben Shneiderman, after his talk at City University, School of Informatics (July 2014), was generous enough to offer insight about the research in a conversation that took place after his talk. Considering how users could be educated about unfamiliar actions, Shneiderman described a more traditional educational approach. Shneiderman contended that the scaffolding concept (Lajoie, 2005; Schneiderman et al., 2010: 583) is an efficient way to educate people throughout instalments and could be used to bring users to learn about unfamiliar gestures vocabularies and interactions within novel and yet unexplored touch-devices. New information should be delivered in short instalments, focussing on only a small number of particular elements, perhaps only one, at any point in time. In addition, a system might move from more detailed initial support, to gradually reducing the level of detail provided as the user became more experienced.

One key principle within scaffolding is that the immediate demands on a user's memory is kept low, with minimal reminders maintained for a period of time after first exposure to an idea or concept. Complementing Shneiderman's key principle, the main researcher anticipated that learning could demand a larger memory load from users as they learn to remember instructions. The number of steps is a factor that can be minimised. Sorensen (2009: 44), for instance, criticises interfaces that require memorisation of more than two steps.

Thus, two recognised researchers in the HCI domain argued for different fundamental principles, which were integrated into the definition of interaction techniques. Wigdor cautions about the importance of visual prompts being introduced *in situ* and seamlessly within the gestural UI. Shneiderman argues for scaffolding, with a minimum set of steps to be followed. As SPG provides a full range of information about a gesture, the user will rely more on recognition of a gesture they are acquiring, rather than recall of elements that are not displayed. In contrast to self-revealing gestures, SPG provides reminders of gestures without the user first having to recall, and to start to execute, a gesture that they may be learning.

The next section describes the 'gesture-and-effect' model for gestural interfaces. The model is rooted in Norman's Theory of Action (Norman, 1988: 45-53), Wu's (2006) Registration, Continuation and Termination model for gestural interactions and Marshall's (2007) 'Schema Model for Problem Solving'.

5.3 The Gesture-and-Effect Model for Touch Interfaces

The new designs and forms of visual interventions need a framework of analysis within which to discuss their effectiveness. To provide the theoretical foundations for such a framework, the works of Norman (1998), Wu et al. (2006) and Golod et al. (2013) were drawn on to create a 'gesture-and-effect' model (GEM) for evaluating touch interfaces. The initial approach when creating the model was to separate the user's planning and action into smaller steps.

Norman's Theory of Action (1988: 45–53; Preece et al., 2007: 120–124) provides a generalized view of a person when interacting with 'the world'. It segments the different stages of a user's action into two main phases: execution (Section 2.4.1.1) and evaluation (Section 2.4.1.2). Norman's theory explains that the phase of evaluation encompasses the stages people go through in rationalizing stimuli from the environment in order to establish a goal in the physical world or in a digital system. A user has to form an intention and plan an action sequence in order to execute actions to fulfil that goal (the stage of execution). Following execution, a new phase of evaluation occurs, in which the user reassesses the environment to check if his or her goal was achieved. Thus, evaluation and execution form a cycle (see Section 2.4.1.3, Figure 10).

Norman's theory allows some simple predictions to be made. Errors in execution are almost certain when the environment inefficiently communicates the action's existence and execution to the user. Errors in execution are the likely consequence of errors, slips or misunderstanding in the evaluation phase that occur before execution. Naturally, users' skill and experience also play a role as they decode the interface and act in response to their interpretation. Designers in general, with this caution in mind, can create design interventions in a way that reduces the scope for misinterpretation by users with different levels of skill and experience.

According to Norman (1988: 45–56), ‘execution’ formally means to perform or do something. The goal has to be translated into an intention, which in turn must be made into an action sequence that can be performed to satisfy the intention. According to Norman’s model, people execute first and then assess the results of their actions afterwards. However, Preece et al. (2007: 120) explain that in HCI many users do not have a clear goal in mind but react to what appears on the screen.

Following the stage of execution, the work reviewed in Section 4.5.1 (Table 6) used interaction techniques that showed guidance after the user touches the screen. This eliminates the possibility that the user will identify potential interaction before he or she acts. While Norman’s Theory of Action is widely respected, it is not specific to gestural interfaces. The research hypothesizes that, in contrast to earlier work, displaying visual cues automatically and before interaction will facilitate the discovery of new gestures, as well as reduce errors in execution.

Rationale for starting Norman’s Theory with the Evaluation stage

Consider the following persona[8]: David, company executive, 52, recently bought a tablet computer to replace his laptop, to save weight when commuting. He normally uses a spreadsheet and document reader in his desktop computer and laptop. The seller in the shop sets up the device for him but, although David has never used a tablet before, he is not keen on asking for guidance when fiddling with new technology. He finds the spreadsheet app and manages to start a new project. At some point, he decides to start writing a document and wants to switch between the two applications.

Considering David’s situation in relation to Norman’s theory, *execution* comes first:

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[8] Preece et al. (2007: 481) explain, “personas are rich descriptions of typical users of the product under development that the designers can focus on and design that product for. They do not describe real people, but are synthesized from a number of real users who have been involved in data gathering exercises”.

1. Establish a goal: find the 'minimise app' button.
2. Form an intention: scrutinize the screen to find where it is (or) tap different places to make the button appear.
3. Specify an action sequence: look around the screen in corners where I would expect to find a 'close' or 'minimize' button (or) choose two locations to tap where I usually find the 'minimize' and 'close' buttons on my laptop.
4. Execute an action: trial-and-error: tap the screen repeatedly but nothing shows up (or) tap on the top right corner.

Then *evaluation* follows:
5. Perceive the state of the world: cannot find the button (or) no change on the system.
6. Interpret the state of the world: perhaps there are alternatives.
7. Evaluate the outcome with respect to goals and intentions: will search the web or ask around for alternatives.

In the example above, Norman's cycle would be interrupted, for no visible perceptible affordances are present at the UI to show David how to minimize the spreadsheet app. This situation contrasts with the familiar WIMP-GUI, which usually displays buttons, icons and other visual metaphors to afford user action and rely on well-known interaction techniques.

Now, considering the use of a 'self-previewing' interface, which shows actions related to the context (and possibly others), it is possible to reconsider Norman's theory starting from the evaluation stage. David's case would look like this:

The *evaluation* stage starts:
5. Perceive the state of the world: system shows gesture to minimize app (with the system program generator (SPG)), along with other possible actions (e.g. close, switch through open apps).
6. Interpret the state of the world: so there is no button, and that is the gesture that switches the application.
7. Evaluate the outcome with respect to goals and intentions: if I execute that gesture, I will be able to minimize the app.

Then *execution* follows:
1. Establish a goal: touch according to instruction to minimize the spreadsheet app.

2. Form an intention: I should touch the screen.
3. Specify an action sequence: touch the screen at the required touch points.
4. Execute an action: perform the gesture in the appointed direction and lift the hand when done.

Then *re-evaluation* follows:
5. Perceive the state of the world: the spreadsheet was minimized.
6. Interpret the state of the world: look around for the ‘documents’ app.
7. Evaluate the outcome with respect to goals and intentions: found the ‘documents’ app.

Therefore, motivated by the problem described in Section 3.2, and Hypothesis (b), the GEM starts with the evaluation stage.

Rationale for adapting Norman’s theory to ‘micro-phases’

Another issue is that Norman’s model aims at scrutinizing user interaction across sizeable spans of time. Norman (1998: 48) explains, “…most activities will not be satisfied by single actions. There must be numerous sequences, and the whole activity may last hours or even days”. In contrast, a user gazing at a screen to identify possible interactions typically acts within seconds. In the two studies of gestural interactions conducted for this thesis, Norman’s ideas for evaluating and executing actions are applied to the level of seconds or less. However, these momentary actions are a crucial element within sequences of activities taking place across larger spans of time.

To make closer observations of the few seconds of actions during which gestural interactions take place, the three steps of Wu’s model can be divided into smaller elements. Wu et al. (2006) focus on the execution of gestures. The authors created the RCT model (Section 2.4.4.1), which also broke down the execution of a gesture into ‘micro’ parts. Golod et al. (2013: 17) in similar fashion describe a ‘gesture phrase’ model for a gesture. The gesture phrase segments the execution of a gesture into ‘microinteractions’ (Section 2.5.3).

As can be seen in Table 16, a correspondence between Wu et al.’s RCT and Golod's concept of a gesture phrase was identified. Golod’s ‘activation’ matches Wu’s ‘registration’, addressing the initiation of a gesture, e.g. to touch (with the appropriate number of fingers and the appropriate position). Golod's 'incremental actions' match Wu's 'continuation', reporting on the gesture itself, e.g. to hold or swipe, and the direction of a gesture, such as inwards or from left to right. Finally, Golod's 'closure' matches Wu's 'termination', describing a user lifting his finger and reassessing the user interface.

Golod's Gesture phrase	Wu's RCT
Idle	OOR (Out of Range)
Activation (Gesture phrase)	Gesture registration (Touch)
Incremental actions (Gesture phrase)	Gesture continuation (Movement)
Closure (Gesture phrase)	Gesture termination (Lift)
Idle	OOR (Out of Range)

Table 16: Correspondence between Golod et al.'s and Wu et al.'s models.

The combined approach of Wu et al. and Golod et al. in separating gestures into 'micro-phases' has the potential to identify specific issues within a user's assessment and execution of the gesture, issues that could have remained hidden within a simplistic 'did' or 'did not' assessment of user performance. Therefore, Golod et al.'s (2013) 'gesture phrase' and Wu et al.'s (2006) RCT model (Section 2.4.4) were adapted to the execution phase within the GEM. The term 'micro-phase' was also adopted and used to describe the phases within the model.

Figure 54 shows the 'gesture-and-effect' model (GEM) created as a framework to analyse touch interfaces (see a larger view in Appendix C).

Within the evaluation phase are micro-phases, in which steps 2 to 6 bear a close relationship to the taxonomy of different types of gesture by Freeman et al. (2009). Freeman and colleagues separated gestures into both single and multi-touch interactions (options at step 3) and dynamic versus static movement (options in step 5, which addresses the direction of motion).

Within the execution phase there are three sub-phases: 'form an intention', 'specify an action sequence' and 'execute an action', which bear a close relationship to Wu et al.'s registration, continuation and termination phases of a gesture. These in turn were also separated into the micro-phases covering the different aspects contained in the execution of a gesture, such as ‘touch to confirm’, ‘set touch configuration’, ‘perform direction’, and ‘notice new system status’ (which corresponds to Wu’s ‘out of range’).

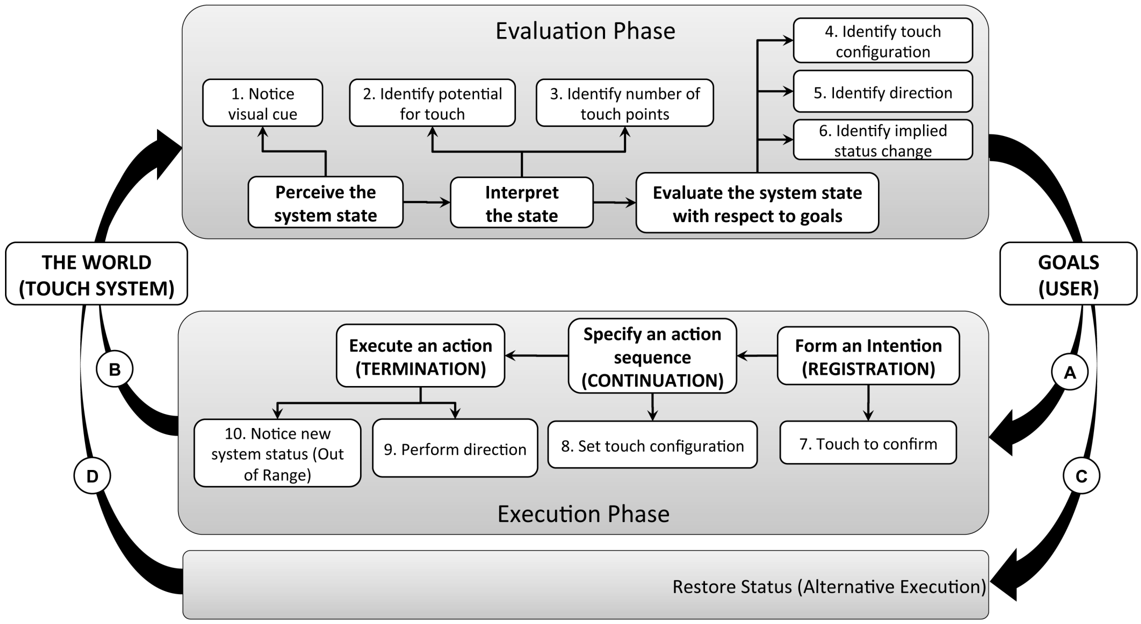


Figure 54: The gesture-and-effect model for touch interactions.

A gulf between the user and the system may emerge between any of the micro-phases found the Evaluation Phase or the Execution Phase. For instance, micro-phase 3 ‘Identify number of touch points’ within the Evaluation Phase correlates directly with micro-phase 7 ‘Touch to confirm’ in the Execution Phase. In cases where the affordances and feedforward available to inform the user within the Evaluation Phase are efficient, issues with the Execution Phase are very unlikely to happen.

We start a detailed consideration of each micro-phase by considering the evaluation phase first.

5.3.1 The Evaluation Phase

The three main phases of ‘Perceive the system state’, ‘Interpret the state’ and ‘Evaluate the system state’, found in Norman’s model, were expanded into six micro-phases. These in turn cover the design aspects of a gesture that the gestural affordance and feedforward serve to inform the user of.

The following steps outline these micro-phases, describing the work a user must do in each.

Step 1: Perceive the system state

1. Notice visual cue: The user may or may not spot the affordance for a control gesture. In the event that the user does not, the user will not continue to the next step.

Step 2: Interpret the state

The user acknowledges the content that they perceive in the visual cue. There is not yet an intention to perform a specific action:

2. Identify potential for touch: The user's anticipation of what the visual cues represent.
3. Identify number of touch points (no. of fingers): The user should describe how many fingers are necessary to initiate the gesture.

Step 3: Evaluate the system state with respect to a goal

The user forms an intention to perform a specific gesture:

4. Identify type of gesture: The user's expectation of how to lay his fingers on a screen to continue the gesture, such as a pinch, swipe, or hold.
5. Identify direction: A description of any directional movement.
6. Identify implied status change: The user should be able to explain the result of the gesture.

5.3.2 The Execution Phase

The 'execution' phase follows, and a new set of micro-phases occurs. It is represented in the model with the 'A and B' labels.

Step 4: Form an Intention (Wu's Registration)

7. Touch to confirm: Only by touching the screen with the appropriate number of fingers will the user set the system in the correct registration mode. An interaction may require the participant to touch with one finger only over a digital object to trigger an interaction.

Step 5: Specify an action sequence (Wu's Continuation)

8. Set type of gesture (configuration): The user should place one or more fingers on the screen, in the right configuration (e.g. in pinch format, or holding the touch), to set the system in the correct continuation mode. There may be specific locations at which the configuration must occur: for example a gesture may need to occur over or within an object.

Step 6: Execute an action (Wu's Termination)

9. Perform direction: The user should perform the gesture in the appropriate fashion or direction in order to accomplish the interaction for instance in the case of a static interaction a single tap, or touch and hold would suffice, but where a swipe is multidirectional a pinch can be performed inwards or outwards. This final stage is paramount for the correct execution of the gesture. Along with the correct registration of touch points, there is no possible successful execution of a gesture if the required movement is incorrect.
10. Notice new system status (OOR - Out of Range): The user should be able to perceive the resulting system feedback and change of status after performing the gesture and lifting his/her fingers from the screen.

Step 7: Restore Status (Alternative Execution)

As can be seen in Figure 54, the moment an initial gestural interaction is correctly performed, a new system status is presented to the user (micro-phase 10). In the first study, participants were asked to undo their actions to restore the system to its previous state, resulting in a new evaluation of the UI and execution of commands. This is represented in the model with the 'C and D' labels.

The issue of undo is not depicted separately in Norman's model. We thus had to add a separate 'Restoration' phase in the model, especially when the work of performing an undo is so complex in the domain of gestural interfaces. This phase implies a new evaluation of the system status and the requirement of a new gesture (execution phase) - different from the initial gesture – to restore (or undo) the system to its previous state.

In search for theories to inform the 'restoration' phase, we reviewed Wigdor and Wixton (2011: 137-138, Section 3.3.5.1.2) insights on the INRC theory (Identity, Negation, Reciprocal and Commutative) within the work of Piaget (1971). A couple of principles within Piaget's INRC closely relate to the issue of 'undo', the *first* being 'Negation', which postulates that any action "can be reversed midcourse, and that reversal will return the system to its previous state". The *second* was 'Reciprocal', which states, "Once an action is completed, a side effect on that action can be undone by another action". Wigdor and Wixton explain the difference between the two: "Negation cancels an operation in progress, while a reciprocal action undoes an action after it is completed but may (or may not) leave some of the consequences of the action unchanged". The user should be able to 'undo' their actions and restore the application to its initial state; therefore restarting the cycle back to its evaluation phase.

The principles of 'Identity' and 'Commutative' should be inherent in any form of UI, including gestural interfaces; thus, these were not depicted in the model. However, a brief explanation is necessary: Wigdor and Wixton (2011: 137–138) explain 'Identity' as a factor responsible for maintaining the identity of primary objects and consistency of actions in a given context. 'Commutative' actions are those that can be performed in any order and yield the same result.

5.4 Summary

This chapter reported on the rationale for moving from perceptible affordances and feedforward towards a gestural understanding. Together with an explanation of the design of self-revealing gestures (Wigdor and Wixton, 2011; Hofmeester, 2012), this established the paradigms that compose the technique introduced in this thesis of 'self-previewing' gestures, or SPG.

In addition, a new model of 'gesture-and-effect' is introduced in this thesis to assess the SPG. It derives from the established theories of Norman's Theory of Action (Norman, 1988: 45-53; Preece et al., 2007: 120-124), Wu et al.'s (2006) RCT theory, and Golod et al.'s (2013) 'gesture phrase'. The next chapter reports on the first empirical study. The GEM was used to assess the user's interpretation of SPG displayed in an iPad application prototype. Feedforward was identified as a powerful technique to bridge the gap between the identification of a gesture and its effect.

CHAPTER 6 - ASSESSING VISUAL PROMPTS FOR TOUCH IN GESTURAL INTERFACES

6.1 Introduction

This chapter presents the first empirical study in the process of laboratory research *through* design (RTD) *for* design. It was carried out in response to a lack of data on how users either succeed or fail to identify potential gestures in a novel interface. As reported in Chapter 4, previous studies have focussed on users' execution of gestures, not how they evaluate an interface to identify potential gestures. Thus, this study provides key initial evidence on user's perceptions while they evaluate an unfamiliar interface.

Interfaces that do not reveal interaction opportunities to users are harder to use than interfaces that provide good perceptible affordances. This especially applies to novel and unfamiliar gestural interactions. By examining the benefits of feedforward *before* touch occurs, following Vermeulen's reframing of feedforward technique (Vermeulen et al., 2013: 1938), design interventions were created in order to mitigate the issue of unfamiliarity. The first study goals were therefore to both create plausible initial designs to communicate potential gestures to users, and also to understand their experience of interpreting those initial designs. It was primarily *formative* as it helped inform the design of improved methods for indicating potential gestures to users, and also it helped inform the experimental method for evaluating particular designs.

There were three major theoretical goals in this phase. *First*, to address the first research question: 'Following the principle of perceptible affordances, what are the visual properties of design interventions that effectively indicate the required configuration of the registration of a gesture?' *Second*, to provide initial evidence to support or reject the first research hypothesis (a), which states, 'Ensuring the registration points are clearly depicted in visual prompts will improve gesture learning and reduce user error in executing gestures.' *Third*, to inform the revision and improvement of the model that corresponds to the hypothesis (c), which states, 'a rating system that segments users' gestural interactions into smaller phases will help reveal issues with users' evaluation and execution of gestures'.

This chapter is organised following the process of Lab RTD. In the first part the development of the initial designs is discussed, explaining how they were critiqued and improved during their development to create credible prototypes. Next, the specific methodology needed to arrive at research insights from these designs, is explained. Finally, the study itself is introduced that deployed this methodology to evaluate the prototype designs, the results of which further the research aims of the thesis.

6.2 Designing Initial Visual Prompts

Gestures comprise three distinct stages that, depending on how they are represented, may facilitate or hamper users' experiences. The *first* stage concerns the number of fingers and the touch configuration that starts the gesture. Is it one or more fingers and in which position? The *second* stage concerns the motion that follows the initial touch. Is it a dragging action and if so, in which direction? The *third stage concerns*, how the system will respond after the gesture completion. These stages correspond to Wu's (2006) Registration, Continuation and Termination theory (RCT). As reported in 5.2.4 the SPG covered these three stages of a gesture. It depicts the visual cue (the registration), and makes use of feedforward technique to demonstrate movement of the gesture (the continuation) and the effect of that gesture on the system (the termination).

It was paramount to ensure the number of touch points of each gesture was explicitly depicted in the designs. A failure at the moment of *registration*, would lead to an irretrievable failure in the rest of the execution of the gesture. Each finger must be in the correct position relative to the others and the designs must each ensure that the 'style' of the gesture is explicitly depicted.

The gestural affordance was those closely followed the natural relative positions of the fingers of the right hand when placed over a multi-touch screen. These positions, of a prone hand touching the screen were used to specify the position of the touch points. In detecting the gesture, the test system allowed for a high degree of variation, of location, to avoid being overly specific to individual anatomy. The user must also make the gesture in the right direction, and both designs include a cue to indicate the correct direction of movement. These design choices were made with an awareness of trade-off implications, following the work of Beaudoin-Lafon's (2000) and Jacob et al.'s (2008) frameworks for NUI design, including visual metaphor concepts such as physics and directionality (Section 2.5).

Finally, matters of continuation, such as tapping and holding, which are not strictly matters of direction, are also included in both designs. Lao et al. (2009: 441) stress the importance of capturing events such as speed, time per gesture and pressure over screen to obtain a wider understanding of users' preferences. Lao et al.'s approach was drawn on to actually depict these events within one of the visual cue styles used.

The reported study took a pair of designs with distinct qualities to investigate which one and which specific features could more efficiently convey meaning (the gestural interaction opportunity), or hinder the interaction. Each design synthesises different, but complementary, deploying ideas from academic research and industrial practice. Both draw, therefore, from research done to inform the creation of the designs (i.e. they followed the principle of *research-for-design,* Section 4.2). To provide additional substance to the choices made, further research *for* design was conducted in the topics of visual perception, interface design for HCI, and user interface practices adopted by companies such as Microsoft, Apple and Google. Sas et al. (2014: 1979) consider this a valid approach to research *for* design, by stating, "validity could be claimed by exploring the similarities between multiple settings or making explicit the findings from multiple studies employed as design resources".

A few fundamental features within visual design were selected that are relevant to the research. Dondis A. Dondis (1973) in *A Primer of Visual Literacy* and Rudolf Arnhein (1974) in *Art and Visual Perception: A psychology of the creative eye*. Dondis (1973) explains, "even though signs and symbols are often culturally defined, the underlying visual elements are universal". The visual elements 'contrast', 'size', and 'pictorial aspects' are therefore elaborated on in regards to the designs created. Additionally, interface design guidelines for touch devices, provided by Windows Dev Center (2014b), Apple Developer (2014), and Google Design (2014) were consulted.

The following expands on qualities pertaining to both designs before exploring the specifics of each. These issues are addressed in turn, explaining how they were used in setting fundamental constraints for the final designs.

1. *'Contrast'*: Arnhein (1974) explains that, "our attention will be drawn toward contrast, toward the element that is unlike the others in some way". Thus, differences that stand out can provide emphasis, highlighting important elements and information. The greater the contrast, the more important the element will appear.

Colour contrast was used to emphasise the visual prompts in relation to the background interface. Both visual styles were kept monochromatic, so as not to interfere with any of the colours already present in application background.

2. *'Size'*: In making a design decision for an upper limit on the size of the cue, clearly come concrete figure needs to be used, preferably using the available evidence about appropriate size. In the lack of detailed academic evidence, drawing on industrial guidelines appeared to be a wise choice.

The instructions provided in the MS touch interactions guide (Windows Dev Center-b, 2014) were another source of inspiration. This guide was particularly explicit about effective sizes of icons in a touch environment, recommending touch points on the screen with at least a 10 mm radius (approximately 37 pixels), which corresponds to an average adult finger. Microsoft therefore uses a fundamental physiological measurement to justify their guideline.

The Apple iOS (Human Interface Guidelines, 2014) recommends the minimum icon size of 66 x 66 pixels for toolbars, which is 17 mm radius; and windows touch style guides (Windows Dev Center, 2014), which recommends 50 x 50 pixels or 11 mm radius. As the purpose of the prompts is to inform and not necessarily to provide targets for participants to touch over the screen, for all designs, the overall size of a single touch-point was constrained by reducing the overall design to a size consistent with app icons on iOS, and a 15 mm radius circle (approximately 56 pixels). Within that space, we accommodated the combined information into a single cue.

3. *'Pictorial aspects'*: Icons are fundamental to interaction with computers. Rossi & Querrioux-Coulobmier (1977) suggest that "the relationship between an icon and its meaning should be automatic and consequently independent of any learning". This means that for an icon to work more efficiently than another representation (such as a textual description), it needs to evoke an implicit understanding of the meaning of the icon. Gray (1999) explains the use of iconic metaphors in computer systems:

"Interacting with the real world requires mental models to predict the outcomes of the actions." Marcus (2002: 7) described icons as the "essential concepts in computer-mediated communication that substitute for the underlying code and terminology of operating systems, applications, and data".

Extending this concept, interacting with objects and performing actions on a computer require mental models for how that interaction should occur. Icons that are based on real life (such as a clock to represent time) require less cognitive work to develop these models since they are already known from interactions with the real world.

As will be further explained, both designs used pictorial representations to depict touch points over the screen. The first used simple circular shapes to 'symbolise' touch points over the screen. The second used blurry and distorted depictions to simulate physical touch over a screen. By providing contrasting approaches to depict gestures, the aim was to identify which version would communicate the implied action with less user errors.

4. *'Textual support'*: Bau & Mackay's (2008) OctoPocus, Freeman et al.'s (2009) Shadowguides, and Gutwin et al.'s (2014) FastTap (Figure 55) techniques used supportive textual labels in English, in conjunction with completion paths to indicate either a required action (e.g. move) or the consequence of a gesture (e.g. open menu). Taking a different approach, and to isolate the contribution of visual, non-textual content, neither designs included text, therefore avoiding dependency on the linguistic skill of participants.

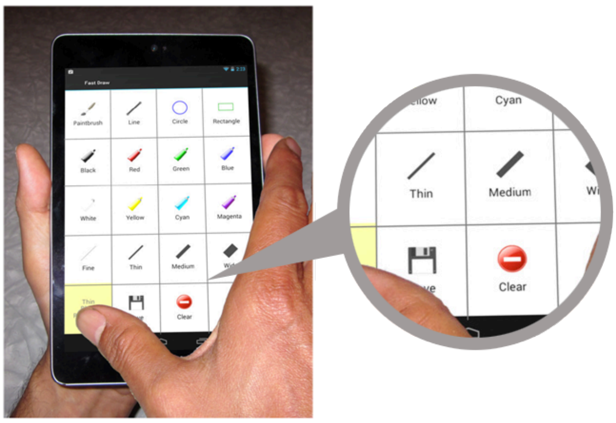


Figure 55: FastTap and text labels (Gutwin et al., 2014).

5. *'Movement'*: Many researchers recommend the use of animated events (Tversky, 2002; Kang, Plaisant and Shneiderman et al., 2004 and Chow et al., 2011) to enhance the effects of an interaction. This approach was considered relevant to the design of gestures that require movement, such as upwards, downwards, inwards, outwards, sideways, and their effects, such as the display of menus or the transition between application screens and these were therefore adopted for both designs in the study.

Sukaviriya (1990) explains that graphical illustrations that portray the sense of animation when used with textual explanations also "enhance human performance to follow procedural instructions". Experimental studies by Boohver (1975) and Palmiter et al. (1991) also indicated this. Chow et al. (2011: 96) contend that animated visual images can help users understand both immediate (perceptual) and metaphorical (conceptual) levels of the interaction at hand. Additionally, software companies like Apple (Apple Developer, 2014), Microsoft (Windows Dev Center, 2014) and Google (Google Design, 2014) recommend the use of animations in their design guidelines pages.

Bedford (2014) confirms the importance of animation by claiming, "When designing an animation, 'to support interface', consider its frequency of occurrence, and its mechanics". Taking this into consideration, and to ensure participants would notice the visual cues, the visual prompts for gestures were displayed twice within the application prototype. This followed Golod's (2013: 15) recommendation of "continuous use of feedback and feedforward" in gestural interfaces. However, Golod (2013: 15) also issues a warning, "in case the feedforward threshold is not enough, frequent appearing of feedforward might be quite disturbing for the user". This influenced the decision to display the visual cue within short-time spans, 3600 to 5000 milliseconds, depending on the interaction requirement. The time frame contemplates the presentation of a visual cue for touch, followed by its required movement and the resulting effects on the UI (e.g. a menu is revealed). However, the review undertaken in Chapter 4 on previous work in the design of gestural interfaces showed a general lack of guidance to help UI designers identify the optimal display time of on-screen visual prompts.

For comparison purposes with previous work, Annett and Bischof (2013: 1122) run a study in which a prototype application, which displayed a visual cue for a gesture. The time span for such was 1500 milliseconds. However, this time frame was required for the display of an animated gesture completion path only - with no animated feedforward for the effect on that system. In the design technique adopted for this research, this time was multiplied (twice or over three times more) to comprehend the display of touch points, its movement and the corresponding effect - all with transitions and animated events (see the reference table at Appendix L).

To conclude this introduction to the designs used, a few other strategies were discarded to create the visual depictions. One such strategy involved creating designs with in-built deficiencies, such as lacking the correct number of touch points, but this was considered to be obstructive to the path of the research. As there were no previous designs to draw on, creating artificial designs that could predictably mislead or misinform the user could not be justified either from research knowledge or by calling on practical wisdom. During any evaluation, profoundly compromised designs could well confuse, distract or frustrate the user in ways that might readily hinder, not assist, the goal of the research. Finally, the SPG concept was realised in two different design families, both of which indicated to the user the number of touch points, style of the gesture (configuration to touch) and direction of movement.

Next we continue by describing the visual designs and their specific characteristics, addressing the visual styling first, followed by the interaction design that underpinned the visual presentation. The user interface, including the prompts and visual content were designed in Adobe Photoshop and Illustrator CS5.

6.2.1 Two Visual Styles

This study deployed two visual designs for the gesture cues. These present contrasting approaches to communicating with the user.

It is important to note that neither set of designs was intended to be ideal, but rather to provide an example of two different approaches for each interaction, which then provided a basis for asking participants for their preferences. The goal was to use the designs to provoke and explore user needs and behaviours, rather than validate either design. The relative success of the two sets of designs with different interactions were intended to observe what factors might assist the user in discovering the available gestures.

The two designs are:

1. 'Circles': The first design, termed 'Circles', comprised simple circles displayed over the interface of the prototype application (Table 17).

In regards to the principle of 'pictorial aspects', it uses simple geometric forms to depict touch points over the screen. According to Tversky (2002:248) "simple graphics with less detail are often more effective than realistic ones, provided that they abstract the essential conceptual information." Furthermore, this design drew on the way touch points are depicted in the BlackBerry Tablet OS tutorial for gestures (Figure 56). Their approach simply used plain circles, providing a very stark and simple image for the user to interpret.

Figure 56: Blackberry Playbook detail of a swipe gesture animation (Aug 2012). The Berne Convention allows the non-profitable use of software print screens.

This design also drew from Bennet et al.'s Simpleflow (2011) technique, which displayed black points as the starting point for drawing on-screen gestures.

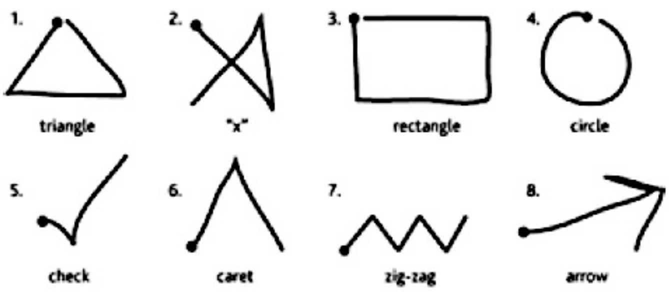


Figure 57: SimpleFlow detail of single point for registration (Bennett et al., 2011).

The visual cues therefore lacked any directional cue and relied on animation to present the required gesture, such as single-finger touch, touch and swipe, touch and hold, and double tap. The second (b) prompt indicated a four-finger swipe (left-right/right-left and bottom up). The last (c) presented a four-finger pinch gesture. The circles converged to the centre of the picture to demonstrate the gesture.

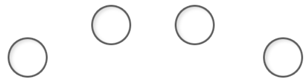
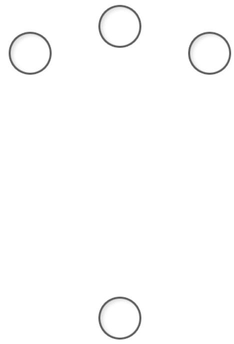
 a. Visual cue for single-finger touch, touch and swipe, touch and hold, and double tap (85x85px)	 b. Visual cue for four-finger swipe: bottom up or right-left/left-right (510x145px)	 c. Visual cue for four-finger pinch (350x540px)

Table 17: Design 1 'Circles' gestural affordances.

2. *'Smudge'*: The 'Smudge' design created an abstract representation of any touch or multi-touch points being pressed over the screen, which causes a visible distortion (Table 18). 'Smudge' drew from two different pieces of research: Freeman et al.'s (2009) ShadowGuides and Wigdor et al.'s (2009) Ripples visual metaphor. These designs both depicted screen distortion under the touch-point as a way to indicate the registration of a gesture.

In the created design, when movement was required by some gestures, the touch points were elongated in the direction of that gesture. The rationale for this design dictated that the larger part depicted the touch point over the screen and the thin portion indicated the direction of that gesture. Furthermore, following the principle of animation described at the beginning of the section, the visual cue was animated, fading out towards the appropriate direction.

In contrast to the previous design set, which relied solely on animation to indicate direction, more designs were created to indicate the various possible directions of a gesture (e.g. top, bottom, left, right). The first icon (Table 18-a) indicated a single-finger swipe from left to right. The second (b) indicated a single-finger touch, touch and hold, and double tap. The third (c) indicated a single-finger swipe from right to left. The fourth (d), showed a four-finger swipe (from right-left and left-right). The fifth (e) displayed a four-finger swipe upwards. The last (f) presented a four-finger pinch gesture. Similar to 'Circles', the touch points converged to the centre to demonstrate the gesture.

a. Visual cue for single-finger swipe: left-right (340x200px)	b. Visual cue for single-finger touch, touch and hold, and double tap (200x200px)	c. Visual cue for single-finger swipe: right-left (340x200px)
d. Visual cue for four-finger swipe: right-left and left-right (940x340px)	e. Visual cue for four-finger touch: upwards (580x440px)	f. Visual cue for four-finger pinch (640x940px)

Table 18: Design 2 'Smudge' gestural affordances.

This design drew from the concept of Naïve Physics (Jacob et al., 2008), which explains that by knowing the world, people can predict specific behaviours in the case of physical acts being applied over *digital* objects, which resemble familiar objects. As can be seen on Table 18, the 'distortion' points out the direction and suggests pressure over screen, recalling to the user previous experience with the physical world.

This design also drew from Freeman et al.'s Shadowguides (2009), and Wigdor et al.'s Ripples (2009) techniques (Sections 3.3.3.1 and 3.3.5.1). For instance, in Wigdor et al.'s technique, a user has to touch and hold to get visual feedback of available gestures, and a selected object has different properties than an un-selected one.

In addition, Wigdor and Wixton's (2011: 90-94) *tethers* touch feedback design (see Figure 41, Section 3.3.5.1), found on Microsoft's 2007 Surface tabletop informed the decision to depict the visual cue as if someone was touching the screen.

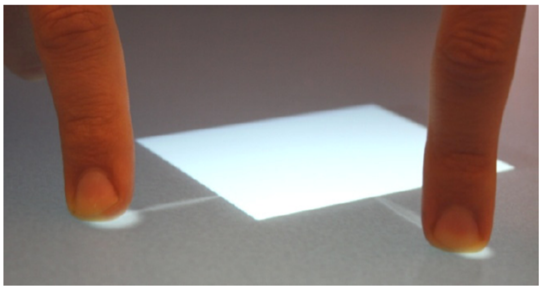


Figure 58: Ripples and a preview of available gestures (Wigdor et al., 2009).

Wigdor et al. used alpha values (transparency) to avoid partially covering the workspace. Their design decision was emulated in the designs created and a transparency value of 30% was added to the visual cue to avoid foreground-background issues (see the principle of *contrast*, above).

6.2.2 Design of the Interactions

This section explains the criteria to define the eight interactions used in the test sessions.

The interactions were informed by the issues described in Section 3.2:
1. No consistent representation of touch points has been displayed by gestural interfaces so far;
2. No automatic presentation of visual prompts to communicate to the user the available multi-touch gestures and hidden UI menus and tools;
3. The 'static nature' of tips and tutorial screens is insufficient to communicate gesture undertaking.

In order to ensure the real-world fidelity of the designs, a pool of existing interactions was drawn on as a baseline to test in the present study. The groups are: *1. Hidden menus and toolbars; 2. Touch-and-hold for object manipulation; 3. Workspace manipulation; 4. Task-switching gestures.*

The four groups of interactions are commonly found in existing gestural user interfaces (e.g. Blackberry touch, MS Surface, Apple iOS)), but are not core interactions that users are likely to have used repeatedly. Commonly used gestures were deliberately avoided (e.g. single tap), as these were very unlikely to be unfamiliar even to an occasional user of gestural interfaces. Selecting seldom-used interactions that are found in real use appeared to balance the needs of real-world fidelity with unfamiliarity.

The interactions are detailed in Table 19 and organised according to Freeman et al.'s 'taxonomy of multi-touch and whole-hand surface gestures' (2009).

Interaction	Registration	Continuation	Movement	Restoration
Hidden menus and toolbars				
1. Reveal Menu	Single finger	1 finger swipe left-right (from bezel)	Path	1 finger swipe right-left/1 finger touch anywhere
2. Drag picture to the page	Single finger	1 finger drag and drop left-right	Path	1 finger drag and drop right-left/reveal menu and drag and drop right-left
Touch-and-hold for object manipulation				
3. Touch and hold for options	Single finger	1 finger touch and hold	No path	1 finger touch anywhere
Workspace manipulation				
4. Zoom in/out	Single finger	1 finger double-tap	No path	1 finger double-tap
5. Flip pages	Single finger	1 finger swipe right-left (page corner only)	Path	1 finger swipe left-right (page corner only)
Task-switching gestures				
6. Switch between apps	4 fingers	4 finger swipe left-right/right-left	Path	4 finger swipe left-right/right-left
7. Reveal task switcher	4 fingers	4 finger swipe bottom-top (from bezel)	Path	4 finger swipe top/bottom/1 finger touch anywhere
8. Minimise app	3 fingers + thumb	3 fingers + thumb pinch inwards	Path	4 finger swipe bottom-top (to find app within task switcher)

Table 19: Table describing the eight interactions by 'registration', 'movement' and 'continuation' poses, according to Freeman et al.'s (2009) classification.

The first column lists the interaction type (from 1 to 8). The second column lists the 'registration', which is subdivided into single or multi-touch points over the screen. 'Continuation' (column 3) describes the gesture necessary to execute the interaction, such as a drag, the direction of the gesture and its starting point. The fourth, 'movement' column describes whether a gesture embeds a 'path' or not. Interactions that have a path indicate that the hand moves along the surface of the screen. For interactions that have 'no path' the hand stays in place. The final right-hand column describes the 'restoration' gesture required to undo an interaction and bring back the system to its previous state.

To ensure the selection of interactions was robust, little-used interactions found in predominant gestural interfaces were selected. In addition the design work was itself informed by the three key issues already identified in Section 3.2:

1. No consistent representation of touch points has been displayed by gestural interfaces so far.

2. No automatic presentation of visual prompts to communicate to the user the available multi-touch gestures and hidden UI menus and tools

3. The 'static nature' of tips and tutorial screens is insufficient to communicate gesture undertaking.

We believe that in order to mitigate these three issues, three corresponding precautions should be taken: *First*, for each of the eight interactions, an image depicting the required touch points was created. *Second*, this visual cue was automatically displayed in the appropriate configuration for touch (e.g. tap, pinch). *Third*, the cue was animated to show the movement, and followed by another animation that showed the system's response to the gesture. The system response (or effect of the gesture) was kept as a constant factor, meaning that the feedforward created was unique and served both designs

The groups and interactions are described in the following sections. Note that the gesture depiction is shown in a magnified view at the bottom of each picture, and the effect of the gesture in sequence of frames. The screen size is 2048x1536px at 264 ppi (Apple iPad models, 2013), and the interactions are displayed over a fictitious booklet application.

The eight interactions are now presented, divided into four sets. The animation of the visual cue for the gesture and resulting effect are depicted in sequence and indicated by letters (e.g. 'a' to 'e').

6.2.2.1 Hidden menus and toolbars

These two interactions explore the affordances (or the lack of) that indicate the existence of UI elements that are initially hidden from sight. Norman and Nielsen (2010) make reference to this issue: "…the lack of consistency and inability to discover operations, coupled with the ease of accidentally triggering actions from which there is no recovery, threatens the viability of these (NUI) systems".

1. Reveal menu: A single-touch gestural affordance emerges from the left of the screen (a) and moves along with the hidden menu, which has 15% of its area displayed. The visual cue for the gesture fades out. A one-finger tap anywhere or a leftwards swipe over the menu would make the menu recoil to its original position (b).

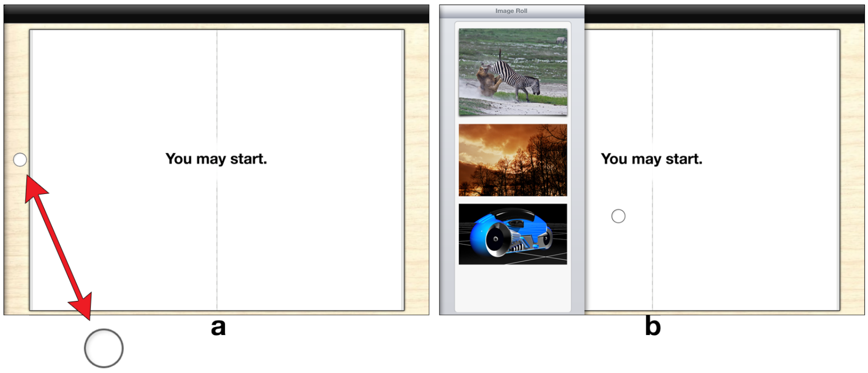


Figure 59: Design 1 'Circles' and Interaction 1 'Reveal hidden menu'.

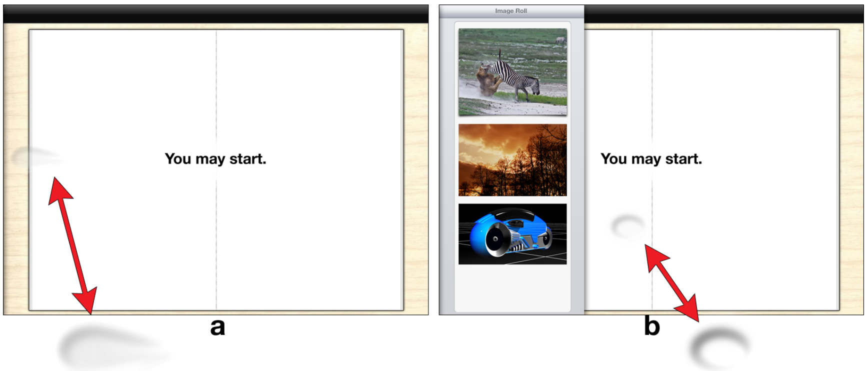


Figure 60: Design 2 'Smudge' and Interaction 1 'Reveal hidden menu'.

2. *Drag picture to the page:* Continuing from a visible menu, a picture moves onto the main workspace, with a single-finger drag. A single-finger gestural affordance (a) drags the picture onto the main workspace (b). The picture is briefly maximised on the right hand side of the screen (c) and the visual cue for touch then fades out.

To return the picture to the list, a one-finger drag of the picture towards the left side of the screen is required, triggering the appearance of the menu, which then 'docks' the picture back to its original place. This set of interactions was designed in consideration of Piaget's 'Negation' postulate as reported by Wigdor and Wixton (2011: 137-138): Any action "can be reversed midcourse, and that reversal will return the system to its previous state".

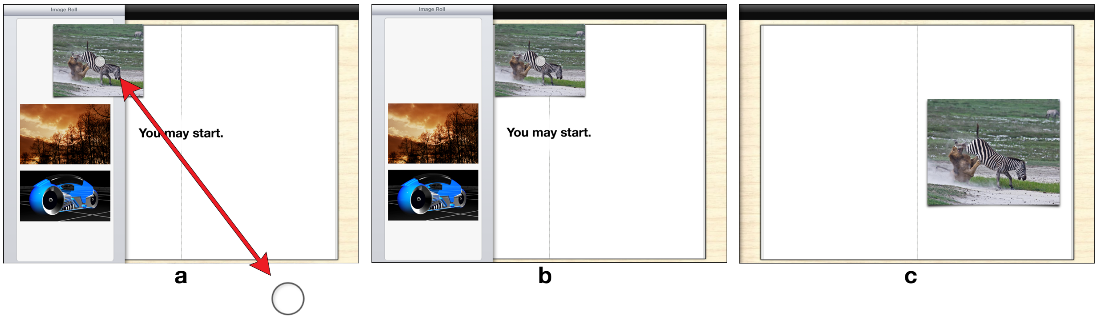


Figure 61: Design 1 'Circles' and Interaction 2 'Drag picture to the page'.

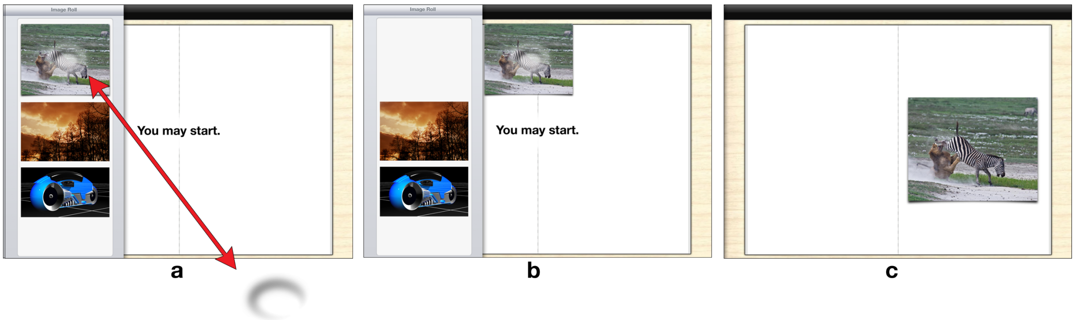


Figure 62: Design 2 'Smudge' and Interaction 2 'Drag picture to the page'.

6.2.2.2 Touch-and-hold for object manipulation

This single interaction was included to explore how well participants are able to discover and perform a touch-and-hold interaction. Hofmeester (2012) verified in his empirical studies with Windows 8 that participants struggle with this sort of interaction.

3. *Touch and hold for options:* A contextual menu appears in response to a one-finger touch-and-hold over the picture (a-b). To restore, one-finger tap over the picture or anywhere else over the screen.

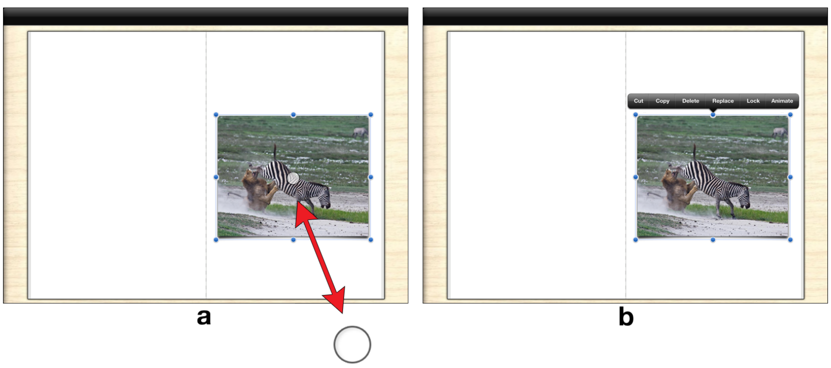


Figure 63: Design 1 'Circles' and Interaction 3 'Press and hold for options'.

Figure 64: Design 2 'Smudge' and Interaction 3 'Press and hold for options'.

6.2.2.3 Workspace manipulation

This group of two interactions explore gestures that manipulate the workspace such as zooming in and flipping pages in a document. Lao et al. (2009: 441) make a distinction between gestures pertaining to specific applications and gestures that make sense when used to control the underlying platform only. Thus, we wanted to ensure that the gestures we used included both control of the overall workspace, as well as the manipulation of content within the workspace.

4. *Zoom in/out:* The whole view briefly zooms in response to a double-tap (a-b-c). A second double-tap restores the view.

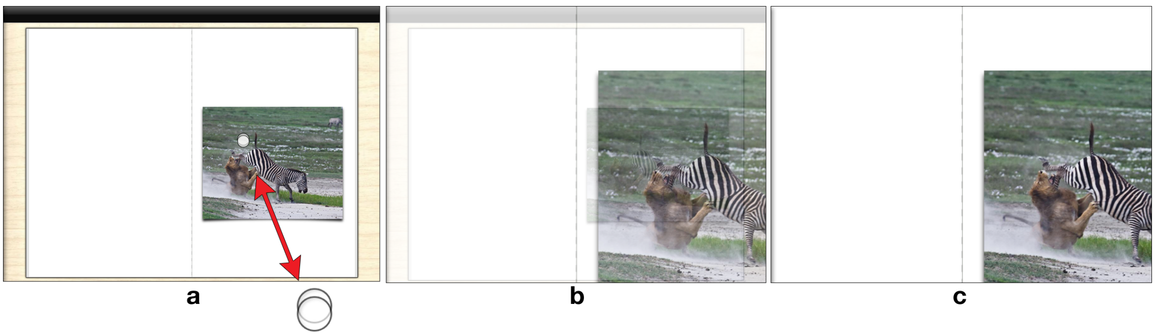


Figure 65: Design 1 'Circles' and Interaction 4 'Double tap to zoom in'.

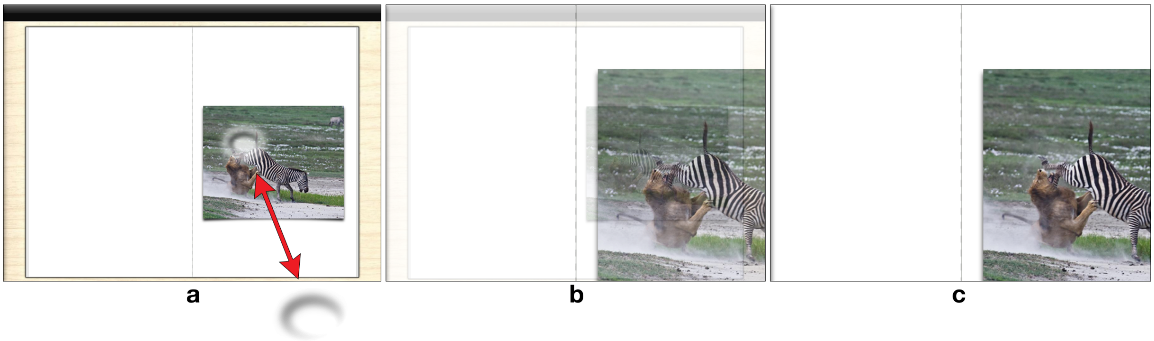


Figure 66: Design 2 'Smudge' and Interaction 4 'Double tap to zoom in'.

5. *Flip pages*: The booklet page corner is displayed slightly bent, suggesting the potential for a page-turning interaction. A single touch-point moves from right to left over the bent corner (a) suggesting a page turn (b) and briefly showing a blank page before fading out (c). Any other touch, such as in the middle or top of the page would not the trigger the interaction.

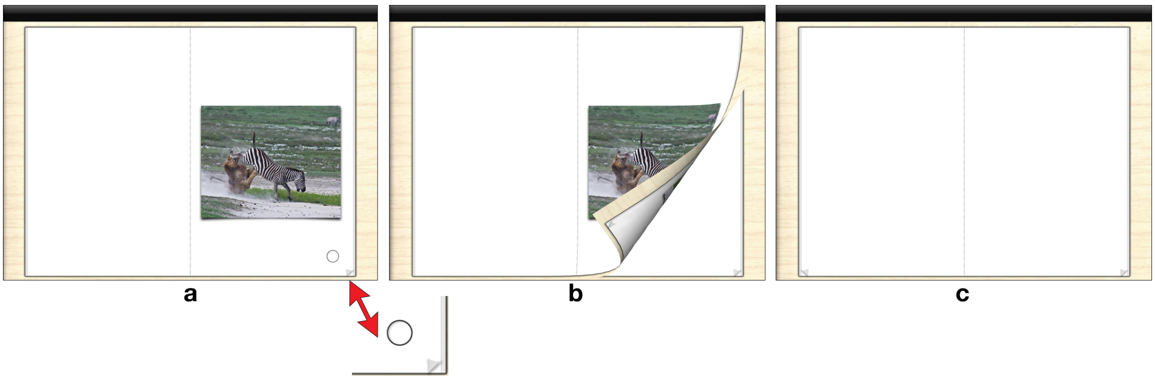


Figure 67: Design 1 'Circles' and Interaction 5 'Flip pages'.

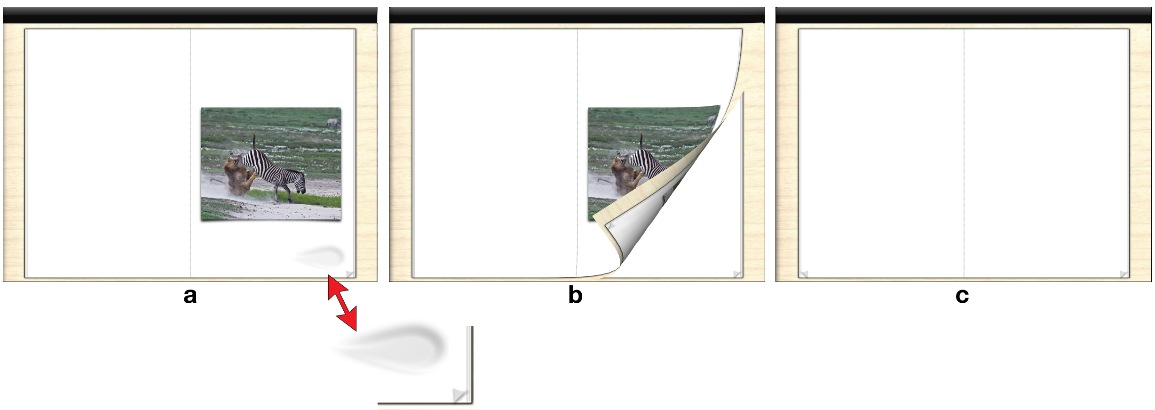


Figure 68: Design 2 'Smudge' and Interaction 5 'Flip pages'.

6.2.2.4 Task-switching gestures

Task-switching is a relatively rarely-used gesture in touch-based operating systems such as iOS and Android. Typically there is a hardware button to enable this action without using a gesture and so while it is available, the gestural control is often less frequently used. There are numerous causes for this that came to light in the course of these investigations into device use. One example is that multi-touch gestures need to be activated through the device configuration on iOS, and are not switched on by default. This naturally lowers the likelihood of their being used.

A common property of task-switching gestures is that they are almost always multi-touch (i.e. using two or more touch points). This set of three interactions was included to explore how well users are able to identify and perform multi-touch combinations that are infrequently used in standard practice. To ensure consistency between the gestures, all were assigned features that change the mode of the system (e.g. switch between alternate windows). Derboven et al. (2012: 714) argue "the lack of well-known standards in multi-touch interface design and in the use of gestures makes the user interface difficult to use and interpret".

6. *Switch between running applications:* A four finger sideways swipe (a) would reveal a hidden application on the side of the screen (b). The next application slides to the main view and the visual cue for touch would then fade out (c).

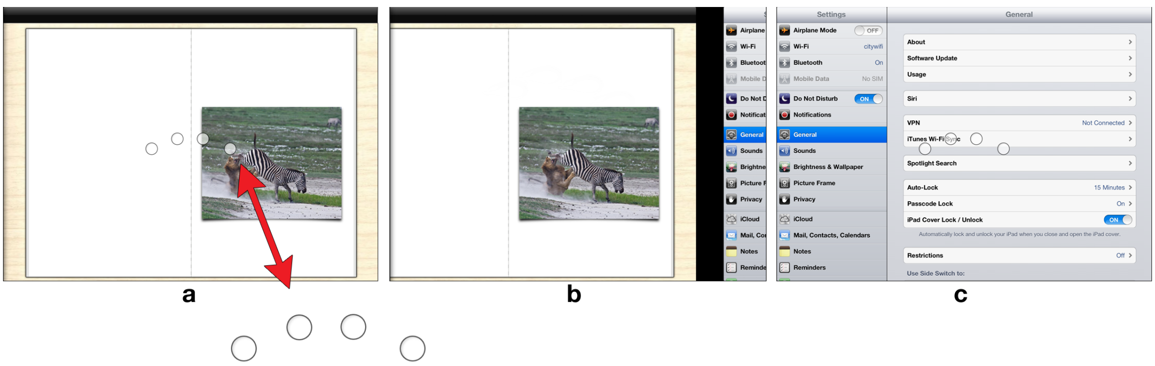


Figure 69: Design 1 'Circles' and Interaction 6 'Switch between apps'.

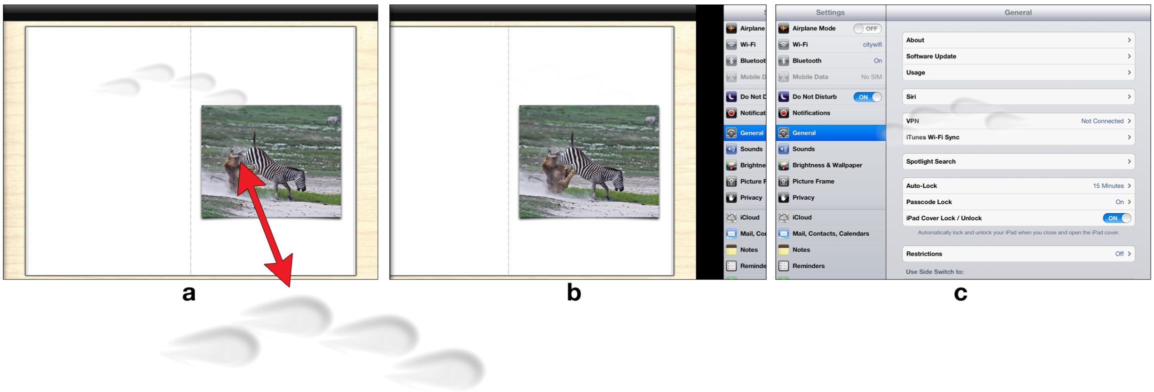


Figure 70: Design 2 ‘Smudge’ and Interaction 6 ‘Switch between apps’.

7. *Reveal task switcher:* A four finger upward swipe (a) would reveal the task switcher from the bottom of the screen (b) and simultaneously push up the view of the current application, which remains in sight. A one-finger touch anywhere on the screen will hide the task switcher (c); or a four-finger swipe downward will trigger the same result.

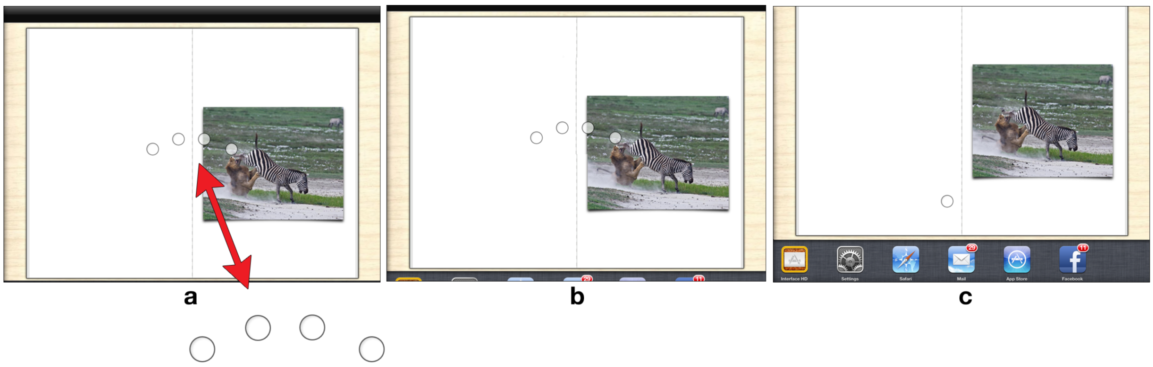


Figure 71: Design 1 ‘Circles’ and Interaction 7 ‘Reveal task switcher’.

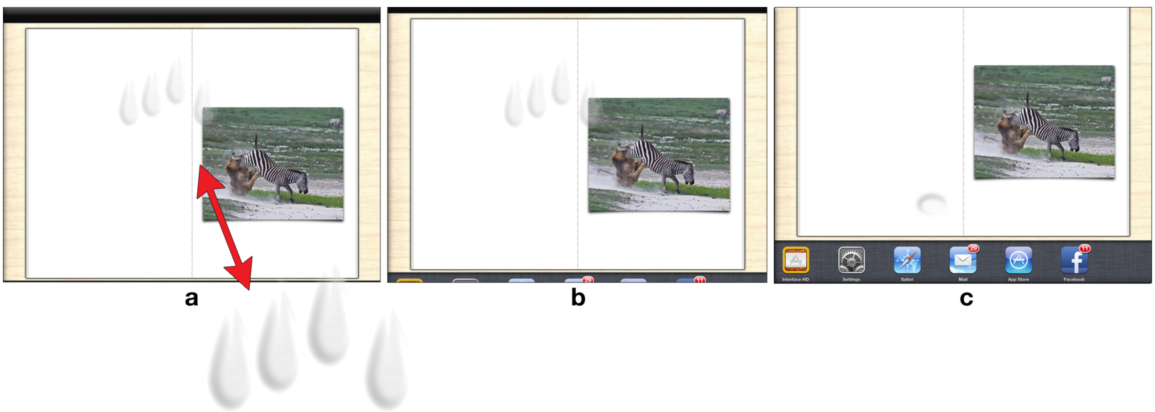


Figure 72: Design 2 ‘Smudge’ and Interaction 7 ‘Reveal task switcher’.

8. *Minimise application*: A four-finger inwards pinch (a) would trigger the app to minimise towards the bottom of the screen (b). The 'task switcher' emerges (c) to 'catch' the minimised app - and then recoils away from sight (d). The home screen fades away and shows the original application state to remind the user this was just a preview (e).

To restore the application, it is necessary to reveal the 'task switcher' (Interaction 7), find the minimised app and restore it with a single touch. This interaction drew from Piaget's postulate of 'Reciprocity' as reported by Wigdor and Wixon (2011: 137-138): Once "an action is completed, a side effect on that action can be undone by another action.

Figure 73: Design 1 'Circles' and Interaction 8 'Minimise application'.

Figure 74: Design 2 ‘Smudge’ and Interaction 8 ‘Minimise application’.

The next sections describe the first version of the gesture-and-effect model used to assess the SPG.

6.3 First Version of Gesture-and-Effect Model

Figure 75 shows the first version of the GEM. Note that the final model has already been reported in Section 5.3. However, before arriving at a final stage the model was refined across the two empirical studies undertaken in this thesis. This section explains its first version.

The phases pertaining to the model followed the form of Norman’s Theory of Action, by keeping the terminology of his original model: ‘perceive the system state’, ‘interpret the state’, ‘evaluate the system state with respect to goals’, ‘establish a goal’, ‘form an intention’, and ‘specify an action sequence’. Note that last three phases within execution drew from Wu’s RCT terminology: Registration, Continuation and Termination (a full description of the model is found in Section 5.3).

The evaluation phase consisted of seven micro-phases: (1) Notice the visual cue, (2) Identify potential for touch, (3) Identify touch configuration, (4) Identify number of touch points, (5) Identify type of gesture, (6) Identify direction, and (7) Identify implied status change.

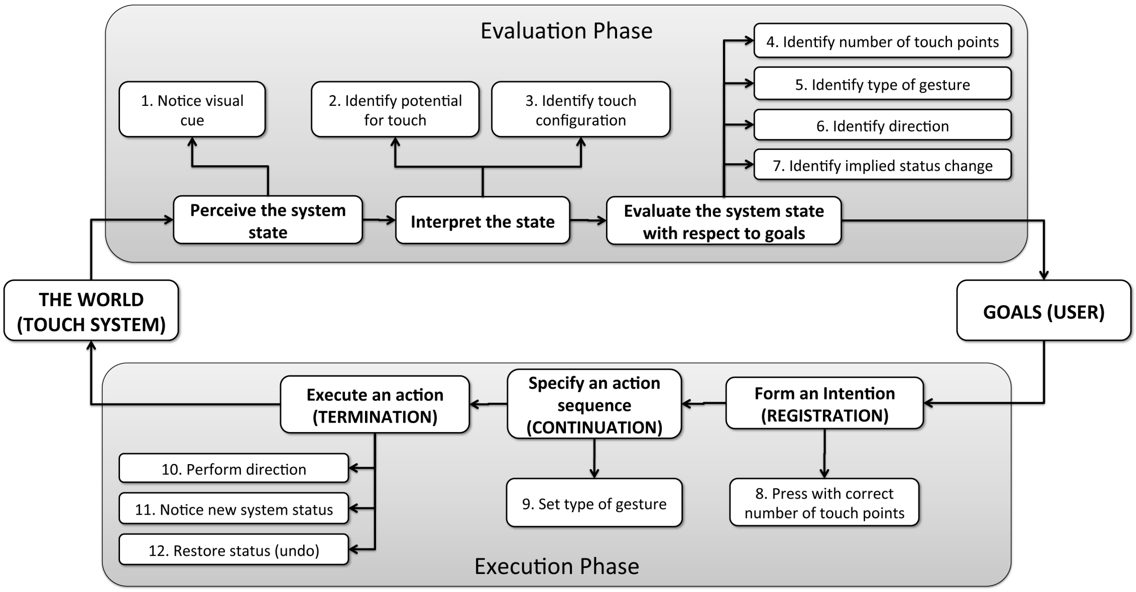


Figure 75: First version of the gesture-and-effect model for touch interactions.

The execution phase consisted of five micro-phases: (8) Press with correct number of touch points, (9) Set type of gesture, (10) Perform direction, (11) Notice new system state and (12) Restore status (undo).

6.4 Methodology

In this section, the participants, materials, study design, and the procedure followed to undertake the study are described.

6.4.1 Participants

The details for the selection criteria are described in Section 4.5. However, some aspects specific to this study are reported here. Leaflets were placed on strategic walls in different City University buildings, which brought in participants with diverse backgrounds (see Appendix D). Thirty-four paid participants (n=34, 13M, 21F) were recruited from various departments, students and staff within City University.

Thirty-four participants were recruited (n=34). Twenty-seven were in the age range from 25 to 44, 4 from the age of 45 to 64 and 3 only from 15 to 24. 13 were male and 21 female. 26 participants were users of Windows, 6 of MacOS, whilst 2 did not answer about the OS they were familiar with. In terms of mobile devices, 14 owned iPhones, 11 Android devices, 2 Blackberries, whilst 7 did not specify their phone platform. For tablet devices, 8 participants were iPad users, 4 used other brands, whilst 22 did not possess a tablet. 8 tablet users used their devices daily, 3 reported using it 1-4 times/week and 1 participant noted they hardly ever used it.

6.4.2 Materials

The study took place at the Interaction Lab, part of the Centre for HCI Design, Faculty of Informatics, during the last trimester of 2012. The test was set up with an iPad 2 running iOS 6 (which was then the current version of iOS), attached to a metal stand for testing mobile devices. A camera with built-in microphone was positioned to record the screen and verbalisations (Figure 76).

Figure 76: iPad study stand, camera with microphone and participant during a test (copyright has been granted).

This set provided a fixed position, which allowed recording of participants touching the screen. Only the participant and the facilitator (the researcher) were present in the room during the test. The e-Book application prototype was created in Keynote for Mac OS-X Yosemite and run on the native iOS Keynote application, which supports interactive presentations and hypermedia. The prototype was thus partially functional and would appear fully functional for the interaction sequences planned for the study. The “app” ran on an original Apple iPad and hence had a superficially high fidelity with a fully functional software prototype. Committing additional resources into developing a software prototype would have made minimal difference to the user experience during the study. The relatively simple gestures used in the prototype also enabled this approach to be effective.

6.4.3 Study Design

A within-subjects experiment design was used. The first set of independent variables (IV) was the two-style visual prompts that depict touch points over the screen. The second set consisted of 11 micro-phases belonging to evaluation and execution phases within the GEM.

Note that the first micro-phase within ‘evaluation’ (notice visual cue) was removed from the analysis following the first review of the experimental results. Quantitatively, 32 (94%, n=34) participants detected the visual prompt. Furthermore, none of these thirty-two made any verbal utterance that related to a problem in discovering the visual cues. There was also no observed hesitation by this group. Only two participants did not initially see the first visual cue within the study session, and these needed a brief initial prompt to guide them. Following this, neither required any further prompting across the study. Thus, given the low error rate and the limited scale of errors, that might be due to a learning effect, and the risk of producing spuriously significant results from small sample sizes (of errors, in this case), this data was removed from the systematic analysis.

The dependent variables (DV) were the ratings for each of the ten micro-phases. Each micro-phase was rated in one of three levels: Correct, Partially Correct or Incorrect, corresponding to how accurately a participant described an evaluation micro-phase, or performed an execution micro-phase.

The independent and dependent variables are listed below:

- IV ‘1’: 2 designs;
- IV ‘2’: 6 micro-phases for evaluation (2 to 7), and 5 for execution (8 to 12);
- DV: Correct, Partial, and Incorrect rates for evaluation and execution.

6.4.3.1 Randomization set

In addition, to avoid biasing results by showing the same sequence of interactions to all participants, the eight interactions and two designs were randomised according to a

Latin square (Cairns and Cox, 2008:7) totalling 16 combinations, which in turn were organised in 4 different sequences (a reference table can be found in Appendix G). The sequences were evenly used across 2 groups of 8 and 9 participants.

6.4.4 Procedure

This section elaborates on the step-by-step process used by the facilitator and main researcher to conduct the study session with participants.

1. A consent form (Appendix E) and pre-test questionnaire (Appendix F) gathered the demographics of the participants and their previous experience with touch-based technology
2. After participants completed the consent form and pre-test questionnaire, the study started with the facilitator introducing the interactions in turn, and clarifying any questions during the study.
3. Participants were allowed to manipulate the iPad freely for 2 minutes to familiarise themselves with it. The use of the home button or any other physical buttons was prohibited during the test, to ensure that participants remained inside the experimental environment, and that tasks were only accomplished by touching the display.
4. The facilitator started the test with a brief explanation about the application. This was followed by the sixteen interactions in one of four sequences that balanced the order of designs and interactions between experiments.
5. The participant was shown the animation that portrayed the gesture for the interaction, followed by its effect on the system. To assess their perceptions of the cue, the user was then asked questions, one for each step of the evaluation phase.
6. The participant then proceeded to the ‘Interaction’ phase where they were asked to perform the gesture. The resulting system status was always presented regardless the user failed to complete the gesture.
7. A black screen was displayed in-between different interactions to prompt participants that the current interaction was over (either by their success or facilitator discretion) and to ready them for the next one.

In order to evaluate the participants' assessments of the SPG concept and their interactions, the rating system was utilised. The findings from the empirical study formed the basis for both design recommendations and the utility of the evaluation system. Sample data is reported within the next section to highlight the quantitative outcomes of the study (the complete set of values can be found in Appendix H).

6.5 Results

The quantitative evaluation of the participants' interactions with the different designs and interactions is now reported. This will use the rating system described in Section 4.7.3.

The results of a comparative GLM were analysed (see Section 4.8.1), using a Log-linear analysis and Chi-square, Mann-Whitney and Kruskal-Wallis tests. These are described in the sections that support the hypotheses. The independent variables were the two designs (Design 1 and Design 2), and the dependent variables were the rating scores across eleven micro-phases. Initially, a Shapiro-Wilk normal distribution test was conducted (see Appendix H) and the results indicated that the H0 could be rejected ($p<0.05$). This result does not affect the following analysis, demonstrating solely that the distribution of results followed a non-normal distribution. The difference between the designs was then calculated with a Mann-Whitney test, which is the non-parametric equivalent of a S*tudent's* 'T' test.

In order to check the reliability of the rules for applying the rating system, a second independent researcher also assessed the scores of eight randomly selected participants. The independent and main researcher assessed the same participants and watched, separately, the playback videos of the test sessions. The independent assessment was 93% 'Correct', 4% 'Partial' and 3% 'Incorrect', while the principal researcher's assessment for the sample was 91.3% 'Correct', 2.6% 'Partial' and 6% 'Incorrect'. These results were calculated using a Pearson product-moment correlation coefficient. The analysis between the two researchers showed ($r=0.94$) for 'Correct', (0.75) for 'Partial' and (0.97) for 'Incorrect', which satisfies the magnitude correlation coefficient. A highly correlated magnitude lies between 0.7 and 0.9.

We start by reporting the evaluation phase, before progressing onto reporting an analysis of the participants' execution of the gestures. The term "assess" will be used for judgements made in the course of the analysis. When the term "evaluation" is used, it refers specifically to the evaluation *phase* of user interaction.

6.5.1 Assessing the Evaluation Phase

Table 20 shows the sums that stem from the rating system, which cover the six micro-phases across the designs. As reported in Section 6.4.3, the first micro-phase within 'evaluation' (notice visual cue) was removed from the analysis.

The 'IPC' letters stand for the rating system: 'C' stands for 'Correct', 'I' for 'Incorrect' and 'P for 'Partial' results. The top row shows the micro-phases within Evaluation. D1 and D2 stand for the designs. The overall sum for the evaluation phase was 84% correct, 5% partially correct and 11% failed to assess the visual prompts.

	2. Potential touch			**3. Touch config**			**4. No. of touch points**			**5. Type of gesture**			**6. Direction**			**7. Effect on system status**		
Des	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
D1	19	12	241	30	23	219	34	11	227	43	10	219	28	3	241	29	19	224
D2	21	14	237	31	18	223	37	11	224	37	6	229	26	4	242	30	20	222
Tot	**40**	**26**	**478**	**61**	**41**	**442**	**71**	**22**	**451**	**80**	**16**	**448**	**54**	**7**	**483**	**59**	**39**	**446**

Table 20: Descriptive table for the evaluation phase: scores for the success of participant identification for each micro-phase (columns) and design (rows).

6.5.1.1 Log-Linear Analysis for Evaluation

To determine any reliable significant differences, and as a first step in the analysis, a global Log-linear analysis was conducted. The analysis of the scores used all three dimensions: a) the three ratings of user performance; b) micro-phases 2 to 7 of the model, and third, c) the two separate designs. Table 21 shows the result of the global test across all factors was statistically significant: $G^2=46.94$, df=22, p<0.001. Therefore, at least one factor provided a significant effect.

Following the global test, pairs of factors were tested in turn (e.g. designs against success rates), without performing counter-balancing for the third factor. In these cases, no significant result for 'B' (micro-phases) was observed when compared to 'C' (designs): $G^2=0$, df=4, p=1, however significant results were observed in the pairs 'A' (ratings) versus ‘B’ (micro-phases): G^2=45.56, df=8, p<0.001 but not for ‘A’ (ratings) versus ‘C’ (designs): G^2=0.1, df=2, p=0.9512. At this point in the analysis, the interpretation of the statistics is that while the designs do not independently interact with the phases (ignoring outcomes), they did interact with each other through the outcomes of user evaluation.

	G2	df	P
ABC	46.94	22	0.0015
AB	45.56	8	<0.0001
AC	0.1	2	0.9512
BC	0	4	1
AB [C]	46.84	16	<0.0001
AC [B]	1.38	10	0.9993
BC [A]	1.28	12	0.9999

Table 21: Log-linear analysis for the evaluation phase.

The third and final step examined the same pairs of interactions while counter-balancing for the effects that had been isolated for the factors in the second phase. In this final set of three tests, the first pairs of factors, ‘A’ (ratings) versus ‘B’ (micro-phases) excluding ‘C’ (designs) yielded significant results: G^2= 46.84, df=16, p<0.001; and ‘A’ (ratings) against ‘C’ (designs) excluding ‘B’ (micro-phases) did not prove significant: G^2=1.38, df=10, p=0.9993. The last pair, ‘B’ (micro-phases) versus ‘C’ (designs), excluding ‘A’ (ratings) did not prove significant (G^2=1.28, df=12, p=0.9999). With no significant effect even with a detailed analysis, both pairs can be discarded. This led to the confident conclusion that the designs vary in their success rates across the different micro-phases. However, further tests are required of individual, pair-wise comparisons of evaluation outcomes in order to isolate the specific effects that are significant.

Given the outcome of the Log-linear test above, it is safe to proceed to analysing the different pair-wise tests of factors (e.g. phases versus designs), which we will look at first.

6.5.1.2 Significance for micro-phases within Evaluation

The first step to make sure that all results related to designs did not occur by chance was to run a Chi-square (χ^2) test for independence for each micro-phase within the evaluation phase. Table 22 shows the ratings *per* design and *per* micro-phase.

	2. Potential touch			**3. Touch config**			**4. No. of touch points**			**5. Type of gesture**			**6. Direction**			**7. Effect on system status**		
	I	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
Des	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
D1	7.0	4.4	88.6	11.0	8.5	80.5	12.5	4.0	83.5	15.8	3.7	80.5	10.3	1.1	88.6	10.7	7.0	82.4
D2	7.7	5.1	87.1	11.4	6.6	82.0	13.6	4.0	82.4	13.6	2.2	84.2	9.6	1.5	89.0	11.0	7.4	81.6
Tot	**7.4**	**4.8**	**87.9**	**11.2**	**7.5**	**81.3**	**13.1**	**4.0**	**82.9**	**14.7**	**2.9**	**82.4**	**9.9**	**1.3**	**88.8**	**10.8**	**7.2**	**82.0**

χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
0.287	2	0.866	0.662	2	0.718	0.147	2	0.929	1.673	2	0.433	0.219	2	0.896	0.052	2	0.975

Table 22: Percentage scores and Chi-square of participant for each micro-phase of evaluation phase, by micro-phase (columns) and design (rows).

No significant results were found across designs and within the micro-phases within evaluation (p>0.05). This demonstrates that there was no association between the designs and the ratings during the evaluation phase, and that the designs were not the determining factor for success or failure of participants' evaluation of the SPG.

6.5.2 Assessing the Execution Phase

Table 23 shows all sums for the rating system per micro-phases and designs. Participants executed correctly 86% of gestures, 3% were partials and 11% incorrect. The ratings mirrored the evaluation phase.

	8. Touch to confirm			**9. Set type of gesture**			**10. Perform direction**			**11. System status**			**12. Restore status**		
Des	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
D1	9	17	246	14	10	248	13	5	254	21	0	251	36	7	229
D2	33	21	218	25	12	235	26	6	240	54	2	216	71	5	196
Tot	**42**	**38**	**464**	**39**	**22**	**483**	**39**	**11**	**494**	**75**	**2**	**467**	**107**	**12**	**425**

Table 23: Descriptive table for the execution phase: scores per micro-phase (columns) and designs (rows).

6.5.2.1 Log-Linear Analysis

Following the same procedure used to assess the evaluation phase, a global Log-linear analysis was also conducted to verify significance between the independent and dependent variables for the execution phase.

The analysis took on the three dimensions: a) the three ratings of user performance; b) the five micro-phases within execution, and c) the two designs. Table 41 shows the result of the global test across all factors was statistically significant: $G^2=168.32$, $df=22$, $p<0.001$.

	G2	df	P
ABC	168.32	22	<0.0001
AB	108.06	8	<0.0001
AC	52.78	2	<0.0001
BC	0	4	1
AB [C]	115.54	16	<0.0001
AC [B]	60.26	10	<0.0001
BC [A]	7.48	12	0.8243

Table 24: Log-linear analysis for the execution phase.

Following the global test, pairs of factors were tested in turn (e.g. designs against success rates), without performing counter-balancing for the third factor. Mirroring the evaluation phase, no significant result for ‘B’ (micro-phases) were observed when compared to ‘C’ (designs): $G^2=0$, $df=4$, $p=1$, however significant results were observed in the pairs ‘A’ (ratings) versus ‘B’ (micro-phases): $G^2=108.06$, $df=8$, $p<0.001$ and ‘A’ (ratings) versus ‘C’ (designs): $G^2=52.78$, $df=2$, $p<0.0001$. In this final set of three tests, the first pairs of factors, ‘A’ (ratings) versus ‘B’ (micro-phases) excluding ‘C’ (designs) yielded significant results: $G^2= 46.84$, $df=16$, $p<0.001$; and ‘A’ (ratings) against ‘C’ (designs) excluding ‘B’ (micro-phases) did prove significant: $G^2=60.26$, $df=10$, $p<0.0001$. The last pair, ‘B’ (micro-phases) versus ‘C’ (designs), excluding ‘A’ (ratings) did not prove significant ($G^2=7.48$, $df=12$, $p=0.8243$). With no significant effect even with a detailed analysis, this pair can be discarded. This led to the confident conclusion that the designs vary in their success rates across the different micro-phases within the execution phase.

Given the outcome of the Log-linear test above, it is safe proceed to analysing the different pair-wise tests of factors.

6.5.2.2 Significance for micro-phases within Execution

As for evaluation, an independent Chi-square (χ^2) test was run for each micro-phase within execution. Table 25 shows the percentage of 'Incorrect', 'Partial' and 'Correct' ratings *per* design and micro-phase. The top row shows the micro-phases within Execution. D1 and D2 stand for the designs.

	8. Touch to confirm			**9. Set type of gesture**			**10. Perform direction**			**11. System status**			**12. Restore status**		
	I	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
Des	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
D1	3.3	6.3	90.4	5.1	3.7	91.2	4.8	1.8	93.4	7.7	0.0	92.3	13.2	2.6	84.2
D2	12.1	7.7	80.1	9.2	4.4	86.4	9.6	2.2	88.2	19.9	0.7	79.4	26.1	1.8	72.1
Tot	**7.7**	**7.0**	**85.3**	**7.2**	**4.0**	**88.8**	**7.2**	**2.0**	**90.8**	**13.8**	**0.4**	**85.8**	**19.7**	**2.2**	**78.1**

χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
12.537	1	0.0	3.250	1	0.07	4.42	1	0.04	18.3	1	0.0	12.463	1	0.0

Table 25: Percentage scores and Chi-square for each micro-phase (columns) across designs (rows) of the execution phase.

The results show significance for micro-phases '8' (χ^2=12.54, df=1, p<0.001), ´10´ (χ^2=4.42, df=1, p = .04),'11' (χ^2=18.3, df=1, p<0.001) and '12' (χ^2=12.46, df=1, p<0.001). Note that system status determines a correct execution; therefore participants undertook 86% correct gestures. The partial rate yielded 0%, and was therefore disregarded.

Finally, it is safe to claim that, by finding statistical significance for some of the micro-phases within execution, we additionally support thesis hypothesis 'c', which claimed a rating system that segments users gestural interactions into smaller phases will help revealing issues with users' evaluation and execution of gestures. This will be further addressed in Section 7.5.7.

6.5.3 Assessing Designs and Interactions

Before supporting study hypotheses, a preliminary analysis is necessary to answer to the initial research questions.

The first research question, asks ‘Following the principle of perceptible affordances, what are the visual properties of design interventions that effectively indicate the required configuration of the registration of a gesture?’ The second, asks ‘How can the concepts of feedforward and feedback be applied to aid users in discovering new gestures?’ Therefore, these two questions aim at investigating the visual properties and interface behaviour that would convey to users, with more efficiency, the opportunity for gestural interactions. One way to gauge efficiency in this case is to compare the error rates for both designs across the three interactions.

In this first step we compare, separately, the error rates for both designs across the phases of evaluation and execution. An initial analysis (Table 43) has shown that neither design was a factor within the evaluation phase for the lack of significant results when compared ($p>0.05$). This confirms the results already found in Section 6.5.1.2.

However, for the execution phase, the first design ‘Circles’ yielded 7% errors in execution of gestures, and the second design ‘Smudge’ yielded 15%. Circles thus proved to be more efficient than ‘smudge’ in terms of lower error rates during the execution phase.

	Evaluation			
Rating	**Circles**		**Smudge**	
	N	**%**	**N**	**%**
Incorrect	31	11%	30	11%
Partial	13	5%	12	4%
Correct	229	84%	230	84%
p value	0.97			
	Execution			
Rating	**Circles**		**Smudge**	
	N	**%**	**N**	**%**
Incorrect	19	7%	42	15%
Partial	8	3%	9	3%
Correct	246	90%	221	81%
p value	0.01			

Table 26: Chi-square for designs 1 and 2.

In the next step, a Mann-Whitney test for independent samples was used to verify significance of ratings across micro-phases, interactions and designs. This is suitable because the interactions are 'co-variables' and should be analysed accordingly.

The test results are reported in Appendix H. It shows that Interactions 1, 2 and 5 did not vary significantly for any micro-phase within either evaluation or execution ($p > 0.05$). However, we have observed that the designs did show statistically significant differences (considering the user ratings) for several specific micro-phases within Interactions 3, 4, 6, 7 and 8. The results are now described in detail:

For Interaction 3, micro-phase '2' Potential for touch was significant with ($F = 38.147$, df=66, $p<0.05$), micro-phase '3' Touch configuration ($F = 3.415$, df=66, $p = 0.05$), '5' Type of gesture ($F = 1.413$, df=66, $p<0.05$), and '7' Effect on system status ($F = 15.311$, df=66, $p<0.05$) within the evaluation phase. No micro-phases within execution were significant for this interaction.

For Interaction 4, micro-phase '3' was significant with ($F = 31.429$, df=66, $p<0.05$), '4' Number of touch points ($F = 25.303$, df=66, $p<0.05$), '5' ($F = 34.469$, df=66, $p<0.05$), '6' Direction ($F = 23.779$, df=66, $p<0.05$), and '7' ($F = 29.366$, df=66, $p<0.05$) within the evaluation phase. No micro-phases within execution were significant for this interaction.

For Interaction 6, micro-phase '4' was significant ($F = 4.871$, df=66, $p = 0.05$), and '7' ($F = 10.882$, df=66, $p<0.05$) within the evaluation phase. For the execution phase, micro-phase '8' Touch to confirm was significant with ($F = 11.737$, df=66, $p<0.05$), '11' System status ($F = 31.341$, df=66, $p<0.05$), and '12' Restore status ($F = 34.436$, df=66, $p<0.05$).

For Interaction 7, micro-phase '5' was significant ($F = 27.129$, df=66, $p<0.05$), '6' ($F = 40.879$, df=66, $p<0.05$), '7' ($F = 10,883$, df=66, $p<0.05$) within the evaluation phase. For the execution phase, micro-phase '8' was significant with ($F = 47.919$, df=66, $p<0.05$), '10' Perform direction ($F = 31.085$, df=66, $p<0.05$), '11' ($F = 46.862$, df=66, $p<0.001$), and '12' ($F = 36.506$, df=66,$p<0.05$).

For Interaction 8, micro-phase '3' was significant with ($F = 38.920$, df=66, $p<0.05$), '4' ($F = 21.084$, df=66, $p<0.05$), '5' ($F = 20,900$, df=66, $p<0.05$), and '6' ($F = 20.900$, df=66, p<0.05), within the evaluation phase. For the execution phase, micro-phase '9' Set type of gesture ($F = 17.943$, df=66, $p<0.05$) was significant, and '11' ($F = 116.016$, df=66, $p<0.05$).

The results indicate that micro-phase '11. Identify system status' was statistically significant for Interactions 1 to 7. This indicates that SPG, regardless of the design style, contributed to participants' description of the possible outcome of a given interaction. Micro-phases '11. Identify system status' and '12. Restore status' were significant for all multi-touch interactions (6, 7 and 8).

Having established the micro-phases that yielded significant results across interactions, this section now proceeds to compare the significance of designs across interactions. Therefore, only Interactions 3, 4, 6, 7 and 8 were analysed.

Table 27 shows the ratings from a simple average between evaluation and execution phases, across interactions and designs. The top row shows the two designs. The 'IPC' letters stand for the rating system: 'C' stands for 'Correct', 'I' for 'Incorrect' and 'P for 'Partial' results. I1 to I8 stand for the interactions.

	D1 Circle			**D2 Smudge**		
Int	**I**	**P**	**C**	**I**	**P**	**C**
I1	5%	3%	92%	3%	1%	96%
I2	1%	2%	97%	2%	1%	98%
I3	25%	7%	68%	17%	2%	82%
I4	22%	2%	76%	11%	1%	88%
I5	3%	2%	95%	10%	0%	90%
I6	6%	6%	87%	17%	13%	70%
I7	7%	5%	88%	26%	8%	66%
I8	5%	5%	91%	20%	6%	74%

Table 27: Success rates per Designs x Interactions.

Overall, Interaction 3 (touch and hold) yielded 21% errors, followed by Interaction 4 (double tap) and Interaction 7 (multi-touch and swipe upwards) with 16%. Interaction 6 (multi-touch and horizontal swipe) and Interaction 8 (multi touch and pinch) yielded 12% errors. The results indicate that the design 'Smudge' yielded fewer error rates for Interaction 3 'touch and hold', with 17% (χ^2=23.254, df=2, $p<0.001$), and Interaction 4 'double tap', with 11% (χ^2=17.858, df=2, $p<0.001$). This demonstrates that this design style can be beneficial for single-touch and static gestures. Furthermore, it intimates that it can help the user identify and perform touch-and-hold gestures. However, this design had issues with swipe movements, specifically the interaction ‘7’ multi-touch swipe upwards: ‘smudge’ yielded double the errors in the execution of the direction of a gesture than the ‘circles’ design. The design 'Circles' also yielded fewer error rates for Interaction 6, with 6% (χ^2=34.877, df=2, p<0.001) Interaction 7 with 7% (χ^2=54.718, df=2, p<0.001), and Interaction 8 with 5% (χ^2=41.736, df=2, p<0.001). This demonstrates that the ‘circles’ design style can be beneficial for multi-touch and dynamic gestures.

6.5.4 Assessing Micro-phases

Research question 3 (Section 1.4) asked ‘Which parts of gestural interactions are users failing to assess and execute?’ For instance, common errors were observed in the registration of number of fingers, or the continuation with the appropriate direction. In the absence of any prior data, no hypotheses were made in regards to this question. Therefore, it was necessary to analyse the results of this study to draw an initial insight into the likely answer to the question. The analysis later supported contribution ‘3’ from this thesis (Section 1.6).

Table 28 shows the ratings (Incorrect, Correct and Partial) per micro-phase within the evaluation phase. In this analysis we disregard the influence designs can have over the micro-phases and demonstrate the overall results.

	I	P	C
2. Potential touch	7.4%	4.8%	87.9%
3. Touch config	11.2%	7.5%	81.3%
4. No. of touch points	13.1%	4.0%	82.9%
5. Type of gesture	14.7%	2.9%	82.4%
6. Direction	9.9%	1.3%	88.8%
7. Effect on system status	10.8%	7.2%	82.0%

Table 28: Ratings per micro-phases within evaluation.

The results were significant for all micro-phases, with ‘2’ ($\chi2$ = 728.574, df = 2, p<0.001), ‘3’ ($\chi2$ = 563.165, df = 2, p<0.001), ‘4’ ($\chi2$ = 608.165, df = 2, p<0.001), ‘5’ ($\chi2$ = 599.529, df = 2, p<0.001), ‘6’ ($\chi2$ = 758.871, df = 2, p<0.001), and ‘7’ ($\chi2$ = 580.548, df = 2, p<0.001).

Figure 77 shows that micro-phases ‘5. Identify type of gesture' and ‘4. Identify touch points’, produced larger error rates across the board, with 14.7% and 13% respectively. By contrast, micro-phase ‘2. Identify potential touch' and ‘6. Identify direction' had the lowest, with 7.4% and 10% respectively.

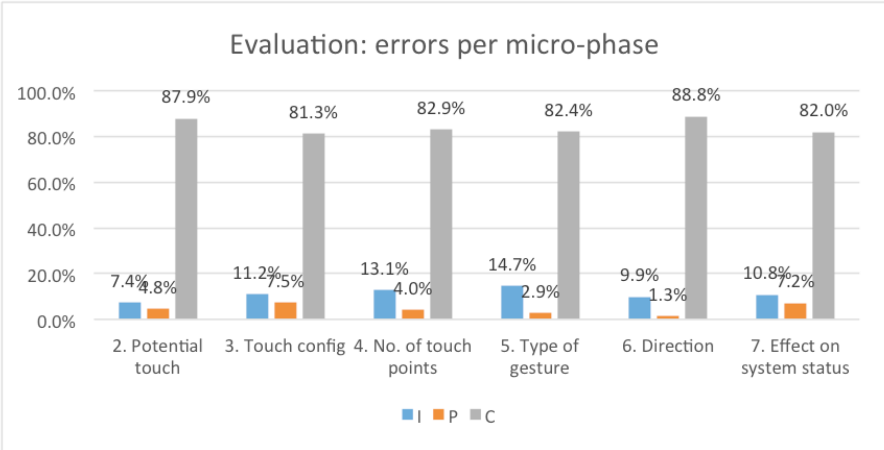


Figure 77: Chart with ratings per micro-phases within evaluation.

Next, we compare user performance in the different micro-phases of execution (Table 29). The results were significant for all micro-phases, with ‘8’ ($\chi2$ = 660.985, df = 2, p<0.001), ‘9’ ($\chi2$ = 753.577, df = 2, p<0.001), ‘10’ ($\chi2$ = 810.842, df = 2, p<0.001), ‘11’ ($\chi2$ = 689.739, df = 2, p<0.001), and ‘12’ ($\chi2$ = 516.026, df = 2, p<0.001).

	I	P	C
8. Touch to confirm	7.7%	7.0%	85.3%
9. Set type of gesture	7.2%	4.0%	88.8%
10. Perform direction	7.2%	2.0%	90.8%
11. System status	13.8%	.4%	85.8%
12. Restore status	19.7%	2.2%	78.1%

Table 29: Ratings per micro-phases within execution.

Figure 78 shows that micro-phase ‘12. Restore status', and ‘11. System status', produced the most error rates across the board, with 19.7% and 13.8% respectively. By contrast, micro-phase ‘9. Set type of gesture' and ‘10. Perform direction' had the lowest, with 7.2% respectively.

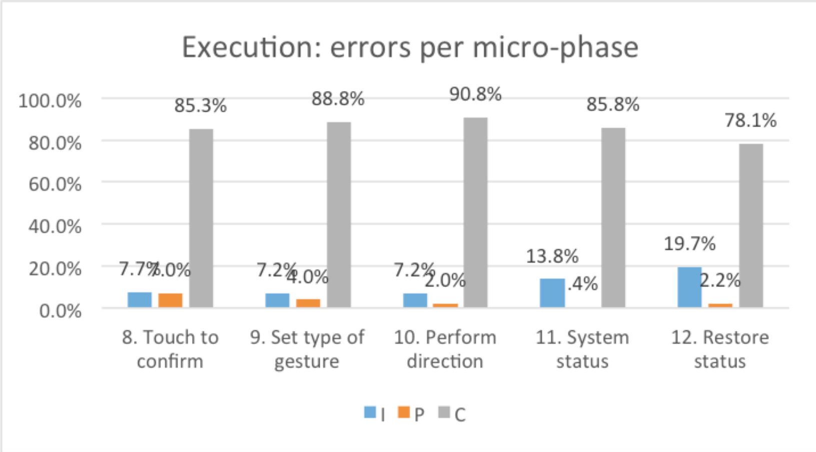


Figure 78: Chart with ratings per micro-phases within execution.

This leads to the safe conclusion that participants had most problems identifying the touch configuration, followed by the correct number of fingers to initiate touch. The results from the execution phase showed that participants had problems restoring the application to its previous state and comprehending the new system status. This indicates that users have issues with 'undo' gestures. Possibly, this is a problem of consistency, in which case the gesture to undo or restore an interaction is in many occasions different from the initial gesture. For instance, Interaction 3 (Touch and hold), Interaction 6 (Switch applications), Interaction 7 (Reveal task switcher) and Interaction 8 (Minimise application) had different gestures for undo. Additional qualitative findings (Section 6.5.7) corroborate these results.

Having undertaken the initial analysis on results for both evaluation and execution, the next section reviews specific data to support thesis hypothesis 'a'. Qualitative data will be provided to give further insight into the statistical findings.

6.5.5 Thesis Hypothesis 'a'

The first hypothesis proposes that 'Ensuring the registration points are clearly depicted in the user interface will improve gesture learning and executing gestures'. The null hypothesis states otherwise that 'Visual depictions of touch points will not improve evaluation or execution of gestures'.

Before providing an analysis of results in order to either support or reject the null hypothesis, it is necessary to point out that the following analysis served to demonstrate, comparatively, which design yielded fewer error rates in specific micro-phases.

However, the error rates to the presence of the SPG were not compared to its absence, thus this study could not prove or disprove this hypothesis. This comparison was done in the next and final study.

Only the micro-phases within execution that showed statistical significance are reported on here although all the ratings of success were considered. Note that no significant results were found for the evaluation phase. Table 30 shows the mean ranking from the ratings of success. It is possible to verify that the design 'Circles' obtained a larger success rate within execution of gestures than the 'Smudge' design. These results are statistically reliable in establishing the differences found in of micro-phases '8', '10', '11' and '12', as reported in the previous section (see Table 25).

Micro-phase	Design	N	Mean	Std. Deviation	Std. Error Mean	Std. Error Difference
8. Touch to confirm	**Circles**	272	.936	.2115	.0128	.0243
	Smudge	272	.840	.3398	.0206	
10. Perform direction	**Circles**	272	.943	.2221	.0135	.0226
	Smudge	272	.893	.3001	.0182	
11. System status	**Circles**	272	.923	.2674	.0162	.0292
	Smudge	272	.798	.4001	.0243	
12. Restore status	**Circles**	272	.855	.3437	.0208	.0338
	Smudge	272	.730	.4397	.0267	

Table 30: Mean square for 'micro-phases' versus 'designs' within execution.

Figure 79 also shows the mean results in a bar-chart format. It is possible to argue that both designs show high rates of success with small differences between them. Micro-phase '11' showed the larger success rate between the designs (12.9%), followed by micro-phase '12' (12.1%).

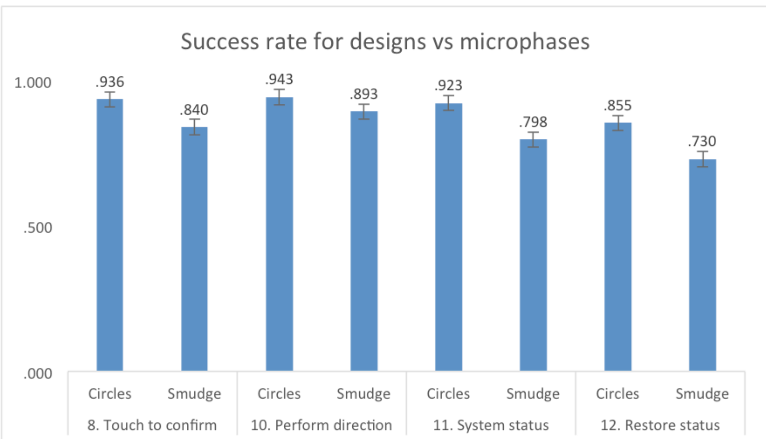


Figure 79: Success rates for 'micro-phases' versus 'designs' within execution.

As can be observed in Table 31, the 'Incorrect' rating for micro-phase '11' was fundamental to discriminate the efficiency of one design against the other. In this case the 'Smudge' design fared worst, with two and a half (x2.5) more errors than 'Circles' (54/21).

			11. System Status			
			I	**P**	**C**	**Total**
Design	**Circles**	**Count**	21	0	251	272
		Expected	37.5	1.0	233.5	272.0
	Smudge	**Count**	54	2	216	272
		Expected	37.5	1.0	233.5	272.0
Total		**Count**	75	2	467	544
		Expected	75.0	2.0	467.0	544.0

Table 31: Count and Expected results per designs for System status.

6.5.5.1 Qualitative analysis for thesis hypothesis 'a'

In this section the emerging themes from the qualitative coding are described, which in addition point out the advantages and disadvantages of both design styles in conveying the opportunity for specific gestures.

Advantages and disadvantages of Circles design

Clear visual depictions are good for multi-touch: The advantage of the 'Circles' design in communicating the number of touch points is shown by 27 comments, including "I think the circles give me a better idea of how many fingers I should use" (P2, Interaction I6) and "shows you exactly how many fingers you're supposed to be using" (P11, Interaction I7). In contrast, participants consistently struggled to identify the number of touch points with the 'Smudge' design for these three interactions (step S4, see Figure 75). This demonstrates the importance of effective cues to inform the user of the required touch points to initiate a gesture.

Unclear for double-tap and touch-and-hold: With the 'Circle' design participants often confused a 'double tap' Interaction 4 (Zoom in) with 'pinch', with participants producing twice as many mistakes. For instance, participant (P5, M, 26) mentioned that he "Preferred the water drops. Allows more flexibility. The dots imply you have to be more precise"; "The 'swipy' you can see is like an imprint where you can push quite hard, and I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe.” (P18, F, 35); and “When that kind of hazy area comes up, makes you feel like hold it, is not that quick suggesting to hold it, whereas the other is more ambiguous.” (P27, F, 40).

Advantages and disadvantages of Smudge design

Clear for double-tap and touch-and-hold gestures: For static gestures, the actions ‘tap’, ‘pinch’, etc. is key. Participant’s comments suggested that ‘Smudge’ better depicted a double-tap (Interaction 4): “If I use my finger anywhere in the picture will highlight that dot…or maybe double tap it…” (P30, 31, F) and when asked how would he start the interaction, participant (P21, 27, M) simulated a double tap without touching the screen.

For Interaction 3 (Touch and hold), more comments were made (17 in total). (P16, 42, F) was one who mimicked the gesture. Others found that the appearance of ‘Smudge’ suggested pressure: “when that kind of hazy area comes up, makes you feel like hold it”. (P27, 40, F) and “The 'swipy' you can see is like an imprint where you can push quite hard”. (P18, 35, F). There were also errors with the ‘Smudge’ design: some participants attempted or described a pinch, or thought that a thumb was required.

Not visually distinctive: The ‘Smudge’ design’s issues with multi-touch stemmed from its visual complexity. Several participants regarded the design as blurry, in turn making it harder to identify the number of touch points: for example “they're not so visually distinctive. Especially over images they don't show up so well”. (P17, 32, F) and “I do prefer the circles because the first time I couldn't see the blurry one” (P12, 27, M).

For the ‘swipe applications’ gesture, the number of fingers to use was the key problem. Interaction 6 (Switch applications), Interaction 7 (Reveal task switcher), and Interaction 8 (Minimise application), which rely on four fingers, proved consistently difficult for those using ‘Smudge’ (12 participants failing to judge this correctly at Step S4), but steps S5 and S6 (type and direction) also proved problematic for the other two gestures.

Smudge design presented issues for informing direction: In the ‘Smudge’ design, the sense of directionality was influenced by comparisons with ‘water drops’: participants were unable in several cases to identify the appropriate direction of a gesture, particularly Interaction 7's vertical upwards swipe. Comments include: "When you see the raindrops it might imply you have to go down because they fall" (P14, 34, F). As a result, seven participants wrongly performed the interaction in the opposite direction e.g. P6, 57, M and P24, 37, M.

6.5.5.2 Summary for thesis hypothesis 'a'

Overall, the 'Circles' design better communicated the number of touch points, but struggled for static gestures that occur at a single point, while the 'Smudge' design had the opposite strengths and weaknesses. In contrast, the 'Smudge' design struggled to articulate direction to users, particularly when there were multiple touch points. The visual sophistication of 'Smudge' appeared to work against it, creating an ambivalence factor concerning its implied directionality. The qualitative analysis that follows supports these conclusions. However, the data does not reject the null hypothesis, for it does not compare results based on the presence versus absence of the SPG in regards to participants' performance when evaluating and trying to execute gestures in the given interface. The next study (Chapter 7) will cover that.

6.5.6 Thesis Hypothesis 'c'

Hypothesis 'c' claims that 'a rating system that segments users' gestural interactions into smaller phases will help to reveal issues with users' evaluation and execution of gestures'. The null hypothesis states otherwise that 'statistical analysis will show no significant differences between evaluation and execution of gestures, or between phases.'

In the search for significance across the micro-phases within evaluation and execution, separate χ^2 tests were conducted. In light of the results observed in 6.1.1.2, it is not possible to reject the null hypothesis for the evaluation phase. In other words, the 'actual' (N) results were very similar to the 'expected' in this phase. However, as observed in 6.5.2.2, the results were significant for micro-phases '8. Touch to confirm' (χ^2=12.54, df=1, p<0.001), ′10. Perform direction' (χ^2=4.42, df=1, p = .04), '11. System status' (χ^2=18.3, df=1, p<0.001) and '12. Restore status' (χ^2=12.46, df=1, p<0.001).

6.5.6.1 Summary for thesis hypothesis 'c'

To summarise, specific micro-phases within the execution phase supported the hypothesis, by demonstrating significance across the model. Furthermore, it is claimed that the rating system can be used as a framework to assess gestural interactions of all kinds (Section 1.6). The results show that the rating system has great potential to associate problems participants had during evaluation and execution of gestures within specific stages of the interaction technique.

6.5.7 Additional Qualitative Findings

The qualitative analysis and post-study questionnaire explored a number of points where previous experience shaped – helpfully and unhelpfully – unpredicted issues on user expectations and interpretations of gestures. These themes did not fit any of the hypotheses reported in this study, but are relevant to the thesis as a whole, and are now discussed. Note that the following topics describe issues shared by both designs.

Issues with multi-touch: At least six comments were made that describe issues with touching the screen with multiple fingers, such as "Not my natural way, touching with 4 fingers…" (P23, 41, F) and "I think the four fingers is very unnatural." (P10, 28, M).

Also, for both designs it was observed that some female participants complained about their inability to reach the screen with their little finger, resulting in difficulties in performing interactions that required four touch points on the screen. This occurrence compromised particularly Interactions I6 (Swipe applications) and Interaction I7 (Reveal task switcher). A few comments exemplify this: "I'm not used to use my little finger for anything…just too short. Perhaps three fingers is more natural, the short finger doesn't seem to reach the screen" (P17, 32, F) and "I'm used to use three fingers rather than four but obviously once you get used to it…I think it's quite weird using the little finger." (P26, 31, F).

The challenge of undo: One repeated issue was the 'undo' step of an interaction (step S12). As an example, when minimising the current application, some participants who had at that point observed both designs (e.g. P19, 56, M and P30, 31, F) tried, perhaps unsurprisingly, the exact reverse of the gesture that they performed to minimise the application. This is logical, but it does not undo the action. This was the step in the

GEM where participants fared the worst: 30% of gestures being wrongly predicted. Over half of these occurred in the three multi-touch gestures (Interactions #6 to #8). However, some aspects that would require another literature review and a different approach to testing are reported in the 'future work' (see Chapter 9).

Feedforward can help: Interaction I8 (Minimising an application) particularly illustrated the value of feedforward. The gesture's animation showed a four-finger 'pinch' gesture resulting in the application closing, with its shrinking window moving towards the hidden taskbar at the bottom of the screen. The taskbar emerged to receive the falling application before disappearing again. This provided a feedforward for the presence of the bar and its role in returning to the application.

Ten comments illustrated this point concretely, including: "As opposed to what actually happens it shows it's still available somewhere" (P9, 26, M) and "I've never seen this before. I didn't know though that it goes to the task switcher" (P28, 43, F). At the end of interaction, (P29, 29, F) said: "For someone that doesn't use many applications this is really good!"

The animation technique used imposed some expectation from the participant's side with regard to the feedforward provided. For instance, participants noted when interactions were lacked feedforward. The main example was the limited feedforward for Interaction I5 (Flip pages). Participants demonstrated a clear anticipation of the effect of a gesture on the system status, evidenced by comments such as "There will be the next page and this will disappear" (P34, 32, F, on Interaction I6). The static bent corner to provide a visual affordance for page turning proved troubling for at least nine participants. When comparing the two designs, comments included: "I've seen the circle move but nothing happened to the page" (P2, 29, F) and "Bubble for the index finger appears on and is dragged to the middle of the screen but nothing really happens" (P3, 25, F).

Bias from mouse and desktop-metaphor interactions: Bias from the desktop metaphor is also highly influential over users' behaviours. Wobbrock et al. (2009), observed such phenomena in their study: sixty-two instances across three interactions demonstrated that participants try to apply gestures that are mouse-like one-point touches. In the reported study one participant (P11, F, 27) said: "I was expecting to find a cross up there", when asked to hide the menu he recently brought from the left bezel, and another (P34, 35, F) said: "See, this why I got rid of the smartphone. I'm looking for an equivalent to a left click on a mouse or a right click but I cannot find anything." This indicates expectation of common WIMP-GUI controls and lack of knowledge on how to close or hide on-screen objects such as a menu.

6.6 Discussion

The study compared two different designs for self-previewing gestures. It aimed to explore the design features that could show participants how to initiate touch and undertake gestures for a given touch interface. By knowing the gestures in advance through visual prompts, the participants would make fewer errors in executing the target gestures. The methodology of laboratory-based RTD for design was used to investigate these aspects (see Section 4.2.1).

In order to provide a framework for the discussion of previous work, we draw again from Wu et al.'s (2006) Registration-Continuation-Termination model for touch-surfaces (Section 2.4.4). Its characteristics include, for instance, the visual aspects of showing touch points for *registration,* or a path that should guide gesture *continuation*. As previously reported, this study focused on investigating which visual aspects of the *registration* of touch points over a screen could yield lower error rates for evaluation and execution of gestures. Neither the *continuation* nor the *termination* of a gesture were addressed in this study, in which case the visual conditions for all interactions were kept as a constant factor and not tested in different combinations.

Both designs were based on existing practice and the principles proposed and tested by earlier researchers. However, the problems users experienced during the study demonstrate that the state-of-the art, for both industry and academic research, is some way behind the ideal. While a direct comparison with previous research is not possible, because not exactly the same problems are addressed, it was anticipated that similar benefits would be seen for users when adopting similar strategies for a related problem. This section now turns to compare the performance of these designs against previous work by reporting on a subset of three papers, which share visual characteristics with both designs used in the study (Section 6.2).

The appearance of Bennet et al.'s Simpleflow (2011) influenced the visual properties of the 'Circles' design. In the reported study, 'Circles' used sharp-stroked dots to demonstrate the registration of the gesture, and participants executed 90% correct gestures after observing this design. Bennett et al.'s (2011) SimpleFlow technique used a black point as the starting point for drawing a representation of the gesture's touch on the screen. This appeared at the moment of registration, in response to a user initiating the gesture. The interaction then guided the user's continuation of the gesture. They investigated the efficiency of the SimpleFlow technique in comparison to a couple of non-predictive gesture entry interfaces. Bennett et al.'s technique enabled participants to perform partial gestures that were shorter than the complete gestures, while simultaneously improving the accuracy and speed of their gesture input. Guidance during continuation boosted user performance.

The 'Smudge' design yielded 81% correct executions. Taking Freeman's technique as an example, participants in their study made significantly fewer errors per trial on target selection task when using ShadowGuides. Wigdor et al. (2009) tested the success and user acceptance of a system named Ripples with a group of participants. Wigdor et al. hypothesised that the use of Ripples would reduce errors in selection of targets and hence improve accuracy. Overall, participants made significantly fewer errors per trial when using Ripples when compared to the control condition.

In Freeman's and Wigdor's studies we see error rates of around 20% for their suggested design and interaction techniques, and larger figures of up to 50% for basic implementations. Comparatively, this study overall error rate of 14% is therefore favourable, but even within that there are, of course, variations across specific micro-phases and interactions. Both studies again demonstrated that guidance reduced user errors during continuation.

Both 'Circles' and 'Smudge' adopted the approaches used to support user performance in *continuation* and also show advantages when used to assist *registration.* This study helped refine the approach that we would adopt in supporting registration, but further work, outlined in the next chapter, will put this hope to the test. Aside to the main thrust of this thesis, a few insights arose in the course of this chapter's research. The findings suggest that the 'Circles' design's visual properties particularly benefit multi-touch, dynamic gestures: sharp and precise visual contours aided users in assessing the number of touch points to correctly *register* a gesture. The ‘Smudge’ design visual metaphor, in contrast, gave a greater benefit to single-touch, static and touch-and-hold gestures over the screen, such as ‘touch and hold’ and ‘double tap’: the blurry design can suggest a depression under a finger applying pressure over a screen.

One issue, which is pertinent to gesture design in general is the question of undoing a command or gesture. Users typically try the reverse of the gesture that made a certain change in order to undo the action. Thus, the original gesture serves as a form of feedforward for the undo gesture, in the thinking of most users. This is natural, and it may well be that feedforward in this case provides a way for cautioning users that a different action is needed to undo the gesture that they have just completed. This issue is further explored in ‘future work’ (see Chapter 9).

6.7 Conclusions

This study aimed at providing initial evidence to address research questions ‘1’ and ‘3’. Thesis hypotheses (a) and (b) were not supported, for did not compare participants’ performance when evaluating and trying to execute gestures across different designs and interaction techniques. A preliminary version of the GEM (Section 6.3) and corresponding rating system were used. The results showed that specific micro-phases within the execution phase supported the hypothesis (c), by demonstrating significance across the model. The study also served to refine the model, and as will be reported in the next chapter, a few micro-phases were reordered or removed.

For unfamiliar gestures, it is unsurprising that affordances within the interface benefit the user. Feedforward particularly helps illustrate the effect of a gesture (as demonstrated by Bau and Mackay, 2008), whilst affordance in the form of visual cues easily communicates the number of touch points. However, for more complex gestures, a combination of feedforward and affordance may be beneficial for static gestures such as pinch, or dynamic gestures with an unusual pattern of movement or combination of fingers (see Wobbrock et al., 2009 and Lao et al., 2009).

The design of effective, easy to perform gestures that clearly communicate their effect to the user is challenging. There is a lack of a method to separate out the different factors that lead to the success or failure of particular affordances and cues to assist the user to identify potential actions. The GEM was found to help diagnose the origin of these problems, by localising the point in the user's perception and action at which difficulty emerges. The findings from this study - and the subsequent - informed two additional contributions from this thesis: the most common issues users have in executing gestural commands, and design recommendations and trade-offs for gestures and touch-interfaces. These are later reported in Chapter 8.

However, this study left two important aspects of SPG unexplored. The first being the components the SPG embeds were not tested in separate. For instance, the animated presentation of the gestural cues was not displayed in contrast to static ones. Gestures were not tested in isolation from their effects, in order to find out which is more important. Finally, automatic previewing gestures were not tested as opposed to ones triggered by the user, nor was the depiction of touch points tested against its absence. Thus, thesis hypotheses 'a' and 'b' need further supporting in a follow up study. Thesis hypothesis 'c' will be re-tested to re-validate the initial findings of the first study.

6.8 Summary

This chapter described the first empirical study. It aimed to explore the SPG concept, which embeds feedforward in animation form. The findings from this study corroborated the value feedforward has in demonstrating to participants gesture undertaking and its effect in an unfamiliar gestural system and provided initial support for thesis hypotheses 'a' and 'c'.

Furthermore, by partially answering the first research question, this study revealed which aspects in each design yielded fewer errors in prompting users about gestures and their effects. The rating system proved valuable in pinpointing where users struggle to comprehend and execute gestures; which in turn provided evidence to support a list of errors for gestural interactions.

CHAPTER 7 - ASSESSING THE EFFICIENCY OF SELF-PREVIEWING GESTURES IN TOUCH INTERFACES

7.1 Introduction

This chapter reports on the second and final empirical study. This study aimed at investigating the remaining research hypotheses that were left unexplored by the previous study. For instance, visual prompts that show depictions of touch points were not tested against visual prompts without touch points. Also a static visual prompt for gestures was not tested against an animated one.

The study addressed in this chapter has three goals. *First* it provides evidence to support thesis hypothesis (a), which states, 'Ensuring the registration points are clearly depicted in the user interface will improve gesture learning and reduce user error in executing gestures.' Taking the approach of laboratory-based RTD for design the initial designs were improved based on data from the previous study (see Section 4.2.1).

Second, this study seeks to support or reject the second research hypothesis (b), which states, 'Displaying automatic visual cues *before interaction* is a way to facilitate discovery of gestures and will reduce errors in execution.' This study is therefore primarily *summative:* it continues the work initiated in the previous study*,* by exploring different combinations of visual prompts and interaction techniques to introduce the SPG within the context of the interaction. Its aim is to explore the combinations that yield fewer error rates in the execution of gestures by participants. An 'oral structured interview' was used to elicit responses from participants (Section 4.6). The gesture-and-effect model (Section 5.3) and corresponding rating system provided the framework to conduct an interview and rate interactions.

Third, it fully supports thesis hypothesis (c), which states that 'a rating system that segments users' gestural interactions into smaller phases will help to reveal issues with users' evaluation and execution of gestures'. In this final study the rating system is refined by evaluating prototype designs in a within-subjects experiment design and explores even further the specific moments within assessment and physical executions that posed most difficulties for participants.

7.2 Designing the Visual Prompts

In this section we explain the design of the final SPG prototypes.

As with the design analysis undertaken in the previous study, key aspects of design are analysed through a selection of visual design concepts (see the works of Dondis, 1973; and Arnhein, 1974). This section again elaborates on the concepts of 'contrast', 'size', and 'pictorial aspects' from Dondis and Arnhein in constructing the designs. It also again draws on the design principles of 'textual support', and 'movement'. These issues are now addressed in turn, explaining how they were used in setting fundamental constraints for the final designs.

1. *'Contrast'*: Colour contrast was used to emphasise the difference between the visual prompts and the background interface. All visual prompts were kept monochromatic, so as not to interfere with any of the colours already present in application background.

In the previous study, one design markedly showed an advantage over the other as a result of higher contrast between foreground and background. The 'circles' design, with high contrast, had lower error rates than 'smudge' with low contrast. Circles used sharp stroke-lines to determine its boundaries, and given the success of this visual form in the first study, we kept this visual characteristic in the current study visual prompts.

2. *'Size'*: In the previous study, users did not appear to have problems with touch points being too small to identify. Neither did they over-interpret the touch points as depicting exact locations at which they had to touch.

As previously mentioned (Section 6.2), the Microsoft touch interactions guide (Windows Dev Center-b, 2014) and the Apple iOS (Human Interface Guidelines, 2014 were consulted to determine a 15 mm radius circle (approximately 56 pixels) as an adequate size to depict a touch point.

3. *'Pictorial aspects'*: All design elements used pictorial representations to depict touch points over the screen.

One of the designs for this study used a visual depiction of a hand, similar to the well-known pointer from existing desktop designs. In the previous study, the use of pictorial aspects was negligible. This initial approach aimed at designing visual cues that depicted physical touch over a screen and avoided the WIMP-GUI paradigm for icon metaphor (e.g. cursor, pointer, minimise, etc.). However, and precisely because the WIMP was the paradigm of interaction for the user for over thirty years, it was deemed necessary to explore the power of communication of desktop metaphors in combination with designs specially created to prompt gestural interactions. This approach could improve user experience and reduce error rates in touch and gesture software. Therefore, this aspect was explored in the second generation of designs.

Existing practice in the design of graphical user interfaces, particularly WIMP interfaces, has traditionally used an arrow pointer that represents the mouse. When the arrow hovers over an active - or 'clickable' - item the arrow typically changes to an iconic hand with a pointing finger. The familiarity of the iconic hand was expected to help participants identify the appropriate number of fingers needed to initiate a gesture, as it drew on a known symbol. A second design - similar to the design approach taken in the previous study - used a contrasting method with simple circular shapes to 'symbolise' touch points over the screen, and no iconic hand was provided. By providing contrasting approaches to depict gestures the aim was to identify which version would communicate the implied action more efficiently.

The previous study showed that participants had issues with both identifying and executing the direction of the gesture. The two designs had different error rates at the moment of execution. During execution, the 'Smudge' design yielded twice as many errors in the direction of the gesture than the 'Circles' design. The problems of both designs, but particularly 'Smudge', suggested that users would benefit from the addition of a cue that indicated the direction of motion. Therefore, directional arrows were embedded in both designs used in this new study to reduce uncertainty about the direction of movement needed by a gesture.

This decision is also supported by feedback from participants in the previous study. For instance, some comments exemplify the difficulties in identifying the direction to perform some gestures, such as "the second doesn't show the movement so well" (P7, 30, F) and "the small ones it didn't show push or swipe" (P18, 35, F). Freeman et al.'s

(2009) ShadowGuides, also used directional arrows to indicate direction of the gesture, which further justifies this decision. Freeman explains “Arrows are added to multi-finger gestures to help users visually parse the direction of the gesture, and to distinguish them from single-finger gestures”.

4. *‘Textual support’*: In the first study, the designs did not use any text. As a result of review on the published literature, textual labels were added for the second generation of designs, as was seen to be a likely means for improving the user experience.

Bau & Mackay’s (2008) OctoPocus, Freeman et al.’s (2009) Shadowguides, and Gutwin et al.’s (2014) FastTap (see Figure 55 in Section 6.2) techniques used textual labels in English in conjunction with iconic representations and visual completion paths to indicate either a required action (e.g. move) or the consequence of a gesture (e.g. open menu).

As a further support the theoretical validity of the decision to embed text in the visual prompts, Hartson (2003) describes affordances that make use of supporting text as ‘cognitive affordances’: “a design feature that supports, facilitates, or enables thinking and/or knowing about something”. For instance, a button with textual label to help users knowing what is going to happen if they click on it. Wensveen et al. (2004) describes the use of e.g. on-screen messages, and lexical or graphical labels as a form of ‘augmented feedforward’, which is “information from an additional source about the action possibilities of a product or system, or the purpose of these action possibilities”.

It was not certain, however, that adding text would always improve the ease of use of an interface. The previous study did not show any explicit evidence that a lack of text was a critical problem. Therefore, for the second generation, half of the designs embedded text labels, and half without. The results of the formal study would allow to test any advantage in the addition of text.

5. *‘Movement’*: The first generation of designs all used movement to communicate to the user. This appeared to be successful, but we did not provide any contrasting, static method.

As reported in the previous chapter (Section 6.2), many researchers recommend the use of animated events (Tversky, 2002; Kang, Plaisant and Shneiderman et al., 2004 and

Chow et al., 2011) to enhance the effects of an interaction. Additionally, software companies like Apple (Apple Developer, 2014), Microsoft (Windows Dev Center, 2014) and Google (Google Design, 2014) recommend the use of animations in their design guidelines pages. This approach was therefore adopted for both designs in the study.

As with text, we planned to test static versus animated depiction of actions in this second generation of designs. Results from formal study would, again, provide good evidence as to what is the most effective form of visual support for the user.

Next we continue by describing the visual designs and their specific characteristics, addressing the visual styling first, followed by the interaction design that underpinned the visual presentation. The user interface, including the prompts and visual content were designed in Adobe Photoshop and Illustrator CS5.

7.2.1 Two Visual Styles

In this new study, we deployed two visual designs for the gesture cues. These present contrasting approaches to communicating with the user, as has been reported above. The two designs are:

1. *'Iconic'*: The iconic version displays a pictorial representation of a hand touching the screen with the appropriate number of fingers to initiate registration of the gesture.

As reported earlier in this section, this design makes use of the *iconic* hand to indicate an interaction possibility, which has been traditionally used in computer systems for over thirty years. Also, as reported in 6.2, standard desktop metaphor makes use of iconic representation to evoke metaphors to understanding of actions and effects in computer systems (Gray, 1999; Marcus, 2002: 7).

Thus, in the context of the experiment, the *iconic* design mimics a user placing his hand over the screen. This provides a straightforward - and hopefully intuitive - mapping between the real world and the users' actions. Furthermore, this design drew from Freeman's (2009) Shadowguides, which also used an iconic representation of a hand and the required touch points. This was termed by the authors 'Registration Pose Guide' (Figure 80), and the authors observed positive results in using this technique in training participants on the available gestures.

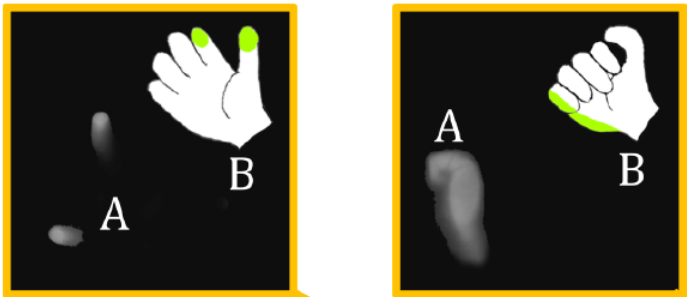


Figure 80: Freeman's Shadowguides: detail of iconic representation of a hand (Freeman et al. (2009).

In addition to using arrows to indicate the direction of movement, it also used *halos* beneath the fingers to indicate which fingers are touching the screen. This aims at supporting the correct 'registration' of touch points and therefore the proper initiation of a gesture. It is also consistent with the principle of 'textual support', by using text labels that indicate the action required (i.e. 'open') or the UI object to be triggered (i.e. 'menu').

A list of all the individual cues shown to the user in the context of the experiment is given below. The first icon (Table 32-a) was animated downwards to show the direction of the gesture. The second (b) prompt was animated from left to right and the last one (c) presented an animation similar to the movement of a clock to indicate a touch-and-hold gesture.

The pictorial representation of the clock (c) used in the background image is consistent with the one used in iOS interface, thus supposedly recognisable by users.

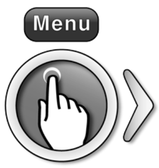
 a. Visual cue for two-finger touch and slide down gesture (Interaction 1, 165x270px)	 b. Visual cue for one-finger touch and slide to the right gesture (Interaction 2, 215x225px)	 c. Visualcue for one-finger touch and hold gesture (Interaction 3, 165x225px)

Table 32: Design 1 'Iconic' gestural affordances.

However there are potential reservations about this design. The principle of ‘size’ would suggest a larger cue is superior, but conversely beyond an unknown value, too large a size is detrimental to the user. Given that this cue includes several combined visual elements, using the 15mm radius for the touch points and then creating the rest of the cue from that constraint, would lead to an extremely large cue, which would obscure many parts of the interface when it appeared.

2. *‘Symbolic’*: The second design ‘Symbolic’ continues the design work initiated in the previous study with the ‘Circles’ design (Section 6.2).

It uses simple geometric forms to depict touch points over the screen. According to Tversky (2002: 248) “simple graphics with less detail are often more effective than realistic ones, provided that they abstract the essential conceptual information.” Table 33 shows the three visual solutions that demonstrate the number of touch points and required movement, which correspond to the previous actions already described.

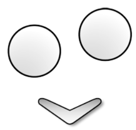
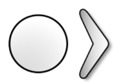
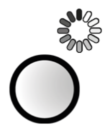
 a. Visual cue for two-finger touch and slide down gesture (Interaction 1, 200x195px)	 b. Visual cue for one-finger touch and slide to the right gesture (Interaction 2, 155x110px)	 c. Visual cue for one-finger touch and hold gesture (Interaction 3, 140x170px)

Table 33: Design 2 ‘Symbolic’ gestural affordances

Like the previous study, the touch points were designed in an uneven fashion to simulate the human touch over the screen. Noticeably, this design style does not use textual support. It is more *abstract* and provides a less direct visual metaphor, in favour of the design principle of ‘size’. In contrast with the previous design, by not using a diminutive hand it emphasises the metaphor of the number of touch points and their configuration over a computer screen. In addition, the symbolic design also aimed at being cross-cultural: no text labels were used. As with the iconic design, the symbolic design also used arrows to demonstrate direction. Note that in the case of the ‘visual cue for one-finger touch and hold gesture’ (Table 33-c) an additional countdown is used to indicate a timed gesture. It is animated clockwise to show passage of time and intended to inform participants the need to hold on the finger over the screen to execute the command.

7.2.2 Interaction Design

This section explains the criteria to select the three interactions used in the test sessions. As will be explained, the difficulties observed in the first empirical study were highly influential on the choice of interactions for the current study.

The previous study used common iOS gestures in familiar tasks sets to elicit from participants both recognition and learning of gestural interactions. Participants who were familiar with Apple systems recognised the interactions, which corroborated the effectiveness of the visual cues. Unlike the previous study, the current employed an unfamiliar gesture vocabulary in order to challenge both experts and novice users. The most important visual aid participants had to rely on to indicate an available gesture was the SPG, rather than previous knowledge. With this approach we aimed at further addressing the first and second issues described in Section 1.3: 'Users lack of awareness of how to initiate a touch gesture is influenced by the lack of supporting designs'; and the 'Lack of visual designs before interaction to communicate to the user the available multi-touch gestures and hidden user-interface menus and tools.' The third issue, 'We do not have a systematic understanding of which parts of identifying and performing gestures most contribute to the errors users make' is supported by thesis hypothesis 'c', and also reported in this chapter.

The interactions are reported in Table 34 and organised according to Freeman et al.'s 'taxonomy of multi-touch and whole-hand surface gestures' (2009), and the rationale to describe each column can be found in Section 6.2.2.

Int Type	Registration	Continuation	Movement	Restoration
1. Open application	2 fingers	2 finger swipe down	Path	1 finger swipe right-left/1 finger touch anywhere
2. Reveal menu	Single finger	1 finger swipe left-right (from bezel)	Path	1 finger drag and drop right-left/reveal menu and drag and drop right-left
3. Touch and hold a picture	Single finger	1 finger touch and hold	No path	1 finger touch anywhere else (on screen)

Table 34: Table describing the three interactions by 'registration', 'movement' and 'continuation' poses, according to Freeman et al.'s (2009) classification.

For each of the three interactions an image was presented on screen depicting the touch points required, the movement, and the type of action (such as a tap or pinch) together with an animation of the system's response to the gesture, before the user was asked to replicate the gesture. The system response was kept as a constant factor, meaning that the feedforward created was identical in both designs. For additional information, a complete description of animation times for gestures and effect can be seen in Appendix L and the initial sketches can be seen in Appendix M.

All interactions embed what Vermeulen (2012) describes as 'functional feedforward', which has the purpose of "making the functional parts visible" and as a result "allow users to determine the relationships between actions and results, between the controls and their effects and between the system state and what is visible by spatial coupling." Unlike the previous study, a novel visual solution was introduced to represent system response. The preview of the 'effect' of the gesture (or system response) consisted of a 'ghost' (a term used in this thesis to indicate a translucent clone of the object) that was animated along with the gestural affordance to preview the correct position for activation. Insights for the interaction techniques were drawn from Wigdor et al.'s (2009) Ripples technique (Section 4.4.1), Wigdor and Wixton's (2011) self-revealing gestures 'chrome' layer for MS Surface (Section 3.3.5), and Hofmmester's (2012) prototype work for Windows 8 touch (Section 3.3.5.2).

The interactions are described next. Note that the gesture depiction is shown in a magnified view at the bottom of each picture and the effect of the gesture in sequence of frames. Identical to the previous study, the screen size is 2048x1536px at 264 ppi (Apple iPad models, 2013) and the interactions are displayed over a fictitious booklet application.

1. *Open application*: In the prototype screen a multi-touch gesture opens an application - which is traditionally opened by a single tap. In the previous study we observed that the interactions that yielded most errors during execution were the multi-touch gestures. These interactions, precisely because they differ from WIMP-GUI 'single-click' interactions, seem to require additional affordances to further support user's learning.

The "open application" interaction proceeds as follows: The gestural affordance appears over the button (Figure 2a). The animation demonstrates the button moving down along with the gesture (b) and recoils back to its place. The user should move the button in the appropriate fashion to open the application (c).

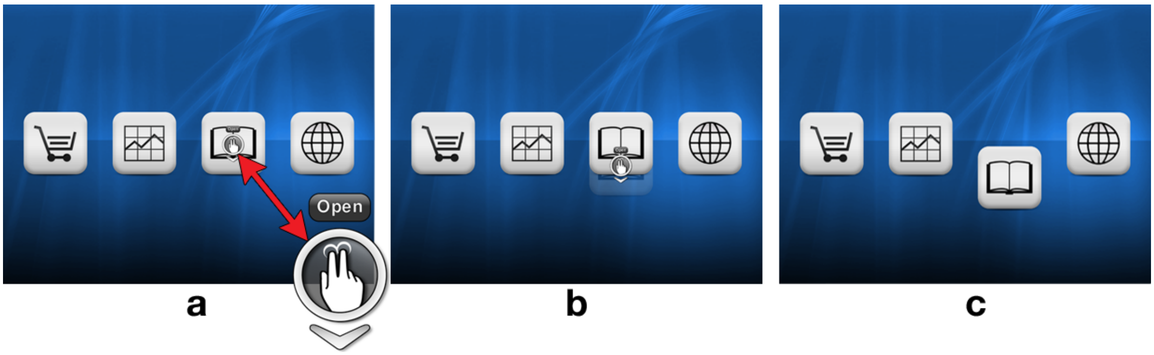


Figure 81: Interaction 1 ‘Open application’ with Design 1 ‘Iconic’.

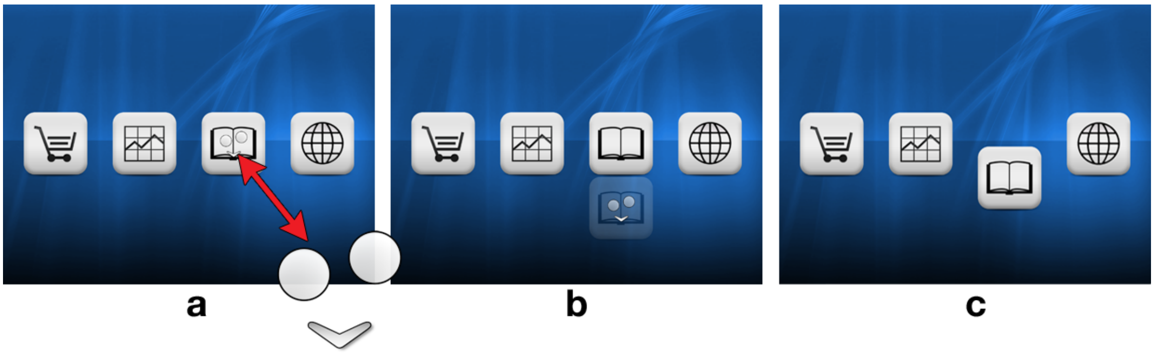


Figure 82: Interaction 1 ‘Open application’ with Design 2 ‘Symbolic’.

2. *Pull hidden menu:* In this case the gesture required the participant to swipe horizontally from an ‘invisible’ activation area to reveal a hidden menu. Neither the optimum touch range, nor the UI component is in sight. Despite the fact that this interaction did not yield large error rates in the previous study, the qualitative analysis demonstrated that this was occasionally difficult for participants to perform, and required further testing.

The interaction proceeds as follows: The gestural affordance appears on the left hand side of the screen (shown in zoom in Figure 4a). The animation demonstrates the menu moving sideways along with the gesture (b) and recoils back to its place. The user should swipe horizontally from the left bezel towards the centre of the screen to reveal the menu (c).

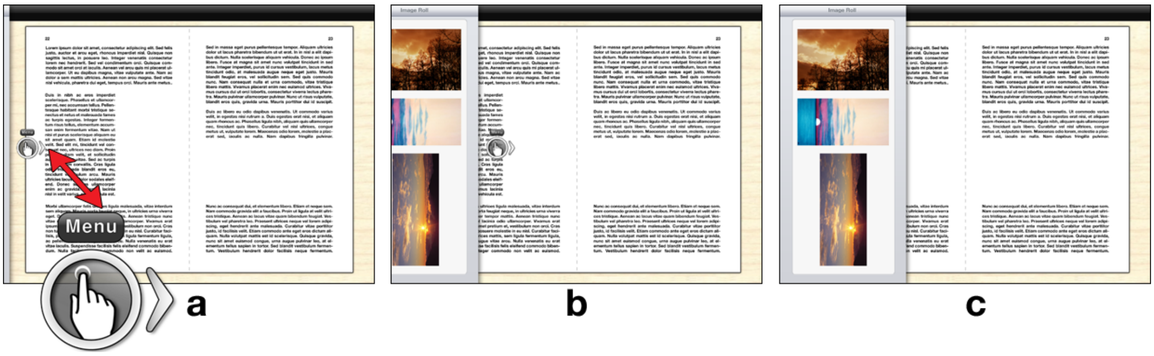


Figure 83: Interaction 2 'Pull hidden menu' with Design 1 'Iconic'.

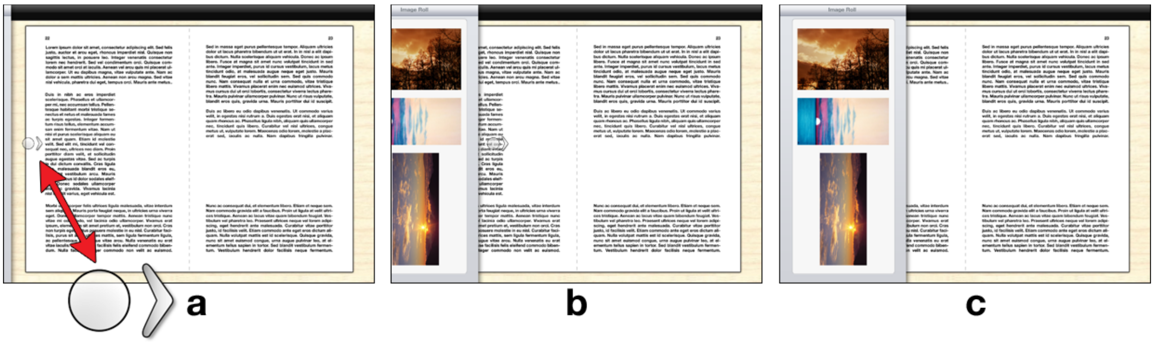


Figure 84: Interaction 2 'Pull hidden menu' with Design 2 'Symbolic'.

3. *Touch and hold a picture:* The current study added an additional difficulty: a touch-and-hold gesture. Norman and Nielsen (2010), Vermeulen et al. (2013) and Norman (2014) note that this type of gesture is particularly difficult for inexperienced users of gestural interfaces. Touch-and-hold interactions, despite becoming more popular over the years, are still unfamiliar to users (as the previous study demonstrated), as it yielded the most percentage of error rates when compared to other interactions. To avoid learning effects, we used the touch-and-hold gesture in a context that would be unfamiliar to most users.

The interaction is now described: The gestural affordance appears over the top picture (shown in zoom in Figure 6a). In the animation the top right corner demonstrates the picture is selected (b) before fading out (showed in zoom in Figure 6b). The user can select as many pictures as wanted and then drag and drop them over the booklet (c).

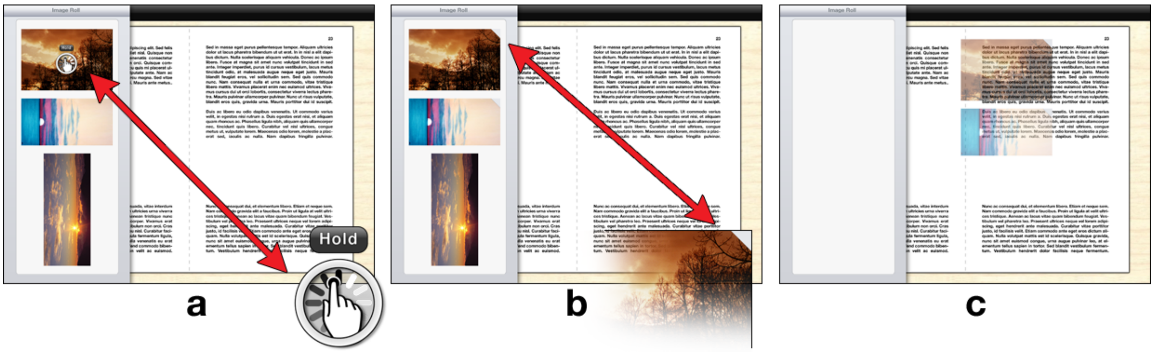


Figure 85: Interaction 3 ‘Touch and hold’ with Design 1 ‘Iconic’.

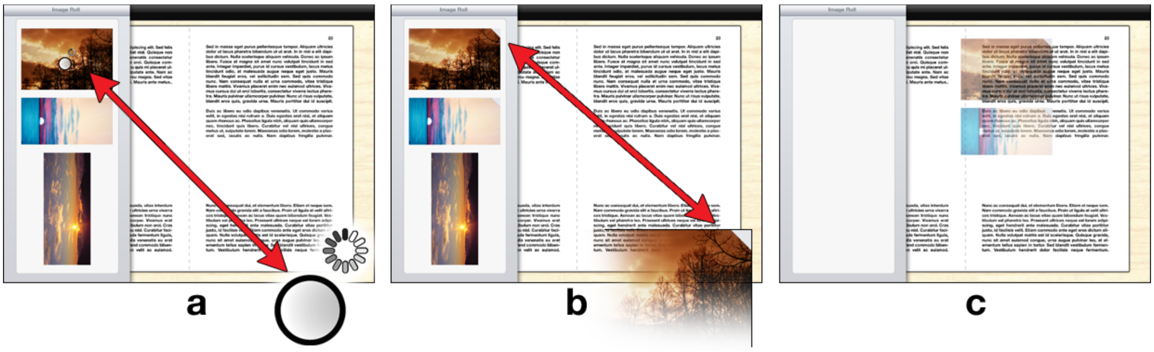


Figure 86: Interaction 3 ‘Touch and hold’ with Design 2 ‘Symbolic’.

This interaction required two steps to be completed. Therefore it was designed as a ‘sequential[9]’ affordance (Gaver, 1991:82, see Section 2.3.3.2) for the purpose of indicating that the picture ‘afforded’ selection as a response to a touch and hold interaction. This affordance took the shape of a small bent corner on the picture’s top right (b) and that corner would remain active after a successful interaction to indicate change of mode to ‘selected’ and available for dragging.

The next section describes a revised version of the GEM that was used to assess the SPG.

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[9] According to Gaver (1991: 82) *sequential* affordances are sequential in time (i.e., acting on an affordance leads to information indicating new affordances).

7.3 Revised Gesture-and-Effect Model

The gesture-and-effect model (GEM) required minor refinements to provide the conceptual basis for the study (Figure 87), as described in the following, starting with corrections that followed from the first study (Chapter 6).

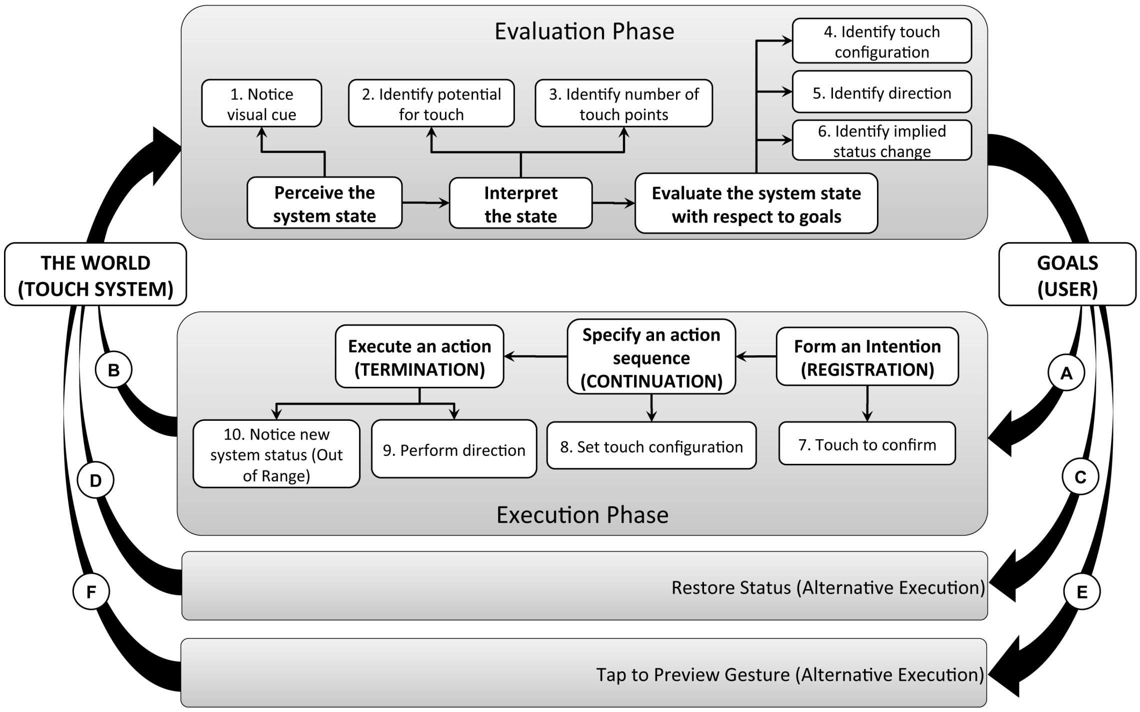


Figure 87: The gesture-and-effect model for touch interactions.

The initial study revealed that participants' responses to the questions corresponding to the micro-phases '3 – identify touch configuration' and '5 – identify type of gesture' in the evaluation phase were similar in meaning. The latter was deemed redundant and was therefore removed from the model.

In addition, the micro-phase 'identify number of touch points' was moved so it preceded 'identify touch configuration'. In the previous study, participants first described the number of fingers required to initiate a gesture, followed by the manner in which they should touch the screen. For instance, two fingers to perform a 'pinch' with index and thumb aligned.

The micro-phases are now described:

The evaluation phase consisted of the following micro-phases: (1) notice the visual cue, (2) identify potential for touch, (3) identify number of touch points, (4) identify touch configuration, (5) identify direction, and (6) identify implied status change.

The execution phase kept the same order as the model used in the previous study: (7) touch to confirm, (8) set touch configuration, (9) perform direction, and (10) notice new system status. Its flow is represented in the model by the arrowed pathway labelled ‘A’ and ‘B’.

The micro-phase ‘undo’ or ‘restore’ is represented in the model with the arrowed pathway labelled ‘C’ and ‘D’. It was tested in the previous study and yielded satisfactory results; therefore, it did not require further testing in this study. However, some aspects that would require another literature review and a different approach to testing are reported in the ‘future work’ section (see Chapter 9).

As can be seen in the model (see bottom portion), another interaction technique was included to represent an upcoming interaction technique in gestural interactions: the ‘tap-to-preview’, as it was termed in the present research (labels ‘E’ and ‘F’). The ‘just-in-time chrome’ technique introduced by Wigdor and Wixton (2011: 153) and Hofmeester’s (2012, Section 3.3.5 and 5.2.3) ‘teaching gesture’ for Windows 8 touch were highly influential in creating this variant within the GEM. Both techniques leave open the possibility of providing some indication of potential action, without the user having already embarked upon that specific gesture. The user simply taps on the screen (e.g. buttons, menus, pictures) to learn, through animated events, how to perform gestures.

The tap-to-preview interaction is depicted in the GEM as an ‘alternative execution’, which triggers a new *evaluation* of the available gesture. It requires a physical intervention from the user – therefore an *execution* – that allows the user to inspect the required command and its effect in a ‘preview’ mode. This technique does not configure a user’s *regular* execution of a target gesture and therefore does not yield an actual change in system status.

The next section describes the empirical study: the criteria for selection and recruitment of participants, materials utilised and the protocol to run the test.

7.4 Methodology

In this section the participants, materials, study design, and procedure to undertake the study are described.

7.4.1 Application Versions

As reported in Section 7.3, this study used revised and improved designs for the visual prompts. The designs are represented in application versions that display the prompts distinctly. This section explains the rationale for selecting the application versions that could answer the research questions and support the thesis hypotheses.

Motivated by the review of previous research in designing gestural interactions (Section 4.4.1), the first design consideration was how to trigger the appearance of the cue (the visual prompt) that informed the user of an available gesture (the interaction technique). One potential method follows Wigdor et al.'s (2011) 'self-revealing gestures' and Hofmeester's (2012) 'tap-to-preview' work, in which the user activates the appearance of the visual cue by tapping on the screen. This tap results in the display of the gesture cue for a few seconds before it disappears again. An alternative, which was created for this study, exploited the principle of feedforward. This interaction automatically displayed cues without user intervention (the self-previewing gesture). A further design consideration was that of animation: should cues contain an animated depiction of the gesture or a static image? Industry and research have used both approaches, without comparisons having been made. The final consideration was whether the cue should or should not explicitly depict the effect, where again practice and research are both inconsistent.

The design characteristics and interaction techniques reported above were candidates for the interaction design. These options are reflected in three different groups: *'design: visual prompts for gesture and effect', movement: static or animated,* and 'interaction technique: automatic and tap-to-preview', which are now explained:

1. Design: visual prompts for gestures and their effect. The prompt reveals the gesture movement only, the effect only, or both the gesture and the effect".

2. Movement Static or animated. The prompt is either animated or static. These properties are mutually exclusive.

3. Interaction technique: interaction to reveal the prompt. The visual prompt can either be automatic - plays without user intervention; tap-to-preview; appears at a user tap; both automatic and tap-to-preview - initially appears without user interaction, and recalled when a tap is detected.

The combination of these characteristics would create a nominal set of 18 different potential designs (3 x 2 x 3), as illustrated in Table 35.

Versions	Automatic	Tap	Static	Animated	Gesture	Effect
1	x		x		x	
2	**x**		x			x
3	**x**		x		x	x
4	x			x	x	
5	x			x		x
6	x			x	x	x
7		x	x		x	
8		x	x			x
9		x	x		x	x
10		x		x	x	
11		x		x		x
12		x		x	x	x
13	x	x	x		x	
14	x	x	x			x
15	x	x	x		x	x
16	x	x		x	x	
17	x	x		x		x
18	x	x		x	x	x

Table 35: All possible combinations for the features: automatic, tap, static, animated, gesture and effect.

However, a study with so many versions would be impracticable. A very large number of participants would be required, and even small errors in the experimental setup may lead to a failure to achieve any reliable result.

For a number of reasons, statisticians prefer samples of over 30 participants. For example, when a study has more than 30 participants, there is a mathematical effect that causes the distribution (of human behaviour) to converge towards a normal distribution (see Chebyshev’s weak law and Taylor strong expansion in Grinstead and Snell, 2006). The relative performance of users in the first study was known, and, while differences were low overall, performance in particular micro-phases was high (i.e. micro-phases 2, 6, 9 and 10; see Section 6.5.4). When undertaking a statistical test by micro-phases (as a factor), this means that moderate sample sizes (20 or more participants, for example) often produce statistically significant outcomes for larger variations, using the log-linear and other tests.

In the reported study we followed Bragdon et al. (2009) in the number of participants (Bragdon used 44), but took the nearest number that would permit a balanced set of conditions (45 = five versions and three interaction sequences), meaning we required a multiple of 15 participants. All participants used both designs in the study, so this factor did not influence the threefold base multiple used to randomise designs, interactions and application versions (see Section 7.4.4.1).

In addition, to corroborate the choice of number of application versions for a comparative study, previous work examined in Section was consulted 4.4. For instance, Bau and Mackay's Octopocus (2008), Freeman et al.'s Shadowguides (2009), Wigdor et al.'s Ripples (2009), Bennett et al.'s (2011) Simpleflow and Gutwin et al.'s (2014) FastTap compared two designs in their studies: an improved version with a baseline interface. Bragdon et al.'s GestureBar (2009) was the sole study that compared their improved version with three interfaces with baseline and improved baseline interaction techniques.

This research again took the example of Bragdon et al. (2009) by considering that a one versus one prototype comparison would not yield the contrast between designs and interactions required to answer the research questions. However, the present study required additional designs in combination with interaction techniques to support Hypotheses 'a' (the use of visual prompts to indicate how to initiate touch) and 'b' (to display these prompts before users touch the screen).

At a more detailed level, there is a specific hypothesis for this study that is an extension of thesis Hypothesis 'b'. If the SPG method is effective, then it is important to explore in more detail the different options for achieving its aims. The study-specific hypothesis (H1) claims that animated SPG cues will be more effective than static cues, and states that animated visual prompts will reduce error rates in gesture evaluation and execution when compared with static and baseline UI. The null hypothesis states otherwise: there will be no significant difference in error rates in execution between animated and static visual prompts.

Therefore, to contemplate the two thesis hypotheses and the one for the present study, it was deemed necessary to compare five versions that embedded the necessary characteristics. As will be reported in the next subsection, two versions correspond to the improved condition, and three correspond to industrial and research forms of baseline.

Table 36 shows the five application versions and their characteristics. The versions are a subset from Table 35, whereby the current V1 to V5 correspond to the previous V1, V6, V10, V11 and V18, respectively.

Versions	Automatic	Tap	Static	Animated	Gesture	Effect
1	x		x		x	
2	x			x	x	x
3		x		x	x	
4		x		x		x
5	x	x		x	x	x

Table 36: Five prototype versions across the features: automatic, tap, static, animated, gesture, and effect.

The next section explains the interaction characteristics of each application version.

7.4.1.1 Selected application versions

For the final study, five versions of the application interaction were prepared. These were evaluated in the study itself. In short, these five versions included:

- One industrial baseline, representing predominant industrial practice.
- Two research baselines, translating state-of-the art research designs for guiding the user during a gesture, into giving guidance before the gesture.
- Two initial designs for the self-previewing gesture interaction.

Thus, the systematic comparisons were made with two SPG designs (the improved condition) and three forms of baseline that matched mainstream practice and academic research.

Note that the inclusion of three forms of baseline is a cautious approach to research in producing reliable results. In case the study adopted a one-versus-one approach, there was a chance that the improved condition would supersede an industrial baseline by a large difference in errors, thus artificially boosting the results for the SPG.

Two research baselines (the gesture-completion path, see Section 4.4.1) were included in the systematic comparison with the SPG. The justification for this comparison lies in the fact that the gesture-completion technique is closely related to the new design technique (the thesis hypotheses). In addition, the low error rate observed in previous work that employed gesture-completion paths is data that can provide context to a comparison that is both plausible and reliable.

The choice of these interactions will now be explained on a case-by-case basis.

Version 1 (V1). *'Static gestures'*: Version 1 provides an industrial baseline, representing a common form of cue found in contemporary software on iOS, Android and other touch-screen operating systems. Mobile applications still rely on static – and inefficient – visual prompts that are either displayed only once at the application first run or in step-by-step tutorials, often ignored by users. The visual cue that depicts touch points on the screen only fades in and out for an appointed time.

Version 2 (V2). *'Animated gestures and effect'*: Versions 2 provides the SPG method. This version shows the number of touch points and the effect of the gesture (e.g. a hidden menu is shown) before the user touches the screen.

Version 3 (V3). *'Tap-to-preview animated gesture'*: Version 3 provides a research baseline, using an existing and proven method for guiding users during continuation. It displays the registration pose (the touch points over the screen) after a user starts touching the screen. This version drew from Freeman et al.'s Shadowguides technique (2009, see Section 7.2.1, Figure 80) and Hofmeester (2012). This feature was included because it was considered that participants could miss the automatic presentation of visual cues.

Version 4 (V4). *'Tap to reveal animated UI response'*: Version 4 provides an additional research baseline. It draws from the work of Bau and Mackay's Octopocus (2008, see Section 3.3.3, Figure 37), and Bennett et al.'s SimpleFlow (2011), which lack the visual prompts to start the gesture (Wu's registration) and shows only the effect of the gesture in the form of a 'gesture-completion path'. Note that this is shown in effect only to users touching and holding on target objects.

Version 5 (V5). *'Complete set'*: Version 5 is one of the representatives of SPG. It is the most complete set; by combining animation that 'self-previews' visual cues for gestures and their effect. It also includes the tap-to-preview feature. By including the latter, the aim was to determine whether this feature could improve gesture discoverability even further by allowing participants to *playback* the gesture and effect in case the automatic cue is missed.

7.4.2 Participants

As with the previous study, participants were recruited via leaflets placed across City University (Appendix N). Participants were sought from diverse backgrounds to ensure that the designs were assessed across a broad pool of users. Forty-five people were recruited to the study. They were referred to as "participant number, age, gender" (e.g. P1, 37, M) to ensure anonymity.

Forty-five participants were recruited (n=45). Twenty-seven participants were in the age range of 19 to 33, twelve from the age of 34 to 48 and six only from 49 to 64. Eighteen were male and twenty-seven female. Regarding desktop computer use, twenty-seven participants were users of Windows, fourteen of MacOS, whilst four did not report which OS they were most familiar with. In terms of smartphones, eighteen owned iPhones, seventeen Android devices, two Blackberry, seven had regular cell phones, whilst one did not specify a phone platform. For tablet devices, twenty-five participants were iPad users; four used other brands, whilst sixteen did not possess a tablet. Sixteen tablet users used their devices daily, ten reported using it 1-4 times/week, five participants noted using their tablet 1-3 times/month and four did not report their usage.

7.4.3 Materials

The study took place at the Interaction Lab, part of the Centre for HCI Design, School of Informatics, during the first trimester of 2014. Identical to the previous study, the test was set up with an iPad running iOS 7 attached to a metal stand for testing mobile devices. A MS camera with built-in microphone was positioned to record the screen and comments. This set provided a fixed position, which allowed participants to be recorded touching the screen. Only the participant and the facilitator (the researcher) were present in the room during the test.

The former study employed a Keynote slideshow software to simulate a touch and gestures application on an iPad (Section 6.4.2). The slideshow always showed the next scene when participants touched the screen, regardless they performing the correct or incorrect target gesture. Unlike the former study, a fully functional interactive prototype application was developed for the current study. The previous prototype, albeit visually realistic, did not deliver a fully functional experience. The interactions were therefore fully functional in the second study and would only be successful if participants executed all phases of a gesture properly.

The prototype application was developed by a third party on Linux and OS/X using Xcode, and ran on iOS 7 (which was then the current version of iOS). It was implemented in JavaScript. A complete description of the software application can be found on Appendix L.

7.4.4 Study Design

A within-subjects experiment design was used. The first set consisted of the five application versions (Section 7.4.1). The second set of independent variables (IV) was a 10x5 where the first set was the 10 micro-phases belonging to the GEM (Section 7.3), which includes 'tap-to-preview'. Similar to the previous study, the first micro-phase within 'evaluation' (Notice visual cue) was removed from the analysis (6.4.3). Quantitatively, 42 (94%, n=45) participants detected the visual prompt. Three participants only did not see the visual cue when the study session started and had to be prompted, but were considered able to continue the study. Thus, given the low error rate and the limited scale of errors, that might be due to a learning effect, and the risk of producing spuriously significant results from small sample sizes (of errors, in this case), this data was removed from the systematic analysis.

The dependent variables (DV) were the ratings for each of the ten micro-phases. Each micro-phase was rated in one of three levels: Correct, Partially Correct or Incorrect, corresponding to how accurately a participant described an evaluation micro-phase, or performed an execution micro-phase. The independent and dependent variables are listed below:

- IV '1': 5 application versions;
- IV '2': 5 micro-phases for evaluation (2 to 6), and 5 for execution (Tap-to-preview, and 7 to 10);
- DV: Correct, Partial, Incorrect rates for evaluation and execution.

7.4.4.1 Randomization set

The designs (2), interactions (3) and application versions (5) were randomised using a Latin square set (Cairns and Cox, 2008:7), yielding a total of 30 combinations. To verify the methodology and to check if the designs or versions required any further improvement, a pilot study was organised (n=4, 2F, 2M, age 26 to 43) with acquaintances from other departments within City University (excluding colleagues from the Centre for HCID).

As observed, participants did not produce relevant comments that suggested the need for any design alterations. Also, most participants managed to produce an adequate description of the SPG within the first 10 presentations, which indicates that showing all possible combinations throughout the test would be unnecessary and time-consuming. Therefore it was decided to display 20 combinations per sequence only and each participant was exposed four times to each of the five versions in a balanced fashion.

Finally, in order to avoid biasing results by showing the same sequence to all participants, we organised three different randomised sequences (a reference table can be found in Appendix Q). It was considered that 15 participants per set would provide a sufficient sample.

7.4.5 Procedure

The protocol used to run the study is described as follows:

1. Participants were asked to sign a consent form (Appendix O) and fill out a pre-test questionnaire (Appendix P) for profiling purposes. They were informed that they could withdraw from the study at any time without any penalty or disadvantage.

2. The facilitator explained that there was a camera focused on the iPad screen, which would capture their interactions with the screen and their comments. Participants were informed that the test would take approximately 15-20 minutes, that there were no right or wrong answers, and most importantly the system was being tested and not the participant.
3. The facilitator positioned the participant comfortably on a chair facing the iPad attached to the mobile stand and explained the context of the application. Participants were advised that although they were observing an iPad, they should disregard any previous knowledge of Apple iOS because such knowledge would be of no use in the current study. They were also asked not to use any physical buttons and informed that all interactions should be performed on the screen only.
4. Participants worked through one of the sequences, consisting of 20 combinations. For each combination, they were first asked to think-aloud about the visual cues. In case no visual cues were displayed by the application, the facilitator encouraged them to interact to find out what it was possible to do. Participants were asked to perform the interactions after describing each cue in the sequence. The facilitator allowed them to try for up to 3 minutes *per* interaction or until they gave up or failed.
5. If a participant performed an interaction successfully, the application would automatically go into a ‘pause mode’, whereby the screen would dim and only the facilitator’s single touch in a hidden spot at the bottom right corner of the screen would trigger the next interaction. The ‘pause’ mode was created to ready the participant for the next interaction and to give them time to finish reporting their thoughts about what was observed.
6. If the participant were unable to describe the interaction or execute the gesture properly, the facilitator would then perform a triple tap on the top right corner of the screen to load the next interaction. This was a gesture created for the facilitator’s discretion only. This was counted in the analysis as a participant failing to execute the interaction.
7. After the test was over, a summary screen was displayed with all successful and failed interactions (a print screen can be observed in Appendix R). This information was used only for the facilitator’s review of the ratings.

8. The facilitator finished the test by stopping the recording and rewarding the participant with a £5 Amazon voucher.

As with the previous study (Chapter 6), videos of the participant sessions were systematically reviewed in detail: verbalisations were transcribed, and the performance of evaluations and executions for each micro-phase were rated and recorded in a spreadsheet for analysis. The logs from the application were consulted, to further assess participants' success in each step of evaluation and execution.

Participants with 100% failure in assessment and performance of all interactions were deemed outliers and excluded from the final analysis. Participants 26 and 37 were both excluded from the final analysis as a result of this issue. Both were students, in their twenties and did not possess a laptop and a tablet. The excluding criteria considered that if a participant was unable to evaluate any of the visual prompts and also unable to execute even one of gestures, it was possible that they had significant problems in using touch interfaces in general. If so, this would lead to the confounding of problems with touch interfaces and the learning of specific gestures. Therefore there was the risk that including data from these users could both make the analysis more difficult and any outcomes less reliable. However their original 'id' represented by a number was kept to avoid any data mismatch and to maintain transparency in the handling of the original data.

Sample data is reported within the next section to highlight the quantitative and qualitative outcomes of the study (see Appendix T for coding scheme and Appendix U for detailed count).

7.5 Results

Next the quantitative evaluation of the participants' interactions with the different designs and versions is reported. This will use the rating system described in Section 4.7.3.

Identical to the previous study, the statistical tests were undertaken to assess the evaluation and execution phases separately (Section 4.8.2), starting with the Log-linear analysis. Initially, a Shapiro-wilk normal distribution test was conducted (see Appendix S) and the results indicated that the H0 could be rejected ($p<0.05$). This result demonstrates that the distribution of results followed a non-normal distribution. The difference between the designs was then calculated with a Mann-Whitney test, which is the non-parametric version of a *student's* 'T' test.

The assessment of the study begins with the evaluation phase and then moves on to an analysis of the participants' execution of the gestures. The term "assess" is used for judgements made in the course of the analysis. When the term "evaluation" is used, it refers specifically to the evaluation *phase* of user interaction.

7.5.1 Assessing the Evaluation Phase

Table 37 shows the basic descriptive data, giving sums for the rating system across both micro-phases and versions.

The 'IPC' stands for the rating system: 'C' stands for 'Correct', 'I' for 'Incorrect' and 'P for 'Partial' results. The top row shows the micro-phases within Evaluation. V1 to V5 stand for the versions. The overall sum for the evaluation phase was 81% correct, 10% partially correct and 9% failed to assess the visual prompts.

	2. Potential touch			**3. No. of touch points**			**4. Touch config**			**5. Direction**			**6. Effect on system status**		
Ver	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
V1	12	45	123	37	10	133	38	15	127	26	3	151	12	28	140
V2	3	30	147	22	5	153	18	7	155	6	2	172	7	25	148
V3	11	41	128	17	11	152	27	16	137	3	1	176	13	28	139
V4	11	45	124	25	8	147	38	8	134	3	2	175	11	30	139
V5	2	36	142	17	11	152	15	6	159	3	4	173	11	22	147
Tot	**39**	**197**	**664**	**118**	**45**	**737**	**136**	**52**	**712**	**41**	**12**	**847**	**54**	**133**	**713**

Table 37: Descriptive table for the evaluation phase: scores for the success of participant identification for each micro-phase (columns) and version (rows).

7.5.1.1 Log-Linear Analysis for Evaluation

To determine any reliable significant differences, and as a first step in the analysis, a global Log-linear analysis was conducted. The analysis of the scores used all three dimensions: a) the three ratings of user performance; b) micro-phases 2 to 6 of the model, and third, c) the five separate versions. Table 38 shows the result of the global test across all factors was statistically significant: $G^2=514.4$, df=64, $p<0.001$. Therefore, at least one factor provided a significant effect.

	G2	df	P
ABC	514.4	64	<0.0001
AB	397.6	8	<0.0001
AC	64.06	8	<0.0001
BC	0	16	1
AB [C]	450.34	40	<0.0001
AC [B]	116.8	40	<0.0001
BC [A]	52.74	48	0.2959

Table 38: Log-linear analysis for the evaluation phase.

Following the global test, pairs of factors were tested in turn (e.g. versions against success rates), without performing counter-balancing for the third factor. In these cases, no significant result for 'B' (micro-phases) was observed when compared to 'C' (versions): G^2=0, df=16, p=1, however significant results were observed in the pairs 'A' (ratings) versus 'B' (micro-phases): G^2=397.6, df=8, p<0.001 and 'A' (ratings) versus 'C' (versions): G^2=64.06, df=8, p<0.001. At this point in the analysis, the interpretation of the statistics is that while the versions do not independently interact with the phases (ignoring outcomes), they did interact with each other through the outcomes of user evaluation.

The third and final step examined the same pairs of interactions while counter-balancing for the effects isolated for the factors in the second phase. In this final set of three tests, the first pairs of factors, 'A' (ratings) versus 'B' (micro-phases) excluding 'C' (versions) yielded significant results: G^2= 450.34, df=40, p<0.001; and 'A' (ratings) against 'C' (versions) excluding 'B' (micro-phases) did also prove significant: G^2=116.8, df=40, p<0.001. The last pair, 'B' (micro-phases) versus 'C' (versions), excluding 'A' (ratings) did not prove significant (G^2=52.74, df=48, p=0.2992). With no significant effect even with a detailed analysis, this pair can be discarded.

From these results, it is possible to confidently assert that ratings vary between the versions and also between the micro-phases. However, further tests are required of individual pair-wise comparisons of user behaviours in the evaluation phase to isolate the specific effects that are significant.

Given the positive outcome of the log-linear test above, it is safe to proceed to analysing the different pairwise tests of factors (e.g. phases versus version, which will be considered first).

7.5.1.2 Significance for micro-phases within Evaluation

The first step to make sure that all results related to versions did not occur by chance was to run a Chi-square (χ^2) independency test for each micro-phase within evaluation. Table 39 shows the ratings *per* versions and *per* micro-phases within evaluation.

The table shows that in four micro-phases the differences between versions are significant: '2. Identify potential touch' χ^2 = 19.982, p<0.05 (df=8, N=900); '3. Identify touch points' χ^2= 16.288, p<0.05 (df=8, N= 900); '4. Identify touch configuration' χ^2= 31.154, p<0.001 (df=8, N=900); and '5. Identify direction' χ^2 = 53.846, p<0.001 (df=8, N=900). Only '6. Identify system status' did not produce a significant result χ^2 = 3.969, p = 0.860 (df=8, N=900).

	2. Potential touch			**3. No. of touch points**			**4. Touch config**			**5. Direction**			**6. Effect on system status**		
	I	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**
Vers	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
V1	6.7	25.0	68.3	21	6	74	21	8	71	14	2	84	7	16	78
V2	1.7	16.7	81.7	12	3	85	10	4	86	3	1	96	4	14	82
V3	6.1	22.8	71.1	9	6	84	15	9	76	2	1	98	7	16	77
V4	6.1	25.0	68.9	14	4	82	21	4	74	2	1	97	6	17	77
V5	1.1	20.0	78.9	9	6	84	8	3	88	2	2	96	6	12	82
Tot	**4.3**	**21.9**	**73.8**	**13.1**	**5.0**	**81.9**	**15.1**	**5.8**	**79.1**	**4.6**	**1.3**	**94.1**	**6.0**	**14.8**	**79.2**

χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
19.98	8	.01	16.28	8	.04	31.15	8	.0	53.84	8	.0	3.969	8	.86

Table 39: Percentage scores and Chi-square of participant for each micro-phase of evaluation phase, by micro-phase (columns) and version (rows).

7.5.2 Assessing the Execution Phase

Table 40 shows all sums for the rating system per micro-phases and versions. The 'IPC' stands for the rating system: 'C' stands for 'Correct', 'I' for 'Incorrect' and 'P for 'Partial' results. The top row shows the micro-phases within Execution. V1 to V5 stand for the versions. Participants executed correctly 80% of gestures, with 2% partials and 18% incorrect. While the execution phase mirrored the correct evaluations, the execution phase showed five times more partial results and two times more incorrect predictions compared to evaluation.

	T. Tap-to-preview			**7. Touch to confirm**			**8. Perform swipe**			**9. Perform direction**			**10. System status**	
Vers	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**P**	**C**	**I**	**C**
V1	NA	NA	NA	31	11	138	37	12	131	27	0	153	43	137
V2	NA	NA	NA	19	2	159	18	9	153	6	0	174	29	151
V3	93	3	84	12	0	168	26	13	141	4	1	175	35	145
V4	112	3	65	15	5	160	33	9	138	7	0	173	43	137
V5	113	1	66	17	9	154	10	9	161	2	1	177	24	156
Tot	**318**	**7**	**215**	**94**	**27**	**779**	**124**	**52**	**724**	**46**	**2**	**852**	**174**	**726**

Table 40: Descriptive table for the execution phase: scores per micro-phase (columns) and versions (rows).

7.5.2.1 Log-Linear Analysis

Following the same procedure used to assess the evaluation phase, a global Log-linear analysis was also conducted to verify significance between the independent and dependent variables for the execution phase.

The analysis used three dimensions: a) the three ratings of user performance; b) second, micro-phases 'T' to 10 of the model, and third, c) the five separate versions. Table 41 shows the result of the global test across all factors was statistically significant: G^2=1364.26, df=64, p<0.001.

	G2	**df**	**P**
ABC	1364.26	64	<0.0001
AB	724.88	8	<0.0001
AC	63.2	8	<0.0001
BC	503.94	16	<0.0001
AB [C]	797.12	40	<0.0001
AC [B]	135.44	40	<0.0001
BC [A]	576.18	48	<0.0001

Table 41: Log-linear analysis for the execution phase.

In contrast to the evaluation phase, in which no significant results were observed for 'B' (micro-phases) when compared to 'C' (versions), and 'B' (micro-phases) versus 'C' (versions), excluding 'A' (ratings), all factors (ABC) within execution enabled a significant effect (p<0.001). This led to the confident conclusion that the versions vary in their success rates across the different micro-phases.

Given the outcome of the log-linear test above, it is safe to proceed to analysing the different pairwise tests of factors.

7.5.2.2 Significance for micro-phases within Execution

As for evaluation, an independent Chi-square (χ^2) test was run for each micro-phase within execution. Table 42 shows the percentage of 'Incorrect', 'Partial' and 'Correct' ratings *per* versions and micro-phases.

Note that Versions 1 and 2 did not embed micro-phase 'tap-to-preview', therefore the χ^2 was undertaken for the versions that incorporated this feature (V3, to V5) and produced a non-significant result (χ^2=5.663, df=2, p = 0.59). Micro-phase '7. Touch to confirm' (χ^2= 30.289, df=8, p<0.05), '8. Set touch configuration' (χ^2= 24.940, df=8, p<0.05) and '9. Perform direction', yielded significant results (χ^2= 49.924, df=8, p<0.001).

	T. Tap-to-preview			7. Touch to confirm			8. Set touch configuration			9. Perform direction			10. System status	
	I	P	C	I	P	C	I	P	C	I	P	C	I	C
Ver	%	%	%	%	%	%	%	%	%	%	%	%	%	%
V1	NA	NA	NA	17.2	6.1	76.7	20.6	6.7	72.8	15.0	0.0	85.0	23.9	76.1
V2	NA	NA	NA	10.6	1.1	88.3	10.0	5.0	85.0	3.3	0.0	96.7	16.1	83.9
V3	51.7	1.7	46.7	6.7	0.0	93.3	14.4	7.2	78.3	2.2	0.6	97.2	19.4	80.6
V4	62.2	1.7	36.1	8.3	2.8	88.9	18.3	5.0	76.7	3.9	0.0	96.1	23.9	76.1
V5	62.8	0.6	36.7	9.4	5.0	85.6	5.6	5.0	89.4	1.1	0.6	98.3	13.3	86.7
Tot	**58.9**	**1.3**	**39.8**	**10.4**	**3.0**	**86.6**	**13.8**	**5.8**	**80.4**	**5.1**	**0.2**	**94.7**	**19.3**	**80.7**

χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
5.663	2	.59	30.289	8	0.001	24.940	8	0.002	49.924	8	0.001

Table 42: Percentage scores and Chi-square for each micro-phase (columns) across versions (rows) of the execution phase.

Finally, it is safe to claim that by finding statistical significance for the micro-phases within evaluation and execution, thesis hypothesis 'c' can be supported. This hypothesis states that the rating system will provide significant results across the evaluation and execution phases. This is further addressed in Section 7.5.7.

7.5.3 Assessing Designs and Interactions

The following is an initial analysis of the outcomes in light of the motivating research questions.

The first two research questions focus on visual properties of the interface and how effectively they convey potential interactions to the user. The error rates for both designs across the three interactions will reveal the relative effectiveness of the different approaches.

In this first step the error rates are compared separately for the two visual designs across the phases of evaluation and execution. Table 43 shows the relative performance of the ‘Iconic’ versus ‘Symbolic’ designs used in this study. The advantage of the 'Iconic' design over 'Symbolic' is statistically significant for both phases.

	Evaluation			
Rating	**Iconic**		**Symbolic**	
	N	**%**	**N**	**%**
Incorrect	17	3.8%	37	8.2%
Partial	52	11.6%	81	18%
Correct	381	84.7%	332	73.8%
p value	0.01			
	Execution			
Rating	**Iconic**		**Symbolic**	
	N	**%**	**N**	**%**
Incorrect	76	16.9%	98	21.8%
Correct	374	83.1%	352	78.2%
p value	0.01			

Table 43: Chi-square for designs 1 and 2.

Secondly, the designs are compared in the context of the three different interactions that the users had to perform during the study. Taking the average error rate for each combination, both evaluation and execution phases are considered.

Table 44 shows the ratings from a simple average between evaluation and execution phases, across interactions and designs. The top row shows the two designs. The ‘IPC’ letters stand for the rating system: ‘C’ for ‘Correct’, ‘I’ for ‘Incorrect’ and ‘P for ‘Partial’ results. I1 to I3 stand for the interactions.

	D1 Iconic			**D2 Symbolic**		
	I	**P**	**C**	**I**	**P**	**C**
I1	18%	8%	74%	18%	5%	76%
I2	8%	2%	91%	7%	1%	93%
I3	8%	9%	82%	16%	16%	68%

Table 44: Success rates per Designs x Interactions.

As seen in Table 44, Interaction 1 (Two finger swipe down the button) yielded the most error rates across the two designs, when compared to the other two interactions, with 18% incorrect responses (χ^2=6.733, df=2, p<0.05). Interaction 3 followed (Touch and hold the picture) with 12% and Interaction 2 (Pull hidden menu) with 7%. Note that 18% error rate is similar to values around 20% errors described in previous work (Freeman et al., 2009; Wigdor et al., 2009, and Section 6.6).

Contrasting the two designs, ‘Iconic’ yielded an 8% error rate for Interaction 2 (Pull hidden menu), and ‘Symbolic’ 7%. Unsurprisingly, this small variation is not significant (χ^2=4.765, df=2, p>0.05). Interaction 2 also showed no substantial contrast between the two visual designs. For Interaction 3 (Touch and hold the picture), differences emerge. 'Iconic' had only an 8% error rate, but 'Symbolic' suffered 16% (χ^2=71.018, df=2, p<0.05).

Participants thus had most problems with Interaction 1 and the ‘Symbolic’ design performed poorly in communicating the touch-and-hold gesture.

7.5.4 Assessing Micro-phases

Research question 3 (Section 1.4) asks ‘Which parts of gestural interactions are users failing to assess and execute? Common errors were observed in the registration of number of fingers and in the direction of the continuation. While specific errors had not been hypothesised or anticipated, the patterns of error shed light on the underlying research question and their analysis extracts deeper knowledge about what errors are made to support contribution ‘3’ from this thesis (Section 1.6).

Table 45 shows the ratings (Incorrect, Correct and Partial) per micro-phase within evaluation. In this analysis we disregard the influence designs or application versions can have over the micro-phases and demonstrate the overall results.

	I	P	C
2. Potential touch	4.3%	21.9%	73.8%
3. No. of touch points	13.1%	5.0%	81.9%
4. Touch config	15.1%	5.8%	79.1%
5. Direction	4.6%	1.3%	94.1%
6. Effect on system status	6.0%	14.8%	79.2%

Table 45: Ratings per micro-phases within evaluation.

We tested for differences between the phases. The results were significant for all micro-phases, with micro-phase '2' (χ^2 = 704.087, df = 2, p<0.001), '3' (χ^2 = 963.727, df = 2, p<0.001), '4' (χ^2 = 860.480, df = 2, p<0.001), '5' (χ^2 = 1497.447, df = 2, p<0.001), and '6' (χ^2 = 863.247, df = 2, p<0.001). Phases thus suffer different gross rates of error. The data is presented visually in Figure 88.

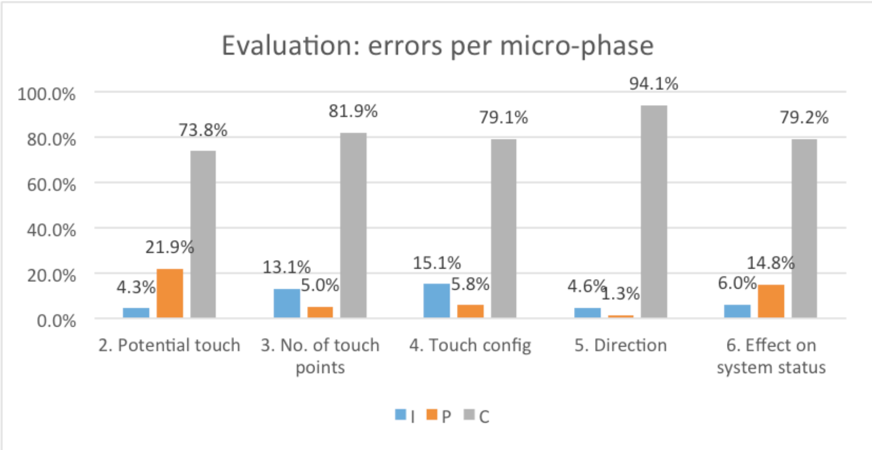


Figure 88: Chart with ratings per micro-phases within evaluation.

User performance between micro-phases within the execution phase is shown in Table 46 and Figure 89. All micro-phases showed significant results: 'T' (χ^2 = 278.878, df = 2, p<0.001), '7' (χ^2 = 1154.687, df = 2, p<0.001), '8' (χ^2 = 907.520, df = 2, p<0.001), and '9' (χ^2 = 1526.747, df = 2, p<0.001). Tap-to-preview showed the highest error rate, and direction the lowest.

	I	P	C
T. Tap-to-preview	58.9%	1.3%	39.8%
7. Touch to confirm	10.4%	3.0%	86.6%
8. Touch configuration	13.8%	5.8%	80.4%
9. Perform direction	5.1%	.2%	94.7%

Table 46: Ratings per micro-phases within execution.

Figure 88 shows that micro-phases 'T. Tap-to-preview', '8. Touch configuration', and '7. Touch to confirm', produced the larger error rates across the board, with 59%, 14% and 10% respectively. By contrast, micro-phases '9. Perform direction' and '7. Touch to confirm' had the lowest, with 5.1% and 10.4% respectively.

Within the standard micro-phases (7-9) one can safely conclude that participants had more problems identifying the touch configuration (8). In general, the results for the execution phase mirrored the evaluation phase; however, tap-to-preview produced the most error rates, exceeding any of the standard micro-phases.

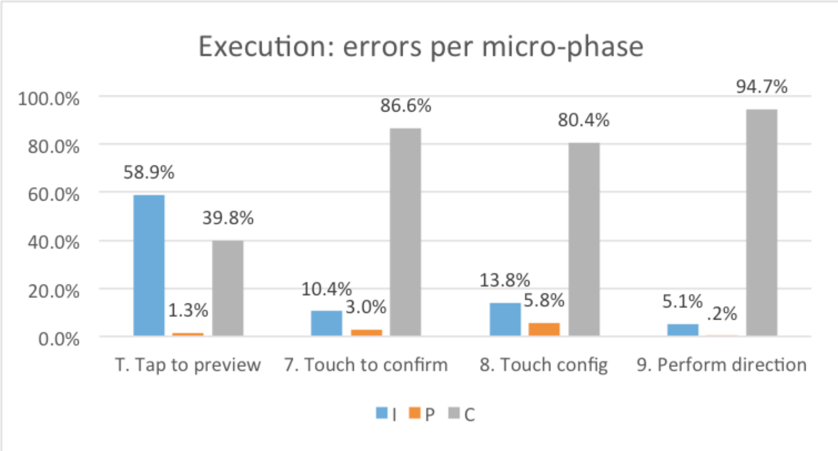


Figure 89: Chart with ratings per micro-phases within execution.

Now that the initial analysis on results for both evaluation and execution was finished, it is safe to proceed to review specific data to support the thesis hypotheses. Each hypothesis will be assessed separately, as the next sections will show; and qualitative data will be provided to give further insight into the statistical findings.

7.5.5 Thesis Hypothesis 'a'

The first hypothesis claims that 'Ensuring the registration points are clearly depicted in the user interface will improve gesture learning and reduce user error in executing gestures'. The null hypothesis in contrast claims that 'Visual depictions of touch points will not improve learning or execution of gestures'.

To either support or reject the null hypothesis, it was necessary to compare Version 4, which does not visually depict touch points, against all other versions that did (V1, V2, V3 and V5). Version 4 is typical of established research in gestural interactions, for example 'gesture-completion paths', where there is no direct support for users to identify available – and hidden – interactions. There is no representation of touch points to initiate gestures, only the touch path or movement (Section 7.4.1).

As can be seen in Table 39, Version 5 had the most correct evaluations for micro-phase '4. Identify touch configuration', with 89.4%, χ^2= 31.154, p<0.001 (8, N= 900) and '5. Identify perform direction', with 98.3%, χ^2= 53.846, p<0.001 (8, N= 900). The results also show that Version 5 had the most correct evaluations for micro-phase ‘4. Identify touch configuration' (88%). Version 4 and 1 had the lowest correct responses to micro-phases ‘2. Identify potential touch' (6.7% and 6.1% respectively), ‘3. Identify touch points' (21% and 14% respectively), and ‘4. Identify touch configuration'. (21% for both). Micro-phase '6' was different and did not show significant results (χ^2=3.969, df = 8, p= 0.860).

This section now examines if there are marked differences in micro-phase results between versions. As can be observed in Table 42, Version 4 had the second most number of errors in execution, in micro-phase ‘8. Touch configuration' (18%) and ‘9. Perform direction' (4%). Micro-phase ‘10. System status’, is treated separately as the result was simply true or false – there was no option for ‘Partially correct’ (for all results see Appendix S). This micro-phase is critical as it is the final determination of whether a participant succeeded or failed in executing a given gesture. Table 47 shows the results of a Kruskal-Wallis used to analyse versions across this micro-phase, which yielded a significant difference (H=2.551, df = 895, p<0.05).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.582	4	0.396	2.551	0.038
Intercept	585.640	1	585.640	3776.886	0.000
Version	1.582	4	0.396	2.551	0.038
Error	138.778	895	0.155		
Total	726.000	900			
Corrected Total	140.360	899			

Table 47: Mean square for micro-phase ‘system status’ across all versions.

In order to assess the difference between versions within system status, each version was tested for the likelihood of correct and incorrect executions. In this final analysis the general performance for all versions, across evaluation and execution was 81%.

There was a statistically significant difference in performance between all versions (χ^2=10.145, df = 4, p< 0.05), which demonstrates that in all posterior analysis the results are statistically significant (p<0.05). Table 48 shows that Version 5 had the most correct executions across the board (87%), while Versions 1 and 4 showed the lowest (76%).

		System status	
		Incorrect	**Correct**
V1	**N**	43	137
	Expected	34.8	145.2
	%	23.9%	76.1%
V2	**N**	29	151
	Expected	34.8	145.2
	%	16.1%	83.9%
V3	**N**	35	145
	Expected	34.8	145.2
	%	19.4%	80.6%
V4	**N**	43	137
	Expected	34.8	145.2
	%	23.9%	76.1%
V5	**N**	24	156
	Expected	34.8	145.2
	%	13.3%	86.7%
χ^2=10.145, df = 4, p<0.05			

Table 48: Expected and actual executions for versions - 'system status'.

Now that we have verified significance across micro-phases and application versions, it is safe to proceed to support or reject the hypothesis: by comparing the versions that show visual depictions of touch points (V1, 2, 3 and 5) versus the unique one that does not (V4). Figure 90 shows the descriptive (N) and expected values for correct and incorrect responses within system status for the groups being compared. Version 4 had larger incorrect executions (24%) when compared to the grouped versions that show visual touch (V1-V2-V3-V5), with 18%. Therefore, as reported above, this difference is statistically significant (p<0.05).

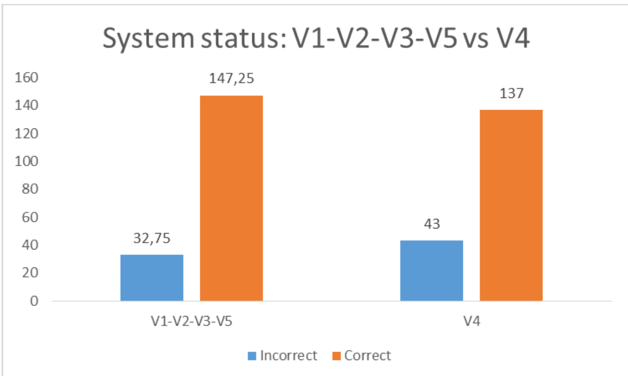


Figure 90: Comparison of Versions 1-2-3-5 versus V4 in system status.

7.5.5.1 Qualitative analysis for thesis hypothesis 'a'

In this section the emerging themes from the qualitative coding are described, which corroborate the current hypothesis.

Visual depiction of touch points inform how to initiate gestures: Indeed as with the quantitative results above, favourable comments are predominantly found in Versions 2 and 5 (together containing over two thirds of these positive comments). For instance, the following comment made by a participant when coming across Interaction 3 exemplifies this: “It was fairly intuitive, took a couple of goes and then I notice there was a countdown, it needs to recognise my finger over the image…yeah it seems quite clever” (P28, M, 34), and “It appears to be loading. You hold on to the picture and drag it” (P41, F, 55).

Clear evidence was observed that the visual cue supported the user's identification of an unfamiliar gesture. For instance, Interaction 1 required the participants to use an unfamiliar two-finger gesture to achieve what is otherwise a commonplace interaction (with one finger). Even faced with a challenge to both unlearn an existing association and learn a new association, the versions could help participants successfully make a difficult leap: “...but thanks to the interactive description otherwise I wouldn't really try to use 2 fingers” (P2, M, 30); “To activate it I have to do what the hand is doing” (P29, M, 48); and “It's actually easy looking the way you're doing it better than reading the instruction. If you want to show someone things it's better to show someone a picture or video…I know I have to put two fingers and move it down” (P32, F, 27).

By contrast, Version 4, which did not display gestural affordances, only the effect of the action, yielded high error rates for evaluation and execution. This was clearly observed in Interaction 1 and Interaction 2, in which six participants complained about the lack of visual cues for gesture or touch points. As an example: “Similar to the one before but with no dots…still unclear” (P40, M, 42); “I'd try to see if the sign comes back” (P46, M, 54); “Doesn't seem to have much point in that. Doesn't tell you anything” (P34, F, 35); and "This time I got the same symbol but without the fingers circles” (P46, M, 54).

7.5.5.2 Summary of thesis hypothesis ‘a’

In summarising this hypothesis, the evidence is supportive, by demonstrating significance across the model. The versions that show a visual depiction for the gesture (Versions 5 and 2) have the lowest error rates. These outperformed the version that does not show a visual depiction (V4). The qualitative evidence further demonstrates the benefits of providing visual depictions to users.

7.5.6 Thesis Hypothesis 'b'

This hypothesis claims that 'Displaying automatic visual cues *before interaction* is a way to facilitate discovery of gestures and will reduce errors in execution'. The null hypothesis claims that automatic events will not improve discovery or execution of gestures and results will be similar to 'tap-to-preview' technique.

In order to support or reject the hypothesis, the versions that self-preview show visual depictions of touch points were compared (V1, V2, and V5) versus V3, which is 'tap-to-preview'. Version 4 was removed from the analysis because it does not provide visual depiction for touch.

Next, a simple mean was drawn from the execution rates (see Table 10) and a larger success rate for Versions 1, 2 and 5 (82.23%) was observed when compared to Version 3 (80.6%). Similar results were observed when analysing micro-phases within execution in detail. For instance, micro-phase '7' Touch to confirm (χ^2=30.289, df = 8, p<0.001), '8' Touch configuration (χ^2 = 24.940, df = 8, p<0.05), and '9' Perform direction (χ^2 = 49.924, df = 8, p<0.001). In fact, all versions that displayed automatic SPG yielded lower error rates for those micro-phases.

Although the comparison between versions was significant, the individual χ^2 showed that the observed (N) result was the same as the 'expected' (35 in face of 34.8) for incorrect executions for Version 3 (see Table 48). This situation was reversed for Version 5, for which the expected value was 34.8 and the observed was 24 for incorrect executions. Therefore this version was more efficient in overall correct executions.

The following analysis is based on a comparison of the grouped versions 1-2-5 with version 3. The absolute values of correct and incorrect responses within system status were drawn together for comparison (Figure 91).

Noticeably, the versions that self-preview the visual touch slightly outperform the versions that require touch interaction: The self-preview group (V1-V2-V5) had fewer incorrect executions when compared to Version 3, which only affords 'tap-to-preview', with 18% and 19.4% respectively.

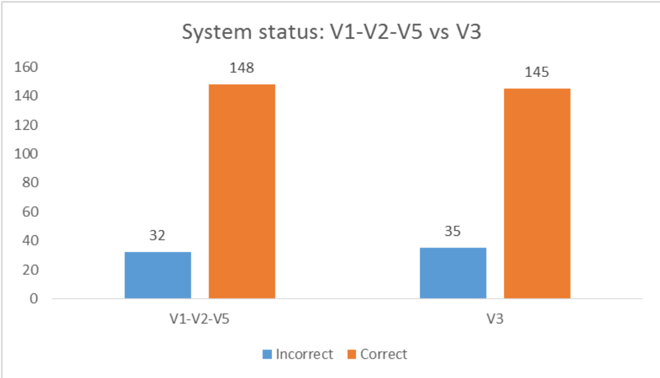


Figure 91: Comparison of Versions 1-2-5 versus V3 in system status.

The hypothesis aimed to provide a detailed examination over micro-phases. The analysis demonstrated significant results for three of them. However, in the final analysis of system status, there was no statistical significance between the grouped versions (V1-V2-V5) and Version 3, so the null hypothesis could not be rejected. Given the small difference in measurements (Figure 91) it appears there was no effect.

7.5.6.1 Qualitative analysis for thesis hypothesis 'b'

Thesis hypothesis 'b' claims that automatic prompts are more efficient than interface solutions that are 'tap-to-preview'. This section reports on the themes that emerged from the qualitative analysis and selected comments support the hypothesis.

Automatic visual prompts help in evaluation and execution of gestures: A few comments show participants' reactions to automatic events, followed by correct descriptions of the implied actions of a given visual prompt. Comments include: "This came up before I touch it this time. The corner thing again. Maybe it says it is selected, no?" (P36, F, 24); and "Something showed and disappeared...two circles...maybe zoom perhaps? Ah, that was two dots, guess had to bring down" (P43, F, 35).

Fourteen participants who learned this feature complained when it was not available, suggesting the formation of an expectation within a short time of experiencing this behaviour. Comments included: "How about now that nothing shows up?" (P42, F, 56); "Will these buttons will just sit there until I tried something?" (P34, F, 35); and "Not getting anything" (P46, M, 54).

Surprise with automatic visual prompts: Five participants expressed surprise in the event of affordances being displayed automatically without any interaction from their side Comments include: “It did that because I tapped or would come anyway?” (P36, F, 24); “I didn't touch that” (P39, F, 56); “Will this always appear in the program?” (P43, F, 35); and "But I haven't done anything! Feels like it was doing something I didn't ask for” (P43, F, 35). Even though automatic events contradict Shneiderman’s (2010) seventh rule for good interface design (Support internal locus of control), this experiment showed benefit in introducing such a feature when error rates from automatic and responsive interface were compared.

Tap-to-preview gestures are discovered by accident but can help learning gestures: Having established the contribution of automatic – and self-previewing – gestures, one increasingly common design approach for communicating gestures (such as found in Hofmeester, 2012) is the use of a ‘tap-to-preview’ technique to show participants how to interact. Nevertheless, users are unfamiliar with this feature and the lack of affordances to indicate its presence makes this interaction only marginally visible. Thirty-four participants discovered it by accident and used the feature at least once to replay the gestural affordance, in order to remind them of the cue, to reassess the cue, or to make it visible when it had at first been overlooked. Fourteen participants expressed dissatisfaction when tap-to-preview was unavailable, which the following comments exemplify: “I don't know how to make the instruction appear again” (P47, F, 26); “I'd like to see that again, if possible” (P40, M, 42); “I wanna see it again…” (P9, F, 39); and “How do I present what I saw before?” (P39, F, 56).

7.5.6.2 Summary of thesis hypothesis ‘b’

No statistically reliable difference was found between the versions that show gestures automatically (V1, V2 and V5) and those that do not (V3), therefore the null hypothesis could not be rejected. This is seen in the very similar error rates achieved at the end of the interaction - in both cases over 80% of participants completed the gesture successfully.

However, there is some suggestive data from the observed behaviour of participants, who discovered tap-to-preview and used it to play the gesture preview. 34 out of 45 participants independently discovered the technique. These participants then used the feature at least once to replay the gestural affordance, in order to remind them of the cue, to reassess the cue, or to make it visible when it had at first been overlooked.

To further answer the research question it was determined that a follow-up study was required. This is later addressed in future work (Section 9.2).

7.5.7 Thesis Hypothesis ‘c’

Hypothesis ‘c’ claims that ‘a rating system that segments users' gestural interactions into smaller phases will help to reveal issues with users' evaluation and execution of gestures’. The null hypothesis states otherwise that ‘statistical analysis will show no significant differences between evaluation and execution of gestures, or between phases.’

Statistical significance was already observed across micro-phases within evaluation and execution (see Sections7.5.1.2 and 7.5.2.2). This already supports the current hypothesis. However, this hypothesis also applies to each micro-phase individually: in total 10 evaluation and execution phases were considered. The null hypothesis cannot be rejected for micro-phases ‘6. Effect on system status’ (χ^2=3.969, df = 8, 0.860) and ‘T. Tap-to-preview’ (χ^2=5.663, df = 2, p = 0.59), because they did not show significant differences.

As whole, these several different pieces of evidence lead to the safe conclusion that, not only did the versions differ, but also they did not differ in the same way or degree in different micro-phases. Those micro-phase differences between versions are themselves statistically significant. This result suggests that the use of the model to create a rating system does provide a different perspective to the gross aggregate data, hence it is safe to affirm that its underpinning rating criteria explored finer detail, which is not explained by random variance.

A couple of additional findings that emerged from the analysis support the current hypothesis. In this case, the proportion of success and failure between the evaluation and execution phases had the added distinction of the ‘Partial’ rating in addition to simply ‘success’ or ‘failure’ (Section 4.8.1). Note that a ‘Partial’ outcome indicates that a user was eventually successful, but after a number of errors in initially assessing the visual cues. Ideally, a good design will have not only low error rates, but also low rates of 'partial' success, as this demonstrates that users would have to make many attempts to eventually succeed.

To assess how the five different versions fared across the board in relation to 'Partial' rates, 'Observed' (Obs.) and 'Expected' (Exp.) results were drawn for both evaluation (Table 49) and execution (Table 50). The 'observed' values are the real data; and the 'expected' values are equally distributed to each version - thus reflecting the null hypothesis that differences are randomly discovered in different conditions. The bottom row shows the average results for all versions - this demonstrates that the proportions expected are valid (as the numbers match). Each micro-phase has different levels of expected partial successes, as it is known that each has different levels of partial success. Not considering this would render the test invalid. However, we do not balance for each version, as the variation of each version from the average level is what is being tested.

	2. Potential touch		3. No. of touch points		4. Touch config		5. Direction		6. Effect		Total	Total
Vers.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
V1	45	39.4	10	9	15	10.4	3	2.4	28	26.6	20.2	17.56
V2	30	39.4	5	9	7	10.4	2	2.4	25	26.6	13.8	17.56
V3	41	39.4	11	9	16	10.4	1	2.4	28	26.6	19.4	17.56
V4	45	39.4	8	9	8	10.4	2	2.4	30	26.6	18.6	17.56
V5	36	39.4	11	9	6	10.4	4	2.4	22	26.6	15.8	17.56
Aver.	**39.4**	**39.4**	**9**	**9**	**10.4**	**10.4**	**2.4**	**2.4**	**26.6**	**26.6**	**17.56**	**17.56**

Table 49: Expected and Observed results for the evaluation phase.

	T. Tap-to-preview		7. Touch to confirm		8. Set touch config		9. Perform direction		Total	Total
Vers.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
V1	NA	NA	11	5.4	12	10.4	0	4	7.67	6.60
V2	NA	NA	2	5.4	9	10.4	0	4	3.67	6.60
V3	3	2.3	0	5.4	13	10.4	1	4	4.25	5.53
V4	3	2.3	5	5.4	9	10.4	0	4	4.25	5.53
V5	1	2.3	9	5.4	9	10.4	1	4	5.00	5.53
Aver.	**2.3**	**2.3**	**5.4**	**5.4**	**10.4**	**10.4**	**0.4**	**4**	**4.63**	**5.53**

Table 50: Expected and Observed results for the execution phase.

Next, Figure 92 shows the total 'Observed' values from each version are compared across the phases of evaluation and execution. In each case, the number of attempts to execute a gesture was fewer than the number of attempted evaluations.

For instance, in Version 1 a mean 'Partial' was observed for twenty evaluations versus seven executions (20/7). Participant attempts at execution were a third of their attempts to evaluate the visual prompts. The same rate was observed for Versions 2 and 5. Versions 3 and 4 showed a more marked difference with a fifth of the number of execution attempts compared to evaluation attempts (19/4).

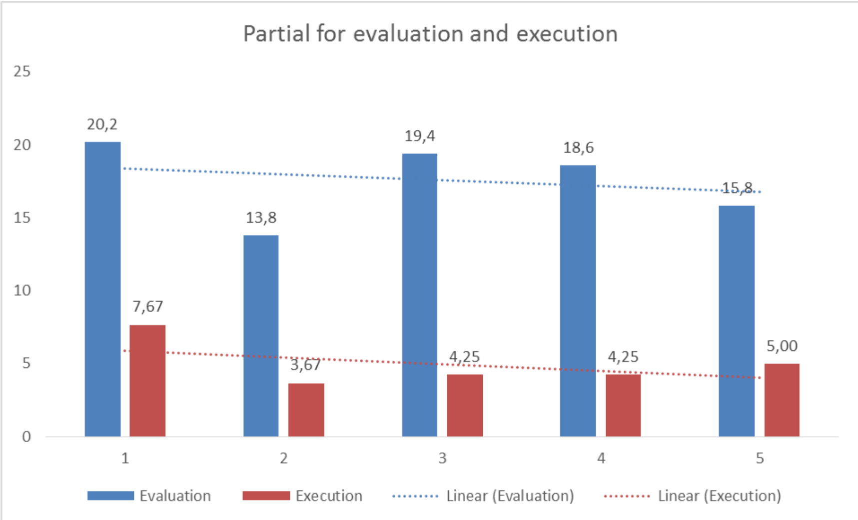


Figure 92: Comparison of Observed 'Partial' results for evaluation and execution phases.

In terms of the total number of attempts, Versions 2 and 5 required fewer evaluations than the other versions. Taking the overall picture for all versions, participants executed a quarter of the number of executions compared to evaluation.

7.5.7.1 Summary of thesis hypothesis 'c'

The three-way rating criteria revealed statistically significant differences between micro-phases, therefore supporting the hypothesis. The model thus helps reveal contrasting strengths and weaknesses in different designs and application versions. The results are a clear indication of research *through* design *for* design, by contributing with new knowledge to the field of gestural interactions. An additional analysis of 'Partial' rates shows that participants executed a quarter of the number of executions compared to evaluation.

7.5.8 Study Hypothesis '1'

The study hypothesis claims that 'Animated visual prompts will reduce error rates in gesture evaluation and execution when compared to static and baseline UI'. The null hypothesis states that ‘There will be no significant difference in error rates in execution between *animated and static* visual prompts’.

To either support or reject the null hypothesis, it was necessary to compare Version 1, which is not animated, against all the other versions that did embed the feature. Table 3 shows that Version 1 had the most error rates in the evaluation phase, with 6.7% in micro-phase ‘2’ (χ^2 =19.98, $p<0.05$), 21% in micro-phases ‘3’ and ‘4’ (χ^2=16.28, $p<0.05$; χ2=31.154, $p<0.001$), 14% in micro-phase ‘5’ (χ^2=53.84, $p<0.001$), and 7% in micro-phase ‘6’ (system status). Versions show distinct differences by micro-phase, with the exception of micro-phase ‘6’ ($p>0.05$). Version 5 had the highest success rates across the board, with only 8% errors in micro-phase ‘4’ and 2% in micro-phase ‘5. Identify direction’.

For execution, Table 42 shows that Version 1 mirrored the results from the evaluation phase, with the most error rates for all micro-phases. For instance, 17.2% incorrect executions occurred in micro-phase ‘7’ (χ^2=30.28, df = 8, $p<0.001$), almost three times more than Version 3 (6.7%). Version 1 also showed 20.6% incorrect responses for micro-phase ‘8’ (χ^2=24.940, df = 8, $p<0.05$), four times higher than Version 5 (5.6%). For micro-phase ‘9. Perform direction’ (χ^2=49.92, df = 8, $p<0.001$), which is essential for the correct execution of the gesture, Version 1, which lacks animation, performed the worst with 15% errors. This is fifteen times more than Version 5 (with 1.1%) and almost eight times more than Version 3 (3.3%). It is therefore clear that Version 1, which shows baseline industry practice, performs markedly lower compared to the alternatives.

In the last phase within execution, system status, only a correct, or incorrect outcome was considered. In this case a logarithmic binary regression is recommended to assess the results. The dependent variable was therefore the ‘system status’, while the versions were included as independent variables, or predictors, which will determine the variation within results. In simple terms, this regression serves mainly to make direct comparisons between the categorical predictors rather than to estimate how the independent variables influence the dependent one.

In addition, we opted to set Version 1 as the baseline, due to it being static and the most conservative design. Table 51 shows that results for regression were statistically significant, having as predictors the five different versions (χ^2=0.341, df=4, p = 0.35) and R^2 with 0.018.

All versions, when compared to Version 1, have an increased chance of a correct execution. However, results were not significant for Versions 2, 3 and 4 when compared to Version 1. Version 5 did yield significant results (p <0.05), and participants subjected to this version have an odds ratio of a 2.05 times higher probability to perform correctly (β Logit= 0.713) when compared to Version 1.

Version	Compared to	B	S.E.	Wald	df	Sig.	Exp(B)
V2	**V1**	0.491	0.268	3.367	1	0.067	1.634
V3	**V1**	0.263	0.257	1.045	1	0.307	1.300
V4	**V1**	0.000	0.247	0.000	1	1.000	1.000
V5	**V1**	0.713	0.280	6.466	1	0.011	2.040
	Constant	1.159	0.175	43.946	1	0.000	3.186

Table 51: Logistic binary regression for all versions.

In final analysis, we yet again draw results from Table 48, which compares the expected and actual executions for micro-phase 'system status' across all versions. By comparing the weighed means from both groups, it is possible to see in Figure 93, that the static version (V1) had larger incorrect executions when compared to the animated group (V2-V3-V4-V5), with 24% and 19% respectively.

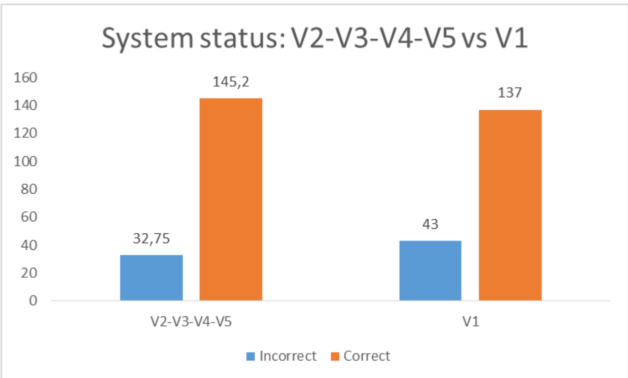


Figure 93: Comparison of Versions 2-3-4-5 versus V1 in system status.

7.5.8.1 Qualitative analysis for study hypothesis '1'

In this section the emerging themes from the qualitative coding are described, which corroborate the current hypothesis.

The lack of animation compromises gesture learning: Participants' comments indicate that the static version (V1) only weakly supported a sense of direction: "Will these buttons will just sit there until I tried something?" (P34, F, 35); and "Ah the arrow and circles? An instruction telling me to do something? But if there was an instruction I don't think I'd get it" (P22, M, 24). By contrast, the following comment referring to Version 4 shows how animated versions can inform an action more efficiently: "Now I saw it. Now I saw it coming down. The previous should have moved as well, better when it moves down" (P43, F, 35).

However, Version 1 still provides a basic self-preview, which was found to be helpful by participants, as the following comment exemplifies: "It's quite nice icon actually, very indicative just by looking at it" (P17, F, 33). Therefore even rudimentary visual cues can be helpful. Hence, all the versions could provide some helpful insight to the participants, but self-previewing and animation appear from the qualitative comments to further support the acquisition of new gestures. This realisation matches the pattern of findings from the quantitative data.

7.5.8.2 Summary of study hypothesis '1'

Overall, participants made more mistakes in both evaluation and execution when using the static version. That version was consistently inferior in all micro-phases, whereas the animated Versions 5 and 2 yielded lower error rates. The analysis revealed statistical significance in specific micro-phases within evaluation and execution and the comparison between versions 1 and 5 in system status was statistically significant. Participants' subjective feedback drew a similar picture to the quantitative data. While even a static design helps communicate an unfamiliar gesture to users, animation appears to be superior in effectiveness. The results are a clear indication of laboratory RTD for design, by contributing with new knowledge to the field of gestural interactions.

7.5.9 Additional Qualitative Findings

The qualitative analysis and post-study questionnaire explored a number of points for which previous experience shaped – helpfully and unhelpfully – user expectations and interpretations of gestures and their behaviour. These themes did not fit any of the previous hypotheses, but were considered highly relevant to the thesis and therefore are described as follows. These findings are also clear evidence of the value of laboratory RTD for design, where creative design enables results beyond formal hypotheses.

SPG and making sense of cues: A total of 66 comments demonstrate that the SPG was one source of helpful information in acquiring a new gesture. For example, Participant 7 (Male, 28) said: “The graphic told me how to do it.” This was in response to Version 5, the most comprehensive implementation of the SPG. However, the interpretation of the visual prompts was not without problems. Participants had some issues in micro-phase ‘2. Identify potential touch' and a few comments illustrate this: “Ah the arrow and circles? An instruction telling me to do something? But if there was an instruction I don't think I'd get it” (P22, M, 24); “Something like a smiley face appeared on the book” (P1, M, 34); and “Something popped up with the book...but to be honest I didn't concentrate on it, maybe is to click here first, to find out what it is” (P23, F, 19).

Textual support: Seven comments exemplify that text labels, when used in parallel to the visual depictions of gestures, reinforce users’ understanding of registration and gesture performance. For instance: “I'd press the icon like that expecting some text to appear” (P29, M, 48); “Need to use two fingers to open the little icon. It said in the little animation the little *open*” (P36, F, 24); “This time it said 'hold', that's easier” (P4, F, 23); “Ah, that's better. Much easier when you have a little command as well as the image” (P34, F, 35). A participant complained when prompts lacked text support, as the following comment shows: “But wasn't written 'hold' beforehand” (P40, M, 42).

Next, the issue of ‘expectation’ is addressed from the users’ side in regards to user interface behaviour. It is a well-known rule within HCI that users will typically re-apply previously learned rules when interacting with new systems. Two different aspects of the impact of learnt behaviour will be addressed: Expectations of basic gestures and expectations of mouse and desktop-metaphor interactions.

Expectations of basic gestures: One recurring theme was that participants’ comments and behaviours revealed a bias in that they first attempted known and familiar gestures on the interface. Most of these attempts were of single-finger gestures, especially tapping the screen. Some also included two-finger gestures, such as pinch and rotation that participants may have used themselves or perhaps seen via media or in observing others use touch-based systems. This tendency to attempt basic, familiar gestures occurred even when the affordances had been displayed as self-previewing gestures.

Twenty-eight participants tried basic single touch interaction to activate buttons. Some expressed a bias against multi-finger gestures: “I find a bit irritating, don't see the purpose of using 2 fingers to drag it down” (P46, M, 54); “I don't know what that function means...instinctively I feel like just pushing that button but nothing happens” (P1, M, 34). However, the constraints of touch-based interaction do mean that different gestures – multi-finger or different swipes or actions – are necessary in touch-based interfaces to provide varied actions in different parts of the screen. Despite visual cues to indicate the role of a multi-finger gesture for a particular behaviour, the learning bias to the familiar single finger actions prevailed in some instances. Practically though, designers cannot always provide the full range of actions with single-finger gestures alone.

Six participants accidentally managed to activate the picture (Interaction 3) with pinch gestures, for example (P15, F, 43), (P45, M, 24), (P39, F, 56). This included four novices and two experienced users, while four experienced users rotated the pictures. An example comment is: “I'd like to rotate them” (P6, M, 25).

Thus, some actions appear to be known even to inexperienced users, but for both experienced and inexperienced users, commonplace actions were being used to guess what might be performed. Swipe was the most frequently attempted gesture, while the pinch and rotation actions were less common. This might follow the relative experience of users, especially considering the bias towards single-finger gestures: users were naturally inclined to experiment with the familiar.

Bias from mouse and desktop-metaphor interactions: It is natural to expect a strong influence from the dominant WIMP and GUI metaphors on user behaviour. Unsurprisingly, therefore, there were a number of comments and expressions from participants that reflected this bias. Many participants appeared to be seeking some features that they had encountered previously on desktop systems. When they were unable to discover these, they expressed their frustration at not being able to find or interact with the system through familiar methods, such as right-click mouse actions or the 'settings' menu commonly found in a desktop OS. Wobbrock et al. (2009) also discovered in an experiment that about 72% of gestures were mouse-like, one-point touches or paths.

Thirty-one participants felt obstructed by not being able to drag pictures on the screen as they would in mouse drag-and-drop interactions, commenting for example “Well, it doesn't come” (P42, F, 56). The participants (P10, M, 33), (P19, F, 34), (P30, F, 27) and (P40, M, 42) tried the gesture several times until an error. Other comments included: “See, this why I got rid of the smartphone. I'm looking for an equivalent to a left click on a mouse or a right click but I cannot find anything…I wouldn't know how, would look for the settings somewhere” (P34, F, 35); “Generally I don't like the iPad interface” (P39, F, 56); and “I have a MacOSX laptop and the finger pad I use two fingers” (P1, M, 34). This was also observed in Interaction 1 'Open app with 2 fingers' with the following comments made: “Will these buttons will just sit there until I tried something?” (P34, F, 35); and “It's unclear to me” (P40, M, 42).

It was observed in Interaction 3 (Touch and Hold to select picture) that fifteen participants wrongly tried to select pictures by double tapping them. This action resembles the familiar mouse double click to select items commonly found in desktop OS systems. For instance, “Will these buttons will just sit there until I tried something?” and during the execution phase (P34, F, 35), (P23, F, 19), (P29, M, 48), (P17, F, 33) and (P22, M, 24) attempted double clicks. Also in Interaction 3, twelve participants wrongly tried to select the target picture drop area (empty slots within the text pages) and then the picture itself. This action resembles interactions commonly found in desktop OS systems and in this case resulted in participants not being able to perform the interaction. Comments included: “Still tempted to drag these pictures across, simply because there is a gap in there” (P46, M, 54) and “Maybe I could touch it here first?” (P24, F, 26).

7.6 Discussion

This section now turns to compare the performance of these designs against previous work.

Existing industrial practice and academic research in gestural interfaces were drawn on to create the designs. This discussion focuses on the selection of six key papers (Section

4.4.1). Although the problems addressed were not the same, they were nonetheless related. So while direct comparisons cannot be made, similar strategies were adopted with the hope of arriving at similar benefits for users.

In order to provide a framework for this discussion of previous work, we draw again from Wu et al.'s (2006) Registration-Continuation-Termination model for touch-surfaces (Section 2.4.4). A subset of three papers is reviewed for sharing visual characteristics with one of the designs and two application versions used (Section 7.2). These characteristics relate, for instance, to the visual aspects of showing touch points for *registration,* or a path that should guide gesture *continuation*.

The first of Wu's three phases is *registration*. In registration, the comparison with previous work focuses on the Shadowguides technique by Freeman et al. (2009). Shadowguides uses an iconic representation of a hand that shows the required touch points (Section 7.3). This in principle guides the user where to place each finger to initiate the gesture. In Freeman's approach the visual prompts are displayed in a training window separated from the main view. Their aim was to reinforce learning in the context of (explicitly) training users on a gesture. In their experiment, Freeman et al. compared Shadowguides against an instructional video. The use of Shadowguides resulted in a significantly lower level of errors in execution. Shadowguides also helped participants memorise more unfamiliar gestures than the video instructions.

The study also compared two designs, 'Iconic' and 'Symbolic'. The 'Iconic' design, which drew closely from Shadowguides, proved to yield lower error rates in both evaluation and execution. This design depicted an iconic hand indicating the required touch points and their configuration over the screen. It proved superior to the 'Symbolic' design, which is more abstract and shows only circles. It appears to be a good principle to maintain this in future designs, unless a further approach is proved to yield even lower error rates.

Version 3 of the five versions also drew closely from Shadowguides. It required participants to initiate touch on the screen for the visual cues of the gesture to appear. This follows from the design of Shadowguides, which also required touch to occur for the guides to appear. Version 3 proved deficient in that there were higher levels of incorrect executions compared to automatic versions. Thus, while the visual aspects of

Shadowguides that informed the ‘Iconic’ visual design proved effective, the other characteristic shared with Version 3 of being ‘tap-to-preview’ only, is not as efficient. Freeman et al. added a response to user action that would reveal potential gestures and their improvement proved effective. However, adding manual levels of control to trigger learning can itself become a barrier to learning. The versions that built on Freeman et al.’s approach show similar advantages to the ones that they report, but prove weaker than competitive designs (Version 2 and 5) at helping users identify and learn unfamiliar gestures.

Moving to Wu’s second paradigm of *continuation,* previous work has not depicted touch points, but it has assisted the user in showing the direction of movement required. Version 4 replicates this design choice. Two examples that make the same design choices as Version 4 are Bau and Mackay’s Octopocus (2008) and Bennett et al.’s SimpleFlow (2011) techniques. Version 4 shows the movement required to activate a given control by ‘animating’ that control with a movement towards the required position. Octopocus and SimpleFlow take a similar, but not identical approach. They display ‘gesture-completion paths’ in response to user's touch and hold on target objects. Visual depictions of touch points are not shown in either Version 4, the ‘Iconic’ and ‘Symbolic’ design or the other techniques and therefore lack *registration* cues.

Bau and Mackay describe the results of two experiments, which show that OctoPocus is significantly faster and improves learning of arbitrary gestures, compared to a conventional Help menu. OctoPocus resulted in significantly fewer errors in execution of gestures.

Bennett et al. (2011) compared two styles that show the necessary route of the gesture’s movement. They focused their experiment on assessing the length of a gesture, in which the shorter the gesture is in indicating success the better, taking into account the accuracy in hitting targets, the speed (the faster the better) and the cognitive load. These two techniques (SFPath and SimpleFlow) were both compared against each other and against a standard feedback design that lacked guidance for the gesture path. The two auto-completion methods proved substantially more efficient than standard feedback.

Version 4 had the second most number of errors in execution; these were in micro-phase ‘8. Touch configuration' and ‘9. Perform direction'. The only design with more errors was the static design, Version 1. Furthermore, this version had more incorrect executions than the versions that show the touch points. In other studies, it appears that micro-phase ‘9. Perform direction’, has relatively low error rates. Version 4 yielded an error rate of 4% for this micro-phase. Bau & Mackay (2008) report the same error rate for their improved design. As other micro-phases have higher failure rates (for instance, the configuration of the gesture, followed by the registration of touch points), this micro-phase appears to be least in need of support in future improvements.

Summarising the reflections to this point, the comparisons between the results yielded by the designs used in the thesis experiment and previous work, show that techniques that display touch points ('Iconic' design and Version 3 versus Freeman et al.’s Shadowguides) and visual-completion paths (Version 4 versus Bau and Mackay’s Octopocus and Bennett et al.’s Simpleflow) are more efficient than non-predictive gesture entry user interfaces. The same principle seems to hold.

On Wu’s final step of *termination*, neither previous researchers nor the thesis experiment found any particular problem at this step. This section now turns to viewing the outcomes of the research itself and recap the main findings. Versions 2 and 5 yielded lower error rates when compared to the other versions across evaluation and execution phases, because they demonstrated automatic self-previewing gestural affordances followed by the effect of the gesture. Version 5 also provided the tap-to-preview feature, which enabled users to playback the visual cue, hence providing the configuration of design and interaction technique that yielded the overall lowest error rates across all interactions. Animation was an important factor in communicating the motion of a gesture to the participants. In its absence it was anticipated there would be extra difficulty for participants in understanding how to perform gestures and determine their effect. Version 1 closely followed existing practice (such as in iOS), displaying a static self-previewing gesture. For instance, Version 1 had higher incorrect executions when compared to the animated group. For micro-phase ‘9. Perform direction', which is essential for the correct execution of the gesture, Version 1, which lacks animation, performed the worst. This was fifteen times more than Version 5 and almost eight times more than Version 3. This confirms the theories of Sukaviriya (1990), Palmiter et al. (1991), Tverski et al. (2002) and Bedford (2014) on the importance of providing animated events to explain concepts within an HCI system.

To sum up, Versions 1, 3 and 4 suffer from particular difficulties with the configuration of touch points in the gesture. When considering the number of touch points, Version 1 resulted in a very poor performance, while both 3 and 4 proved relatively better. However, if the overall error rates yielded by micro-phases only are considered, participants failed the most in setting the touch configuration (the continuation), followed by number of touch points (the registration) with very few errors for direction. As anticipated, when users encountered a novel behaviour of the system, such as the automatic animations, complaints and confusion emerged. It is well known within HCI that new and unfamiliar paradigms can throw users into a forced adjustment and reduced efficiency of interaction. For instance, many participants failed to identify the potential to tap on the screen in order to preview interactions, perhaps because this was unexpected and any triggering of it was primarily accidental. In addition, some participants thought that tapping to preview was a requirement to set the system in the appropriate mode. Furthermore, many tapped the SPG affordances as if they were buttons. These two points resonate directly with the difficulties participants encountered in Hofmeester's (2012) prototypes.

The evidence obtained with this study highlights the importance that the depiction of touch points has in making users aware of available gestures and how to initiate them. It also corroborates the theory that feedforward is a powerful technique that improves users understanding of action-consequences of their interactions with a given system. Therefore, the technique in an initial comparison is able to demonstrate success rates comparable to the previous results from other researchers, and indeed, for the designs of this current study, to exceed them.

7.7 Conclusions

This study aimed at supporting or rejecting the three research hypotheses, and therefore providing evidence to address research questions '1' to '3'.

Thesis hypothesis (a) was supported, by demonstrating significance across the model. The versions that show a visual depiction for the gesture outperformed the version that does not show a visual depiction. The qualitative evidence further demonstrates the benefits of providing visual depictions to users. Thesis hypothesis (c) was also supported. Similar to the previous study, the three-way rating criteria revealed statistically significant differences between micro-phases, therefore supporting the hypothesis. The null hypothesis for thesis hypothesis (b) could not be rejected, thus research question ‘2’ requires further addressing (see future work, Section 9.2).

The previous study underlined the role that feedforward has in educating users in the execution of a gesture. The final study has explored in a more systematic fashion the different factors that lead to the success or failure of particular visual prompts to assist the user to identify potential actions for touch, multi-touch and gestural interactions. The study presented the users with two different visual design styles, and five different versions of self-previewing gestures. The interface prototype applications were tested in order to compare the effectiveness of different approaches to revealing available gestures, and specifically improve the likelihood that users would be able to comprehend how to perform gestures and to anticipate their effect. The methodology of Lab RTD for design was used to investigate such aspects (see Section 4.2.1).

Due to the lack of guidelines on effective design practice for communicating gestures to users, the visual solutions for the self-previewing gestures were each created with a certain degree of risk. However, the design choices were not random, they were informed by research *for* design (see Chapter 3 and Section 4.4), and findings from the previous study (see Section 6.7). Furthermore, none of the versions used in the empirical study was intended to be ideal (see Section 7.4.1). Without empirical evidence, any preference would be speculation.

There were good reasons to suspect that some approaches would be less optimal if based on the experiences and insights gained from the previous study. For example, Version 1 (static), while representing much of standard common practice, can be critiqued as being potentially less effective in communicating direction of movement. The study has also revealed that animated feedforward, in the form of self-previewing gestures, is superior to static affordance. Furthermore, tap-to-preview on its own proves to have limited effectiveness although more effective than a basic static approach. Self-previewing affordances were more effective again, and it appears that the option of having a tap to repeat a recent affordance may be beneficial, but more evidence would be required to determine its importance to users (see ‘future work’, Section 9.2).

The model-based rating system proved helpful in distinguishing different aspects of user performance, both during evaluation and execution stages of the interaction. While the current designs are not yet ideal, the scoring system has proved even more useful in this study than in the previous one. The initial study revealed that participants' responses to the questions that corresponded to a couple of micro-phases within the evaluation stage were almost identical. Thus, one of the micro-phases was deemed redundant and removed (see Section 7.3). In addition, reducing the number of stages to be tested reduces the number of participants required to achieve statistical significance. The GEM and rating system have been refined through the findings of common errors to perform gestures and design recommendations. Even in their early forms showed user errors and can be used by other researchers and industry practitioners as a methodology to assess their touch and gestural interfaces.

7.8 Summary

This chapter described the final empirical study. It tested the different components pertaining to the SPG in determined combinations. The findings indicated which designs and versions were more efficient in educating participants about the available unfamiliar gestures. It also revealed the micro-phases within the evaluation and execution phases in which participants failed the most.

This study, combined with the previous, supported the thesis hypotheses (a) and (c) and answered research questions '1' and '3'. The null hypothesis for thesis hypothesis (b), however, could not be rejected, which indicates that research question '2' requires further work.

The next chapter consolidates the results from both empirical studies. It presents a list of common errors in gestural interactions, followed by design recommendations to mitigate such errors.

CHAPTER 8 - DESIGN RECOMMENDATIONS FOR GESTURAL INTERACTIONS

This chapter consolidates the approach of laboratory-based research *through* design *for* design (see Section 4.2.1) adopted by this thesis. *First*, it synthesises the results from the two empirical studies and compares it with previous work; *second*, the most common problems users experienced when confronted with an unfamiliar gestural interface are consolidated; *third*, design recommendations are drawn as informed by these findings and aimed at mitigating each problem listed; *fourth*, problems and design recommendations are correlated in a comparative table, which provides visual recommendations to exemplify possible design solutions.

The recommendations that follow should serve as insight – and not mandatory guidelines – of good practices to design affordances and feedforward for gestures in the form of visual cues.

8.1 Synthesis of Results

The findings from the two studies were discussed in the relevant chapters (Sections 6.6 and 7.6), however, to fully synthesise the two experiments in the context of this thesis, a final comparison with and contrast to existing work is necessary. Previous work in the field demonstrated that providing guidance for the completion paths for the user to follow during the continuation phase was effective. This approach yielded an overall 80% success rate when users attempted to execute a gesture that they were in the process of learning. This was a marked improvement when compared to baseline methods, which had not provided visual guidance during continuation.

Drawing on six key papers (e.g. Bau and Mackay, 2008) that investigated how to provide effective user support during continuation, both design and methodological ideas were transferred and re-applied to the challenge of registration of touch points (Sections 4.4.1 and 4.5.1). While a direct comparison is not possible, because the problem addressed is not exactly the same, it was hoped there would be similar benefits for users by adopting similar strategies for a related problem. Like the Ripples technique (Wigdor et al., 2009), which provided visual cues to assist the user *during* continuation, prompts were used to give information *before* registration. Wigdor et al. demonstrated a reduction in user error through their method. Overall, participants made significantly fewer errors per trial when using Ripples, with a mean error rate of 19.4%, versus 46.9% with the control condition. Their experiment focussed solely on the phase of execution, when the user endeavours to perform a gesture.

When the self-previewing gesture (SPG) technique was applied in the first study, there was a similar drop in user error rate. Taking the execution of the gesture that Wigdor and others have previously focussed on, the study demonstrated a drop in overall error rates from 15% for a baseline implementation, to 7% for the most advanced design. Unlike the previous researchers, who focussed only on gross rates of error, we could further unpack individual aspects of users' interpretation of visual prompts for gesture training and for following the execution of commands. Again in the final study, the baseline technique suffered error rates as high as 15% – for direction of movement – whereas the improved SPG technique demonstrated a much lower rate of 1% for the same part of the execution. Hence, at the overall level of error, there were similar changes to user success rates (or falls in error rate) as previous researchers had found when adding purpose-made design interventions. This corroborates the decision to adopt a similar approach, and suggests that design concepts that have been applied to supporting the user during continuation could helpfully – at least in some cases – be transferred to before interaction.

There are, however, differences in the problems being researched, which make direct comparisons problematic. When Freeman et al. (2009) assessed their Shadowguides system they focussed on the user's rehearsal and acquisition of a new gesture. In contrast, training was not provided in order to see what the un-coached performance of users would be. Freeman et al.'s focus on learned performance of execution sets the identification of new gestures as a separate task. In contrast, for this research, successful execution served to confirm that a user had correctly understood an available gesture with the aid of informative visual prompts.

8.2 Recurring Problems in Learning New Gestures

The findings produced by the two empirical studies provided a clearer understanding of which micro-phases within gestural interactions participants are making the most errors.

It also revealed unforeseen subjective findings, which were elicited from participants during the think-aloud phases. These were consolidated in a list of problems, and below the main findings and corresponding data are listed. Data samples from participants' errors are used to illustrate the identified problems.

1. *Touch and hold is hard to perform*: This gesture suffers from the problem of a lack of perceptible affordances, as reported at the beginning of this chapter (Section 1.3). Touch-and-hold gestures have become prevalent in standard multi-touch devices. This gesture requires a user to press and hold on a given screen object for a certain time to yield additional manipulation options (e.g. copy, cut, delete, move). However, both empirical studies demonstrated that some participants are still unaware of this gesture or have issues in actually executing it.

   The first study demonstrated that touch-and-hold gestures had an execution error rate of 21%. In contrast, the final study demonstrated an improved (reduced) error rate of 12%. One common error was that users would attempt a pinch gesture when a touch-and-hold action was needed. Seven participants made this error, making comments such as "I'd try pinching it". (P15, 50, F), while both P19 and P29 made a pinching gesture with their index finger and thumb to articulate their expectation.

2. *Multi-touch is hard to perform*: As with touch-and-hold actions, the problem with multi-touch gestures is they are weakly signalled to the user in prevalent interfaces (Section 1.3). Many current gestures require one or, at the most, two fingers. In the thesis studies, users consistently had problems performing gestures that used two or more. This is an increasingly significant problem when many core system actions now require multi-touch gestures.

   In the first study Interaction 7 (three fingers and swipe upwards) yielded 16% errors, while Interaction 6 (three fingers and horizontal swipe) and Interaction 8 (three fingers and pinch) had a 12% error rate. Twenty-eight participants had problems performing multi-touch, commenting for example "I think the four fingers is very unnatural." (P10, 28, M).

In the final study, the interaction that required a two-finger swipe down to open an application yielded 18% errors in execution, the highest across the board. The specific micro-phases during evaluation in which the user identifies both the number of touch points and their spatial arrangement were repeated points for error, with error rates of 15% and 13% respectively for both empirical studies. During execution, including second and later attempts, the micro-phases ‘touch configuration’, and ‘touch to confirm’ produced 14% and 10% errors respectively in the final study. This highlights that errors with multi-touch gestures remain a significant problem, and participants vented their frustration, commenting for example “I find a bit irritating, don't see the purpose of using 2 fingers to drag it down.” (P46, 54, M).

3. *Swipe from bezel is hard to perform*: This gesture suffers from the second problem noted at the beginning of this chapter (Section 1.3): a lack of informative visual cues *before* interaction. This results in the user failing to identify the presence of a gesture. In both studies, there was an interaction that required participants to swipe from the screen bezel in order to reveal a hidden menu. Swiping is a familiar gesture for most users of touch devices, however the lack of affordances to indicate hidden menus and toolbars in different corners of the screen present problems – and this is a technique used in interfaces such as Microsoft Window’s touch interface.

   In the first study participants made 4% errors in this type of interaction. In the second study participants made 7% errors; and ten participants repeatedly tried to drag the menu from the bezel into screen without success. This happened because they did not hit the required threshold area to activate the start of the gesture.

   Despite the fact that this interaction did not suffer error rates as high as touch-and-hold for example, the qualitative analysis demonstrates that this is an issue for participants. Seventeen participants had problems when attempting to activate the invisible target area, commenting for example “I think I'd press right there but nothing is happening” (P1, M, 34).

8.3 Design Recommendations for Gestural Interactions

The recommendations that follow are based on empirical evidence gained through iterative research. They identify the designs that were most efficient and yielded lower error rates during gesture evaluation and execution. The first part gathers visual properties for the design of prompts that communicate the available gestures. The second part addresses other properties of cues, such as the timing of their display.

8.3.1 Design properties

a. *Blurry visual prompts are recommended to show single-touch and hold interactions*: Two pairs of design styles were compared in the first study. This was done to assess which design would help participants to evaluate and execute gestures with fewer errors. The visual characteristics of each design correspond with the principle of ‘pictorial aspect’ (introduced in 6.2). The appearance of a cue can help or hinder specific metaphors that indicate action, effect, property of an object, etc.

   In the first study, the design termed ‘Circles’ was constructed with sharp contours to indicate touch points over the screen. The second design, ‘Smudge’, depicted an abstract representation of any touch or multi-touch points being pressed over the screen, which was mirrored in a visible distortion. The second design yielded lower error rates when used to indicate a single touch and holding interaction: 82% of the participants executed the target gesture correctly for this interaction when exposed to the ‘Smudge’ design, against only 68% for ‘Circles’. A few examples of comments show participants’ correct interpretation of ‘Smudge’: “when that kind of hazy area comes up, makes you feel like hold it...” (P27, 40, F) and “The ‘swipy’ you can see is like an imprint where you can push quite hard” (P18, 35, F).

b. *Sharp-stroked visual prompts are recommended to show multiple touch points*: This design property relates to the principle of ‘contrast’. The stark depiction of touch points over the screen provided the emphasis required for users to distinguish between foreground and background content. This helped users to specially identify multiple numbers of fingers to initiate a gesture.

As an example from the first study, the 'Circles' design yielded fewer error rates across the three multi-touch interactions, with an average 6% error rate. In contrast, 'Smudge' was much less successful, with a 21% error for the same interactions. The advantage of the 'Circles' design in communicating the number of touch points is reflected in 27 comments, for example, "I think the circles give me a better idea of how many fingers I should use" (P2, 29, F) and "Shows you exactly how many fingers you're supposed to be using" (P11, 27, F). The second study used a similar, improved visual style termed 'Iconic' and 66 comments confirm its efficiency, for example, "I think the symbol looked like two fingers rather than one...and run both over it" (P19, 34, F).

Therefore, the design characteristic of sharp contrast can aid users *first*, in providing a stronger contrast between foreground and background within the UI, and *second*, in identifying multiple number of touch points to start a gesture.

c. *Activation areas need visual cues*: Participants repeatedly had problems with menus and other active elements that are hidden at the different bezels of the screen. Touching the screen near bezels is increasingly common as a gesture, for instance in Windows 10 (Section 3.2). As one example, ten participants in the first study repeatedly tried to drag the menu from the right bezel into screen without success. This happened because either they did not hit the required threshold area or were simply unaware of the presence of the menu.
Other comments indicate that SPG can mitigate the problem by ensuring the gesture is visible to the novice user: "The image of a page, something else will come out...maybe the main menu or another image I don't know" (P1, 41, F) and "Something else appeared on the right side" (P3, 25, F). The second study reinforces the point, as the following verbalisations show: "Will give me chapter options, start or end of the book...or going back to the main menu again" (P18, 21, F). Therefore, the presentation of visual cues is recommended to inform the

user that different bezels of a touch screen hide objects, such as menus and toolbars.

d. *Icons with text labels support unfamiliar interactions:* This design property reported relates to the fundament of 'textual support' (Section 7.2). Text was used to disambiguate the action required for a gesture or to demonstrate its effect.

The second study showed a statistically significant Chi-square for the designs in the execution phase (Section 7.5.3). In that study, the 'Iconic' design (with text labels) yielded 4% errors in evaluation of gestures, and the design 'Symbolic' (no text labels) yielded 8%. 'Iconic' yielded 17% errors in execution of gestures, and 'Symbolic' 22%. A simple average between evaluation and execution phases, across the three interactions and the two designs showed that the 'Iconic' design had 8% incorrect responses for Interaction 3 (touch and hold the picture) while the 'Symbolic' design had 16%.

Therefore, the design with text labels outperformed the design lacking those. The quantitative results could not determine with certainty if the text label was the factor responsible for the positive results. However, the qualitative analysis suggested this. Seven participants praised the cues with text labels as the following comments demonstrate: "This time it said 'hold', that's easier" (P4, 23, F), and "Ah, that's better. Much easier when you have a little command as well as the image" (P34, 35, F). Whereas one participant complained when prompts lacked textual support': "But wasn't written 'hold' beforehand" (P40, M, 42).

8.3.2 Display properties

e. *Show visible touch points*: Both studies showed that interfaces that display affordances for gestures can benefit users when it comes to learning unfamiliar gestures. This contrast was even more significant in the final study, because it compared application versions that display touch points against a version that does not. In order to arrive at a target "good" error rate, existing literature was consulted. However, existent work does not mention an ideal value for performance. Instead, their conclusions are based on comparisons. For instance, Freeman et al. (2009), and Wigdor et al. (2009) considered an 80% execution success rate for their improved versions to be high. Bau & Mackay (2008) found significantly fewer errors for gestures trained with their design technique, 4%, compared to a conventional help menu, 8%.

Similarities were observed by comparing the results from previous work with the results from the two empirical studies undertaken in this research. In the first study participants' correctly executed 86% of gestures. The results from the second (and final) study mirrored the first: participants executed correctly 80%. In the final study it was observed a drop in overall error rates from 15% for a baseline implementation, to 7% for the most advanced design. Application Version 5, which shows visual depictions for touch points over the screen, had the most correct executions across the board (87%), while Version 4 (which lacks touch points) showed the lowest (76%).

f. *Show touch points before user action*: Interfaces that self-preview the touch points of gestures *before user action* were marginally more efficient in the second study. As observed in Section 7.5.6.2, the null hypothesis could not be rejected for thesis hypothesis (b).

Therefore, this recommendation is based on qualitative analysis, and a few comments exemplify this point: "I remember how to bring the menu because I saw the little cue at the beginning" (P38, 43, M), and "This came up before I touch it this time. The corner thing again. Maybe it says it is selected, no?" (P36, 24, F). Fourteen participants who learned this feature complained when it was not available, suggesting the formation of an expectation within a short time of experiencing this behaviour. Comments included: "How about now that nothing shows up?" (P42, F, 56);"Will these buttons will just sit there until I tried something?" (P34, F, 35); and "Not getting anything" (P46, M, 54).

g. *Show animated touch points*: This design property reported relates to the fundament of 'movement'. As reported in Section 6.2, many researchers recommend the use of animated events (Shneiderman et al., 2004 and Chow et al., 2011) to enhance the effects of an interaction.

In the final study, prototype Version 1 was static: the visual prompt would fade in and out with no real movement besides the depiction of a directional arrow. This version performed the worst in the micro-phase ‘Perform direction’, which is essential for the correct execution of the gesture, with 15% errors, which is fifteen times more than Version 5 (with 1.1%) and almost eight times more than Version 3 (3.3%). For the execution phase, the overall incorrect responses for the Version 1 (static), accounted for 24% against 18% from the animated versions. The following verbalisations reflect that: “I've seen animations to show me how to click it, how to do it...it's like moving from top to down and up again.” (P45, 24, M), and “It's actually easy looking the way you're doing it better than reading the instruction. If you want to show someone things it's better to show someone a picture or video…” (P32, 27, F).

h. *Show the visible effect of a gesture:* As highlighted by many researchers (Wensveen et al., 2004; Freitag, 2012; Vermeulen et al., 2013) feedforward is a powerful user interface design technique that previews to users how they should manipulate the interface and the effects of their interactions. Empirical studies have confirmed the efficiency of this approach (Wigdor et al., 2009; Freeman et al., 2009; Nacenta et al., 2009) when researchers compared error rates in users executing tasks in interfaces that are responsive and anticipatory to their actions with conventional interfaces, which do not display any form of feedforward.

The value of feedforward was proven in the first study, which showed that the micro-phase ‘System status’ – within execution – yielded the most success rate between the designs (12.9%), followed by ‘Restore status’ (12.1%). Both micro-phases were significant for all multi-touch interactions (6, 7 and 8), which indicate that the SPG was particularly efficient in presenting the new system status (Wu’s *termination*) and in indicating to participants how to undo recently performed gestures. A few comments exemplify the impact feedforward has when there are no visible affordances. In the first study participants learned through an animated feedforward the effect of the gesture: “It showed how to put the application in there below, I like it” (P8, 25, M). In the final study the SPG successfully showed participants the hidden menu on the left bezel: “Now I know what I need to do!” (P7, M, 28), “Ah, this will give me the menu” (P42, F, 56).

The evidence from the two empirical studies also substantiated the recommendations for the design of visual prompts that show users how to perform gestures. These were consolidated in the list below.

8.4 Problems with Gestures and Design Recommendations

This section makes some suggestions for on-going avenues of research in improving methods to assess gestural interfaces, and in designs that could make users’ less prone to errors when facing unfamiliar - and sometimes challenging - gestural UI. A connection is drawn between the list of problems identified in gestural interactions and the previous section of design recommendations.

By listing common errors observed empirically, the context where they occurred, and a suggestion of a visual solution to mitigate the error, this provides the interface designer and HCI researcher with a style guide that can help their own design work be effective.

The rationale for organising the tables drew from Freeman et al.’s ‘taxonomy of multi-touch and whole-hand surface gestures’ (2009). The first column shows the problem, in the order it was described in Section 8.3. The second column shows the registration pose required to initiate a given gesture (single or multi-touch). The third column describes the movement, subdivided in ‘path’ and ‘no-path’, which correspond to interactions that require the hand moving along the surface or one in which the hand stays in place. The type or context column explains the type of interaction and the context in which the issue was observed. The design recommendation column lists as many suggestions as necessary to mitigate the corresponding one issue.

Finally, the ‘visual suggestion (research)’ column shows the design recommendation to mitigate the corresponding issue. The designs are those that use SPG to preview touch points in both empirical studies. The following right-hand column lists the ‘visual suggestion (others)’ found in standard devices (smartphones and tablets), or designs used in previous research in the field. There are countless online repositories with visual style-guides for a wide range of Operating Systems. Many of these guides are provided as PDFs, with static depiction of the visual designs and lack any animation to show a design’s movement on-screen as this research recommends.

As space precludes the display of a large variety of assorted designs, the selection is limited to visual cues that correspond to the design work undertaken in the research. Each design is numbered, and its reference listed at the bottom of each table. Note that the recommendations ‘d’ to ‘h’ (d. Icons with text labels support unfamiliar interactions, e. Show visible touch points, f. Show automatic touch points, g. Show animated touch points, h. Show the visible effect of a gesture) are relevant to all issues (1-4) listed above. Table 52, Table 53, Table 54 show the errors and corresponding design recommendations. The list is self-evident and comprehensive, thus it does not require further explanations.

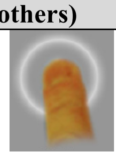
Issues	Regist. pose	Move ment	Type/ Context	Design recomm.	Visual suggestion (research)	Visual suggestion (others)
1. Touch and hold is hard to perform	Single-touch	No path	Touch-and-hold int.	***a. Blurry visual prompts are recommended to show single-touch and hold interactions*** ***d. to h.***	(i)  (ii)	 (iii)  (iv)
i. Design 2 ‘Smudge’ for single-touch and hold gesture (Study 1) ii. Design 2 ‘Symbolic’ for touch-and-hold gesture (Study 2) iii. Wigdor et al. (2009:7) Ripples touch-and-hold gesture iv. Onori, P.J. (2014) ‘A Gesture Icon System’ touch-and-hold gesture						

Table 52: Issue 1 and design recommendations with visual suggestions.

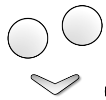
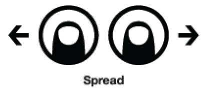
Issues	Regist. pose	Cont. pose	Type/ Context	Design recomm.	Visual suggestion (research)	Visual suggestion (others)
2. Multi-touch is hard to perform:	Multi-touch	Path	2 or more fingers	***b. Sharp-stroked visual prompts are recommended to show multiple touch points*** ***d. to h.***	 (i)  (ii)	 (iii)  (iv)
i. Design 2 'Symbolic' for two-finger touch and slide down gesture (Study 2) ii. Design 1 'Iconic' for two-finger touch and slide down gesture (Study 2) iii. Wroblewski, L. (2010) 'Touch Gesture Reference Guide' two finger horizontal drag gesture iv. Onori, P.J. (2014) 'A Gesture Icon System' two finger horizontal spread gesture						

Table 53: Issue 2 and design recommendations with visual suggestions.

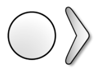
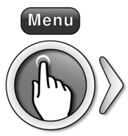
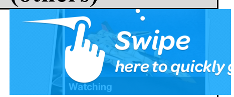
Issues	Regist. pose	Cont. pose	Type/ Context	Design recomm.	Visual suggestion (research)	Visual suggestion (others)
3. Swipe from bezel is hard to perform	Single-touch	Path	Swipe to reveal/ drag to activate	***c. Activation areas need visible cues*** ***d. to h.***	 (i)  (ii)	 (iii)  (iv)  (v)
i. Design 2 'Symbolic' for single-finger swipe to right gesture (Study 2) ii. Design 1 'Iconic' for single-finger swipe to right gesture (Study 2) iii. eBay for iOS: Introductory screen and detail of swipe from left bezel to reveal menu (May 2012) iv. Twitter for iOS, swipe screens horizontal gesture (March 2014). v. iPhone home screen. Hidden notification tab duly flagged with visual cue (July 2014)						

Table 54: Issue 3 and design recommendations with visual suggestions. The Berne Convention allows the non-profitable use of software print screens.

8.5 Summary

This chapter reports on the recurring problems users suffered in learning new gestures, during the experimental work. Then it provides a speculative design guideline that employs the self-previewing gestures (SPG) interaction technique, and a section that correlates problems and design recommendations.

By discovering which designs helped participants in making less mistakes when evaluating and executing unfamiliar gestures, the research contributed with insights and design recommendations for gestural user interfaces.

The next chapter concludes and summarises the thesis. It also discusses the limitations of research and future work.

CHAPTER 9 - CONCLUSION AND FUTURE WORK

Given the increasing pervasiveness of gestural interfaces, it is timely to look for ways to reduce the error rate for users undertaking unfamiliar gestures – something that is widely recognised as a problem (Norman and Nielsen, 2010; Wigdor and Wixton, 2011; Norman, 2012–14; Vermeulen et al., 2013). Current research amply demonstrates that users fail to discover hidden gestures or have difficulties in executing them. As described in Section 1.3, three underlying challenges were identified for this research:

1) Users' lack of awareness of how to initiate a touch gesture is influenced by the lack of supporting *designs*.
2) There is a lack of visual designs *before* interaction to communicate to the user the available multi-touch gestures and hidden user-interface menus and tools.
3) There is no systematic understanding of which parts of identifying and performing gestures most contribute most to the errors that users make.

To address these issues, the approach of laboratory-based research *through* design *for* design was adopted (Section 4.2.1). According to Zimmerman (2007: 310), research through design focusses on the quality of the research output, by framing the work within the real world, and articulating reasons the community should consider this or that state "to be preferred". According to Frayling's (1993: 1) definitions of research and design (see Section 4.2), the work undertaken in this thesis can be considered Research with a capital 'R', being concerned that the outcome of the empirical studies and the research is reliable, transferrable, generalizable and reproducible. The designs and the methodology developed should inform other researchers and practitioners in the field of HCI in their own work.

This concluding chapter recaps the key contributions of the thesis, which are described in Section 9.1: *first*, a 'gesture-and-effect model and corresponding rating system', *second*, the 'identification of common problems in performing gestures, and corresponding designs that mitigate these errors' and, *third*, 'the self-previewing gestural concept of interaction'.

Two empirical studies were undertaken in laboratory settings to prove or reject hypotheses. The limitations of the methods concerning the 'evaluation method', the 'visual design' and the 'interaction technique' are discussed in turn, and future work in response to each set of issues is provided. The 'evaluation method' sub-section describes limitations to the definition of the GEM and use of corresponding rating system. The 'visual design' sub-section describes the visual characteristics of the touch points (e.g. the aesthetics, display length) and the choices of designs that were not included in the testing activity. The 'interaction technique' sub-section describes the selected forms to trigger the visual prompts (e.g. self-previewing, tap-to-preview) and avenues unexplored by this research. Finally, a closing statement is provided.

9.1 Key Contributions

The three contributions the thesis makes are outlined next, beginning with the model and rating system that enabled the research to proceed.

1. A 'gesture-and-effect' model and corresponding rating system

A major challenge identified in the literature review is that within the field of design for gestural interactions, there is no systematic understanding of how people are making mistakes in assessing the UI and executing gestures. To address this issue, a 'gesture-and-effect' model (GEM) was created to help diagnose in which parts of the gestural interaction users make more mistakes (see Section 5.3). The theoretical foundations for this framework are Norman's Theory of Action (1998), Wu et al.'s RCT theory (2006) and Golod et al.'s gesture 'phrase' (2013).

Having constructed the model, it was adapted into a practical tool that enabled a systematic method for comparison. The work of Bragdon et al. (2009) provided the foundations for the design of an *a priori* coding scheme. Following this example, a rating scheme was established, consisting of 'correct', 'partial' and 'incorrect' rates to assess the different micro-phases (Section 4.5.1). The *a priori* coding scheme developed for this research received additional support from qualitative data analysis: codes and themes emerged from transcribing and categorizing participants' utterances and verbalisations.

2. Identifying common problems in performing gestures, and corresponding designs that mitigate these errors

As a further contribution to the scientific understanding of user behaviour in acquiring new gestures, a list of recurring problems is synthesised in Section 8.2. The problems were identified empirically, in a laboratory setting.

Listing common errors observed empirically, the context in which they occurred and a suggestion for a visual solution to mitigate the error provides the interface designer and HCI researcher with a style guide that can help their own design work be effective (see Section 8.3).

3. The self-previewing gestural (SPG) concept of interaction

The first challenge identified at the beginning of this chapter is that users' lack of awareness of how to initiate touch is influenced by the lack of supporting visual prompts. The second challenge is the lack of visual designs before interaction to communicate to the user the available multi-touch gestures and hidden user-interface menus and tools.

To address these challenges, a new design concept, termed *self-previewing gestures* (SPG), was created to provide support; this was investigated in two empirical studies. A different focus was taken from that adopted by previous researchers, such as Bragdon et al. (2009) and Bennett et al. (2011), who examined the later phase of *continuation* rather than *registration* of touch points (to use Wu's 2006 terminology). Instead, this thesis focussed on the *registration* of touch points. It creates design interventions in the form of 'self-previewing' visual prompts that depict touch points before the user touches the screen of a gestural device.

However, any one piece of work is unlikely to be the final word, especially when a problem has emerged in the relatively recent past. While Chapter 8 elaborates on identified problems within gestural interactions during the empirical studies, and suggests designs that could mitigate these issues, there is ample scope for further work.

9.2 Limitations and Future Work

This section discusses the limitations of each of three key elements of the research method in turn: the ‘evaluation method’, the ‘visual design’ and the ‘interaction technique’. For each element, the limitations are followed by suggestions for future work.

9.2.1 The evaluation method

The testing of the visual prompts in an experiment was a key foundation of the research in this thesis. As the reliability of the other contributions depends upon the robustness of the evaluation methods used, these questions will be addressed first. It was through these evaluations that the thesis addressed the third research question on the errors users made in identifying and executing unfamiliar gestures.

A rating system, built on existing theories, was refined across two empirical studies. While it is in its early stages, initial results indicated that it has potential utility in assessing gestural interfaces and identifying the specific problems that users experience. Consequently, the third research question was partially answered. However, the *a priori* coding scheme has some limitations, and thus has scope to be improved.

Limitations of the evaluation method are now introduced, followed by a suggestion for future work:

1. Rating system is not fully validated: Ideally, any evaluation system should be validated and proved reliable by its use by other researchers. It is desirable that others are able to adopt and adapt the system. Similarly, the same study undertaken with the same method should lead to the same results, giving increased evidence of the reproducibility of the findings.

The construction of the rating system was carried out carefully, to extend and build upon prior work. Bragdon et al. (2009) was simplified, adopting a threefold criteria (Correct, Incorrect and Partial), rather than their more elaborate two-measure system. This initial three-point scale drew on data from a brief pilot study (see Section 4.7.3) and the participants’ behaviour was used to arrive at the threshold values for the rating of ‘partial’ success.

Validation by another researcher is a desirable step, even in initial, exploratory work. As reported in Section 6.5, a preliminary check of the rules for applying the *a priori* coding was undertaken with one independent researcher. The results showed good agreement between the independent researcher and the main researcher. This success meant it was possible to adapt the rating system with more confidence.

However, there is a risk that the comparison with only one independent researcher does not provide absolute proof. Ideally, one would like an impartial and reproducible test to ensure the reliability of the method. There are statistical methods for testing inter-rater reliability, such as Fleiss's Kappa (Carey, 2013: 317).

Potential problems include, for instance, disagreement between researchers about the criteria for applying the ratings. One common issue relates to the exact definition of heuristics – e.g. one researcher could regard six attempts for a 'correct' interaction to be too many, and prefer a more conservative value. Bragdon et al., for instance, distinguished between successful interaction across one to three attempts and more.

A second caveat would be the limited number (10) of participants used in the pilot study, which is in itself a small sample for corroborating the *a priori* criteria. While our later studies used larger samples without major issues emerging for the researcher, it would be wise to continue with further steps to test the system's reliability.

Scope for improvement and future work

The utility of the rating system for other researchers should be assessed through use by other, independent, researchers. Further data on the threefold criteria of rating (Correct, Incorrect and Partial) would allow the rating scheme to be tested for inter-rater reliability and, if the definitions are vague or the heuristics prove ill-defined or debatable, the rating scheme could be revised. Similarly, further data from participants in other studies could be used to refine the definition of partial success further.

Overall, further data from the use of the scale by independent researchers and data on participants in other studies should lead to an improved instrument that provides stronger correlation between future studies. This will ensure the validity (Carey, 2013: 27) and standardisation (reproducibility) of the method.

2. Gesture-and-effect model is not fully validated: A deductive process defined the stages and micro-phases pertaining to the GEM. This process was founded in Norman's Theory of Action (1998), Wu et al.'s RCT theory (2006) and Golod et al.'s gesture 'phrase' (2013).

It was observed in the two empirical studies that a few micro-phases within the stages of *evaluation* and *execution* of gestures yielded similar error rates. For instance, the micro-phases in which the user identifies both the '*number of touch points*' and their '*configuration*' (spatial arrangement) showed similar error rates of 15% and 13% respectively. In the final study, including second and later attempts in the execution stage, the micro-phases '*touch configuration*', and '*touch to confirm*' produced 14% and 10% errors, respectively. These problems occurred especially for multi-touch gestures, but also for touch-and-hold.

The micro-phases within the model guided the questions asked in the 'oral structured interview', which was part of the elicitation method (see Section 4.6.2). One concern with the results of both studies is that in some cases the error rate of neighbouring micro-phases is similar.

This raises several possibilities: one, that participants found it hard to express or separate different properties in the gesture (e.g. the number of digits versus their position); two, that these problems are interdependent, and may naturally yield similar values as a result; and three, that this is simply a statistical coincidence. To ensure that the method is reliable, we need to be sure which case applies. If questions cannot be made discernibly different to participants, or if participants in general cannot differentiate between properties of the interaction, there may be some redundancy in the scheme, and even the elicitation method. If so, corresponding changes would be needed.

Scope for improvement and future work

In order to refine the GEM, independent researchers should apply the method themselves. The data from those further studies should be compared to examine more closely the utility of the short-questions corresponding to the model's micro-phases. This should identify any redundant micro-phases within the model, or lead to improved questions to elicit the user's responses.

For example, it was observed in the analysis of results from both studies that the first micro-phase of '*notice visual cue*' did not yield significant results. Most participants saw the SPG and, as a result, this micro-phase was removed from the statistical analysis. Future versions of the GEM should not include this micro-phase and should begin with 'identify number of touch points'.

9.2.2 The visual design

The evaluation method was applied to alternative designs of providing the user with guidance on unfamiliar gestures. This thesis has sought to identify effective visual designs to communicate this information in such a way as to reduce errors by users when identifying and executing gestures. The limitations of the design work undertaken in this research through design are now discussed.

To produce effective designs, many researchers and practitioners draw on existing practices and artefacts. One barrier to creating optimal designs in this research was the lack of material to support the design work. There are few guidelines on effective design practices to use when communicating gestures to users. As a result, the visual solutions for the self-previewing gestures were each created with a higher degree of risk than is ideal. Designs may be ineffective or confusing to users, for example.

To arrive at principled designs, they were informed by findings from both the studies in this thesis and by existent academic research. For example, Freeman et al. (2009) successfully used the direct representation of the number and position of touch points. That approach was applied in all of the designs in this thesis, especially because key elements of the GEM (e.g. touch configuration and number of touch points) directly correspond to the design Freeman et al. used.

In terms of visual design, selected online libraries were studied to identify potential design inspirations. A number of designs were chosen as potential starting points for the designs for SPG (e.g. Wroblewski, 2010; Onori, 2014). Similarly, the iconography used by readily available industry-produced software was considered (e.g. Apple iOS, Android, Microsoft). These potential designs were also critiqued in view of the limitations of human vision, as captured in theories of visual perception such as the works of Dondis (1973) and Arnhein (1974).

As observed across the two empirical studies (Chapter 6 and Chapter 7), most participants performed the target gestures and overall error rate was low (as low as 14% for study 1 and 18% for study 2). These results match the outcomes of related work already reported in Chapter 4. This suggests that the design interventions proposed in this thesis fulfilled their role in aiding participants to discover and execute unfamiliar gestures.

However, the visual presentation of prompts for gesture training was not without issues. There is room for improvement, as is now discussed.

1. Limited exploration of the design of visual prompts: Participants across the two studies experienced four visual styles of presentation (two in each study). This leaves a large volume of potential presentations unexplored.

As the number of possible test combinations for design (e.g. smaller versus larger visual cue sizes, different stroke lines, pictorial style, transparency factors, the use of directional arrows against its absence, optimal length to display, etc.) is practically infinite, the empirical work adopted a strategy that was feasible for the available time and resources. Thus, by exploring four design styles, a number of other possible designs with different characteristics were left outside the scope of the research. Unanticipated issues emerged in the two studies regarding the visual presentation of the prompts. This would require further design work to mitigate these undesirable effects. These issues include:

a. Participants had problems with the duration of the SPG display: Neither the industry nor academia consistently uses the automatic presentation of visual cues to train users in gestures. Thus, there is a lack of guidance to help identify an appropriate display time. A display time of 3 to 5 seconds on average per visual prompt was adopted, which included the fade in, animation and fade out of the visual cue for the gesture and the resulting effect on the user interface (Appendix L). However, as observed in the final study, across the 3 interactions, 18 comments demonstrate that some participants were unable to observe the visual cues because of the short display. Comments included "There was something displaying but I couldn't read it" (P5, F, 22); "Something popped up with the book...but to be honest I didn't concentrate on it, maybe it's to click here first, to find out what it is" (P23, F, 19); "The command should stay for a few more seconds. Looks great but it then just vanishes" (P34, F, 35).

b. Location-specific gestures were problematic: Some gestures rely on being made in specific regions of the touch screen (e.g. bezel, bottom). This is a common practice, which was reproduced in some of the designs. However, the prompts failed to ensure that users touched in exactly the right place – often they would miss the target area by a small amount. For example, in the first study, ten participants repeatedly tried to drag the menu from the right bezel into the screen without success. This happened because on many occasions they did not hit the target area where the gesture had to be made.

There are potential solutions. One would be to take a more 'permissive' approach (Thimbleby, 2001: 334) by accommodating a greater physical screen area to trigger the effect. Alternatively, the active touch region might be explicitly shown to the user alongside the existing visual prompts. In similar fashion, the physical size of the human hand and fingers is known to be a factor in designing gestures – and indeed a contested one. According to Windows Dev Center-b (2014), the average adult finger is about 11 millimetres (mm) wide, while that of a baby is 8 mm, and some basketball players have fingers wider than 19 mm. The Apple iOS (Human Interface Guidelines, 2014) recommends a minimum icon size of 17 mm radius. An average variation of these measures was taken to set the visual cues for target touchpoints used in the empirical studies, with an overall 15 mm radius. However, this heuristic is untested, and may be a further factor.

Scope for improvement and future work

There is ample opportunity for refining the visual styling and design of the interfaces, and indeed alternative approaches may significantly enhance the effectiveness of the interface as a whole. If future researchers want to embark on a systematic process for designing a suite of alternative designs, the work of Rogers (1989) could be followed. Rogers makes explicit the exploration of pictorial aspects such as ambiguity, form and function, mapping between pictorial aspects and implied action, visual memory, relevance of text labels embedded within the icon, etc.

To arrive at more optimal designs, further work is advisable to explore systematically and compare factors such as different aesthetics, different (time) durations for the display of the prompts or different animation methods. Systematic testing of pairs of designs with limited variations in characteristics (e.g. text labels versus no text) should help to arrive at focussed insights into which design features are more scrutable and understandable to a wide range of users. This approach should assess further design alternatives for visual cues that should yield even lower error rates in showing participants how to initiate and execute gestures.

9.2.3 The interaction technique

The ultimate contribution of this research is the provision of a new technique – self-previewing gestures. This answers the first and second research questions. The specific hypothesis for the second study (H1) claimed that animated SPG cues should yield lower error rates when compared to static cues.

As noted above, there was a wide variety of potential interaction techniques that could be used underneath the visual design presented to the user. Five interaction techniques (termed application versions, in Chapter 7) were chosen for detailed testing. The works of Bau & Mackay's (2008) OctoPocus, Freeman et al.'s (2009) Shadowguides, Wigdor et al.'s (2009) Ripples technique (Section 4.4.1), Wigdor and Wixton's (2011) self-revealing gestures 'chrome' layer for MS Surface (Section 3.3.5) and Hofmeester's (2012) prototype work for Windows 8 touch (Section 3.3.5.2) were reviewed to support the choice of interaction techniques.

In the second study, the versions of the SPG interaction that self-previewed gestures marginally outperformed the version that provided 'tap-to-preview'; thus, thesis hypothesis (b), which expected automatic display of gesture prompts to be more effective than a manually triggered method, was not supported. The data from the second study suggests that research question '2' requires further addressing. While the specific design was ineffective, there is a good possibility that an alternative design might prove far superior to the one chosen in this research. In this section, we discuss the limitations that may have caused H0 to be rejected and offer suggestions for future work.

Limitations of the interaction techniques used in the studies are now introduced, followed by a suggestion of future work:

1. Limited exploration of the potential range of SPG versions: As reported in Section 7.4.1, there were 18 application versions were candidates for testing the following interaction techniques: 'automatic versus tap-to-preview', 'static versus animated' and 'gesture versus effect'. These were defined to address thesis hypotheses (a) and (b). However, for statistical reasons, the nearest number that could permit a balanced set of conditions was taken (see Section 7.4.1). Thus, 13 alternatives were left unexplored and a subset of five versions that embedded the necessary characteristics was selected. Two versions corresponded to the improved condition (the SPG), and three to different forms of baseline (industrial practice and research baseline).

As with the selection of designs in Section 9.2.3, there is the possibility that the 'ideal' configuration could have been found within one of the remaining 13 versions. The identification of the 18 versions drew on common characteristics of existing interactions found in academic research and industrial standards. There is a risk, however, in mirroring pre-existing designs. There may be factors that current designs overlook, and so drawing from them leads to a design bias. Thus, given this possible design bias and the exclusion of thirteen known potential designs, there is ample scope for experimentation with further interactions to achieve even lower error rates.

Some unanticipated issues emerged from the empirical work undertaken with the versions that were tested:

a. Limited experimental control of tap-to-preview versus SPG during the second study: One increasingly common interaction technique used in gestural interfaces (such as that found in Hofmeester, 2012) is the use of a 'tap-to-preview' gesture necessary to undertake a certain action. However, users are unfamiliar with this interaction technique, and the lack of affordances to indicate its availability makes this interaction only marginally visible. Participants were not familiarised with the technique within the study and the goal of the study was to discover users' behaviour without (facilitator) training.

Thirty-four participants discovered the tap-to-preview by accident. An unexpected, but positive, outcome from this accidental discovery is that participants used the feature at least once to replay the gestural affordance. Incidentally, eight participants formed the expectation that tap-to-preview was a mandatory part of the interaction that had to be performed before the gesture itself, which could be viewed as the consequence of a 'priming effect': "I understand that first I have to do a small touch for the corner to fade…then I have to hold it and drag it" (P9, F, 39).

On reflection, the experimental method could have provided better control of the condition. What was not explicitly known before the study was that users can quickly adopt the opportunity of using tap-to-preview, and this appears to produce a rapid shift in behaviour and expectation. Once it was discovered, users attempted to use it at other times. This factor was not controlled for within the study, as it was unknown beforehand. Naturally, a further study that better controls for this effect would be highly desirable.

b. Low effectiveness of current and proposed interaction techniques in showing undo gestures: Users typically try the reverse of an action that made a certain change in the system in order to undo the action. This issue was previously raised by both Shneiderman (1982) and Dix (1996) regarding the WIMP-GUI desktop metaphor.

Previous researchers have tried to address this long-standing issue, as noted in Section 3.3.5.1.2. Wigdor and Wixton (2011) recommended the use of abstract principles of transformation to direct the design of gestural interfaces. They argue that holding to these principles would create interactions that are easier for users to acquire and understand.

During the design work carried out in this thesis, the two principles that most directly matched the problems we observed in undo actions were negation and reciprocity. As reported in Section 5.3.2, Wigdor and Wixton (2011: 137-138) explain the difference between the two: "Negation cancels an operation in progress, while a reciprocal action undoes an action after it is completed but may (or may not) leave some of the consequences of the action unchanged".

These two principles are in fact broken by the designs for undo found in dominant touch-based interfaces such as iOS and Android. For example, undo in many iPad apps is a shake of the entire device – an action that is rarely if ever used in other contexts. If we consider the principle of feedforward on the one hand and that of negation on the other, a plausible approach would be to use the opposite gesture for the undo of an action to the gesture originally performed to do the gesture. For example, dragging an object to the right naturally 'undoes' a previous drag to the left. However, such direct mappings are not always readily available (to the designer), if they are indeed at all plausible – e.g. minimising an app typically makes it invisible, and so it is inherently problematic to make contact with an invisible object (see Section 5.3.2).

Data from our first study exemplifies this problem, and provides some evidence to support the reasoning one might extrapolate from Wigdor and Wixton. That study used new designs that included animation and feedforward to show users both original gestures and their corresponding 'undo' actions. The aim of that approach was to increase the chance of users successfully completing the 'doing' or 'undoing' of an action. That study particularly suffered from a high number of errors in assessment and execution by participants trying to 'reverse' or 'undo' gestures, with 19.7% of users making errors (Section 6.5.4).

Not all the undo actions fulfilled the principles of negation, reciprocity or feedforward, as they drew on industrial designs, and naturally suffered similar problems in the study to those reported by Shneiderman, Dix and others. However, where the designs met these principles, error rates were lower (the undo phase yielded 12.1%). Furthermore, a number of participants were observed attempting the opposite action of the gesture they wished to undo. This suggests that the tentative moves towards that approach made in the first study merit further investigation.

Scope for improvement and future work

Issue 'a': The tap-to-preview technique should be further explored. Eight participants (of forty-five) were prone to repeatedly making a tap-to-preview 'tap' because they believed the step was mandatory when in fact it was discretionary. This is clearly undesirable. Further work will be needed to explore if this misunderstanding can be avoided, e.g. by changing the timing of the introduction of the tap-to-preview principle (e.g. when the application is first loaded, trial-and-error, within a limited set of repetitions, etc.). It is possible that at present it is over-priming some users.

Although tap-to-preview was quickly adopted by most, its effects on learning gestures beyond the first moment of acquisition were not directly studied. That phase of learning more closely relates to the memorisation phases that were the focus of previous work, such as Freeman (see recall in Section 4.5). This is one area where the integration between SPG at the first moment of making a user aware of an action needs to be theoretically and practically connected to the work already performed on repeating actions for the purpose of learning them. Data on, for example, how many times participants used the tap-to-preview to actually re-display the target gesture or its effect, and indeed which of the gesture actions or gesture effects they wished to confirm, could helpfully inform future research and design of SPG and other gesture teaching techniques.

Issue 'b': In relation to the 'undo' gesture, it is recommended that the potential of feedforward to improve user acquisition of undo gestures be studied. The potential benefit of feedforward in reducing user error in this vulnerable and error-prone type of action was shown in the first study. However, the scope of this thesis was not focussed on undo actions only, and much has been left undone. One challenging issue is how to portray to the user an undo gesture when there is no natural opposite action to the original gesture itself – e.g. the case of minimising an application. While a design could show users how to restore an application to full screen, for example, the timing of this cue, and its content, are both poorly understood at present. This area is therefore one worthy of further design work and of careful investigation of the effects of different designs.

2. Lack of integration with gesture-completion paths: As previously reported (Section 3.3.3 and Section 4.4.1), the prevalent approach in academia is to provide gesture-completion paths in response to users touching control objects on a screen. For instance, Bau & Mackay's (2008) OctoPocus technique shows all possible gesture-completion paths in response to a user maintaining contact with the screen and moving his or her finger over it.

This research has been influenced by others who have sought to guide the user in the continuation phase of executing a gesture. Those researchers have aimed to improve users' recall of newly discovered gestures, or of infrequently used ones. The goal of this thesis is complementary, seeking to improve the likelihood of discovering a new gesture, and of effectively executing it for the first time.

Scope for improvement and future work

The option of combining the SPG technique and gesture-completion-paths has not been investigated. It would be desirable to arrive at a design concept that encapsulates and combines both techniques. Our research has focussed on making users aware of unfamiliar gestures, a known point of error in touch interaction. Prior researchers have more closely studied how users can learn a gesture until they clearly remember both its action and effect.

To be effective, and experience a low error rate, users clearly need to perform effectively at both these closely interlinked steps. Arriving at a well-combined and integrated approach is therefore a natural ideal to pursue. Future research should explore which combinations of these techniques can yield the lowest overall error rates. It is possible that designs that optimise one of the two aspects of first encounter or short-term learning are not easily combined with those that optimise the other. The most effective hybrid might require a compromise on one or other aspect to maximise user performance overall. Such issues require both careful planning in design and systematic evaluation of the effectiveness of any proposed designs.

3. Limited exploration of the timing and context to show the SPG prompts: An interaction technique that was not explored in the empirical work was that of 'intelligent' interfaces. Vanacken et al. (2008) explain that intelligent interfaces can detect users' need for guidance. An implicit strategy may, for example, detect the repeated usage of single-touch interaction techniques when the system requires the use of multi-touch; for instance, a user might try to scale a picture with only one finger when it would be more efficient to use two fingers.

Another strategy would be providing contextual help after a delay in the user's actions. This system could also stop showing visual guidance after reaching a pre-determined condition, such as detecting that the user had already activated control objects the system had previewed. However, in case another user who is unfamiliar with the interface takes control of the system, there is the possibility that the educational process will be compromised. In this case, the system should detect the incorrect gestures and yet again display visual cues. Further studies should explore these approaches in isolation and in combined form.

Scope for improvement and future work

The designs tested in the second study used two simple mechanisms for controlling when the SPG cues were shown: manual ('tap-to-preview') and automatic (self-previewing). Vanacken et al.'s (2008) principle of intelligent interfaces suggests that a better approach would be to reveal cues only at an appropriate (computer-detected) moment. Our designs had a limited number of interactions that users had to acquire, and we introduced gestures one by one.

In a complex interface, there would be many gestures to acquire, and user attention can only be drawn to one at a time. Hence, which of the many to select to show to the user, where it is to be shown and when it is shown are all issues that, Vanacken argues, could effectively be controlled by an intelligent system. This thesis has not addressed the complications that would naturally arise with a large vocabulary of gestures or how to manage this; almost certainly drawing on Vanacken's context-aware (or context-sensitive) approach would be a wise first step.

The selection of which gestures to show and when is a design issue in itself, and how to successfully combine design expertise with an intelligent system, or indeed to control the cues shown to users in any other way, is a complex design problem in its own right. A rigorous investigation of potential approaches, and a comparison of those alternatives, is very much needed.

9.3 Closing Statement

Like most doctoral research projects, this one encompassed a theoretical part, which was covered in the literature review chapter. Nevertheless, its main contribution stems from a laboratory-based RTD for design activity: application prototypes were painstakingly designed and tested. Over eighty participants were recruited across two empirical studies. A GEM and a rating system for gestural interfaces were created to assess gestural user interfaces.

The findings from these studies contribute to research *for* design. These are transferable, and contributed a deeper understanding of the problems users have when interacting with touch systems. The findings also contemplate design recommendations to mitigate these errors.

Other researchers and practitioners could use the GEM framework in different studies with gestural user interfaces. The SPG design concept showed promising results, and is therefore very likely to mitigate user issues with novel gestural interfaces and unfamiliar touch interactions.

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APPENDIX A - BCS HCI 2011 DOCTORAL CONS.

INVESTIGATING PERCEPTIBLE AFFORDANCES OF NATURAL USER-INTERFACES: AN EYE TRACKING STUDY

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This research investigates Perceptible Affordances and their role in informing users about visual cues for interaction with emerging NUI (Natural User-Interface) technologies. Perceptible Affordances theory is explained through the prism of Gibson (1979), Norman (1999) and Gaver (1991). A study utilising eye-tracking technology followed by a non-concurrent think-aloud is described, which focused only on the observational phase of participants' interactions with a digital interface. The iGoogle Personal Web Portal was selected as a case study and drag-and-drop interaction was identified as a non-obvious feature that could be unknown to users. At last we have arrived at some initial findings that demonstrate how previous knowledge is a key factor on spotting specific interface control features; and the interface itself did not present visual cues that would inform users about available features for customization and grad-and-drop interactions. During the last year of this research, three iPad icon libraries will be designed and compared by means of a practical investigation with a between-groups design. This empirical case study aims to unveil which version users would be keener to adapt and adopt and thus which designs and UI behaviours present better-adapted perceptible affordances for touch-based NUI.

HCI, GUI, NUI, Embodiment, Perceptible Affordances, Eye Tracking, Post-WIMP Interfaces.

1. INTRODUCTION

The introduction of novel hardware for computing and gaming during the last decade is changing the way we physically interact with everyday devices (Dam, 1997), such as touch based computers and phones (e.g. MS Surface, iPad and iPhone), gesture-based gaming (e.g. Nintendo Wii, Microsoft Xbox 360 with Kinect) and even eye tracking interactions (e.g. Tobii P-10 and Tobii LeNovo).

In a move away from traditional graphical user interfaces (GUIs), new control technologies have also lead to the introduction of 'Post-WIMP' (Beaudouin-Lafon, 2000; Jacob et al, 2008) interfaces, which no longer necessarily incorporate familiar WIMP (Windows, Icons, Menus and Pointing device) control schemes and 'desktop' metaphors.

This introduces issues regarding identification and ease of use of the range of new controls and gestures. While the 'natural' emphasis in the term NUI goes some way to remedy these concerns, novel technologies will still require learning and adaptation in the same way users once had to learn and adapt to the mouse and keyboard. They have to learn a new visual vocabulary, and new ways to interact (Wigdor, 2011: 9), which raises a number of questions including: How do users make sense of what the controls are (or could be), where the control language might not be familiar? Would unfamiliarity lead to these controls not to be spotted? Fundamentally this is an issue of how to 'teach' users – through the interface – what are the controls and how to operate them.

Some issues that have initially been identified during the course of this research that could generate problems for users on identifying potential interactions within NUI are described as follows:

1. Unfamiliarity with novel visual metaphors within NUI and physical modes of interaction (Dam, 1997; Buxton, 2008; Jacob, 2008) different from WIMP-GUI,
2. 'Hybrid solutions' (Dourish, 2004; Sorensen, 2009) of NUI devices displaying former desktop based OS,
3. The inability of users to spot hidden menus and toolbars (Norman & Nielsen, 2010) within NUI,
4. The inability of users of learning specific 'hidden gestures' (Norman, 2012) to display hidden menus and toolbars or simply interacting with content (e.g.

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swiping pages and zooming in/out pictures) within NUI devices.

There aren't enough examples within present HCI literature (Jacob, 2008; McGrenere et al, 2000) about how to assess the introduction of new interaction and control paradigms within NUI, and furthermore, how to test them; they mostly address WIMP-GUI which was the technology available on the moment of different publications. More recently, Wigdor (2011) made a thorough approach on how to design NUI but do not present experimentation and user feedback data from real usage of touch-based devices.

Touch-based devices (e.g. iPad), which present the abovementioned issues will be utilised as empirical case studies during the course of this research. The objective of these studies is to find out if participants can spot available controls; if they can understand each controls' metaphorical potential and how controls could be activated – before any physical action takes place. The activation of controls through physical interactions and user understanding of the outcome of their actions/system feedback will be scrutinised as well, in order to obtain the full understanding of evaluation and action cycles, as regarded by different authors (Norman, 1988; Amant, 1999; Preece, 2009).

2. RESEARCH QUESTIONS

The research questions devised were resultant from two enterprises: First, from a series of informal studies that were conducted with several NUI technologies for interaction, in order to contemplate the issues of 'Unfamiliarity', 'Hybrid Solutions', 'Hidden Interfaces' and 'Hidden Gestures' (e.g. Microsoft X-Box with Kinect, Microsoft Surface, Tobii P-10 and LeNovo for assistive technology, iPad, Windows 8 consumer preview).

Second, from a comparative empirical study that explored the development of a specific protocol for conducting test with participants. The protocol utilised eye tracking followed by a non-concurrent think-aloud component.

After conducting the abovementioned studies it was possible to organise the following research questions:

1. How can we make users spot visual cues for activation of controls within NUI systems?

1.1. After spotting these cues will users make the correct assumptions of how to interact through physical modes (e.g. touch, gestures, voice, etc.)?

The question was partially addressed by results obtained with the aforementioned empirical study.

2. How to design visual cues for NUI interaction that would enhance physical and gestural affordances the system provides?

The protocol used on the first study is being revised and updated with a component that encompasses activation of controls and examination of user's understanding of system feedback.

3. What are the most appropriate methods to investigate Perceptible Affordances within NUI?

3.1. How to better analyse empirical data that covers identification, understanding and activation of controls available for physical interaction?

3. THEORETICAL MODELS UTILISED

The core models that have been used in this research to understand this first encounter between a user and a system are Perceptible Affordances theory (Gibson, 1986; Norman, 1988 and Gaver, 1991) and Norman's theory of action (Norman, 1988, Preece et al, 2009: 121). They identify the various steps a user's thinking goes through when evaluating features available in a computer system interface; and they also distinguish actions, which translate to execution of commands and activation of controls.

Amant (1999), for instance, has a similar approach within his framework to support GUI representation of affordances. He splits affordances into 'evaluation, 'representation' and 'execution', where the preconditions of an affordance or its properties, afford some specific activity in that their absence would make the activity more difficult or that their presence facilitates the activity in comparison to alternative activities.

As can be seen on the model depicted on 'Figure 1', Perceptible Affordances are placed as the intermediate phenomena between evaluation and execution cycles in relation to NUI interfaces and physical modes of interaction. From this research approach, the theory of Perceptible Affordances resonates and complements the very different stages of Norman's Theory of Action, in particular to the evaluation cycle, where the user is still assessing and trying to make sense of a system. Still, the role of affordances is regarded as a bridge between the two gulfs, once interaction can only be regarded as effective embodied action (Dourish, 2004).

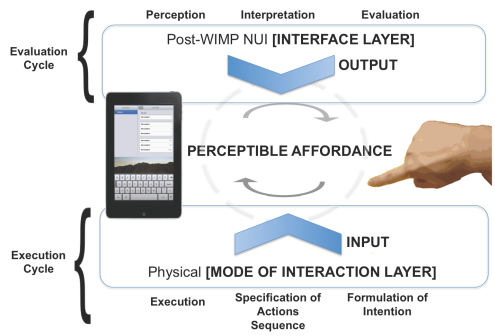

Figure 1: *Norman's Theory of Action (1988) in relation to Perceptible Affordances.*

4. THE IGOOGLE CASE STUDY

In this study it was hypothesized that drag-and-drop features within iGoogle Personal Web Portal do not signal efficiently its potential for interaction (according to Spool, 2005, Nielsen, 2008); and users depending on their expertise do not spot this feature. An empirical comparative study with Eye Tracking was conducted in order to better understand how the website signals the possibility for drag-and-drop interaction of the content. By comparing quantitative and qualitative results of different expertise groups we confirmed the hypothesis that expertise influences how able a user is to identify and understand cues for interaction within the interface. In the case of personal web portals, a general lack of familiarity with this type of website hinders the effective use of these systems by new users. Clearer and stronger cues for perceptible affordances are needed to ensure that users can quickly adopt and adapt.

4.1. Methodology

A methodology to conduct an empirical test with eye tracking technology and posterior think-aloud was developed for this research. It focused on how participants (p = 10, 4M 6F, ages 22 to 54) perceived iGoogle portal, before any interaction through pointing device took place. Participants were randomly selected from a cohort of different departments students and staff within City University London. In order to avoid biased interaction, it was decided that participants should be tested on the website only if they had never used it before. Three expertise groups were identified, based on participants' response to a questionnaire: four 'Advanced', four 'Intermediaries' and two 'Beginner' skilled users were identified.
In this study, the first goal was to investigate if participants would be able to spot drag-and-drop interactions of widgets contained within iGoogle portal dashboard; and second, if they would be able to recognise the website as a customizable web service different from regular web portals.
The raw data obtained from Tobii x60 eye-tracker (e.g. saccades plots and fixations times) was analysed quantitatively and the following think-aloud was analysed qualitatively through Open Coding (Cairns: 2008, 141); and participant's utterances were organized into classes, using Gibbs' (2007) inductive approach for qualitative data analysis.
The method was split in three phases:
1. Participants were given about thirty seconds to observe the website. This phase was intended to allow them to get acquainted to its visual structure without any task in mind.
2. The facilitator presented four questions subsequently, and participants were instructed not to use the mouse or keyboard and not to verbalize for the very first 10 seconds after questions were introduced. The questions are listed below:
Q1: What is this website for?
Q2: What can you do in this kind of website?
Q3: Do you think is possible to change the screen the way you like it?
Q4: Is it possible to move anything in there?
This questionnaire was designed to drive the participant eye and capture how he/she scrutinizes the interface with specific goals – in our case study it aimed to capture how they seek and identify visual cues that relate to the questions made.
3. After each ten-second-observation slot they were asked to think aloud about their perceptions of the screen for about a maximum of fifteen minutes. Contrasting results emerged from participants with different expertise and will be addressed in the following section.

4.2. Findings

An aspect of interest this research wanted to verify was if during the study participants were gazing randomly at the interface or there were particular points they were focusing on. Usually larger Areas of Interest (AOI) are looked first if a specific order or stimuli is not introduced. The introduction of questions changed this trend by mitigating participants' memory and thus knowledge of similar interfaces. The eye tracking data and posterior verbalizations yielded the following conclusions:
1. The quantitative data demonstrated that participants were focusing more on small then large AOI, thus contrasting with projected values, if considered area size only. Significant results ($p<0.001$) were obtained with 'Fixation Count', 'Total Fixation Duration' and 'First Fixation Duration' filters. It was verified that projected numbers for time spent on small AOI (e.g. 'widget control area' with an AOI of 5.88% and 'widget move area' with an AOI of 3.83%) displayed approximately four times less then average numbers for all filters. Projected numbers for time spent on a large AOI such 'widget content' (43.23%) displayed approximately twice less then average numbers for all filters.
2. The qualitative data demonstrated that specifically intermediate and advanced users were aware about customization and drag-and-drop controls. When asked about the possibility of moving objects within the portal the majority responded "Yes" with 50%, some responded "Maybe" with 20% and some responded "No" with 30%. All participants that responded positively were within the 'Intermediate' and 'Advanced' expertise groups. Beginner expertise users did not look to relevant controls and concentrated more on imagery and textual content, which matched their utterances.

5. CONCLUSIONS

As could be learned from the first study, participants did not learn controls for drag-and-drop and customization features, just by looking at the interface, which suggests the absence of evident visual cues to inform otherwise. This is a concerning factor once this research stresses the argument that designing clearer and stronger visual cues is paramount for user identification of controls within digital interfaces – especially with the emerging gesture controls for NUI devices. Based on this statement, the contributions are listed as follows:

1. A cognitive theoretical model that includes eye-tracking with non-concurrent think-aloud protocol for analysis of NUI embedded in physical input devices. The model structures experimental process for empirical testing of perceptible affordances displayed by these systems and was based on Amant's (1999) Conceptual Framework on Perceptible Affordances and Marshall's (2007).
2. A framework for designing NUI systems (initially touch-based). The framework has a user-centred approach and checks throughout different heuristics the variety of strength and weaknesses of design aspects. The framework was based on the work of Beaudin-Lafon's (2000) Interaction model for Designing Post-WIMP UI and Jacob's (2008) Framework for Designing Post-WIMP Interfaces based on Reality-Based Interaction.
3. Valuable data will be obtained with the cognitive theoretical model, which will be used to validate how the introduction of visual cues for physical interactions could effectively improve perceptible affordances of the aforementioned control gestures. Three iPad icon libraries will be designed and compared by means of a practical investigation with a between-groups design. Initially the test aims at investigating how users discover and interact with hidden menus and hidden gestures for 'swipe' and 'pinch' interactions.

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APPENDIX B - IPAD GESTURE VOCABULARY

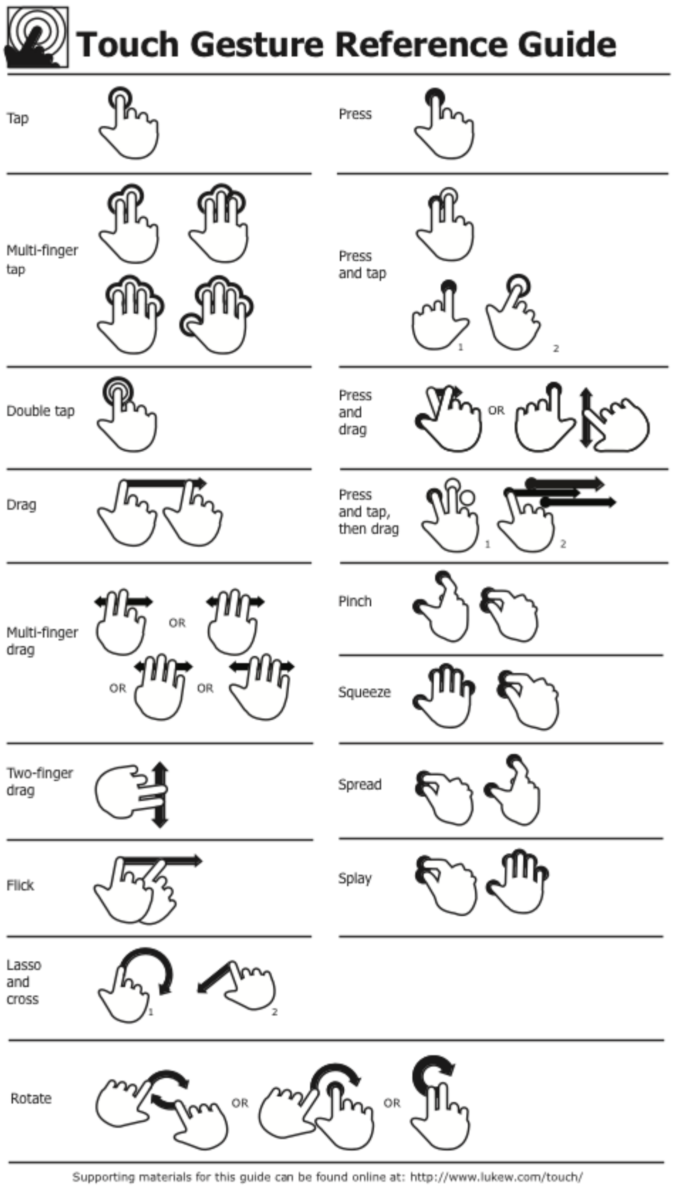


Figure 94: iPad gesture vocabulary (London, May 2012)[10].

[10] http://graffletopia.com/stencils/587

APPENDIX C - GESTURE-AND-EFFECT MODEL

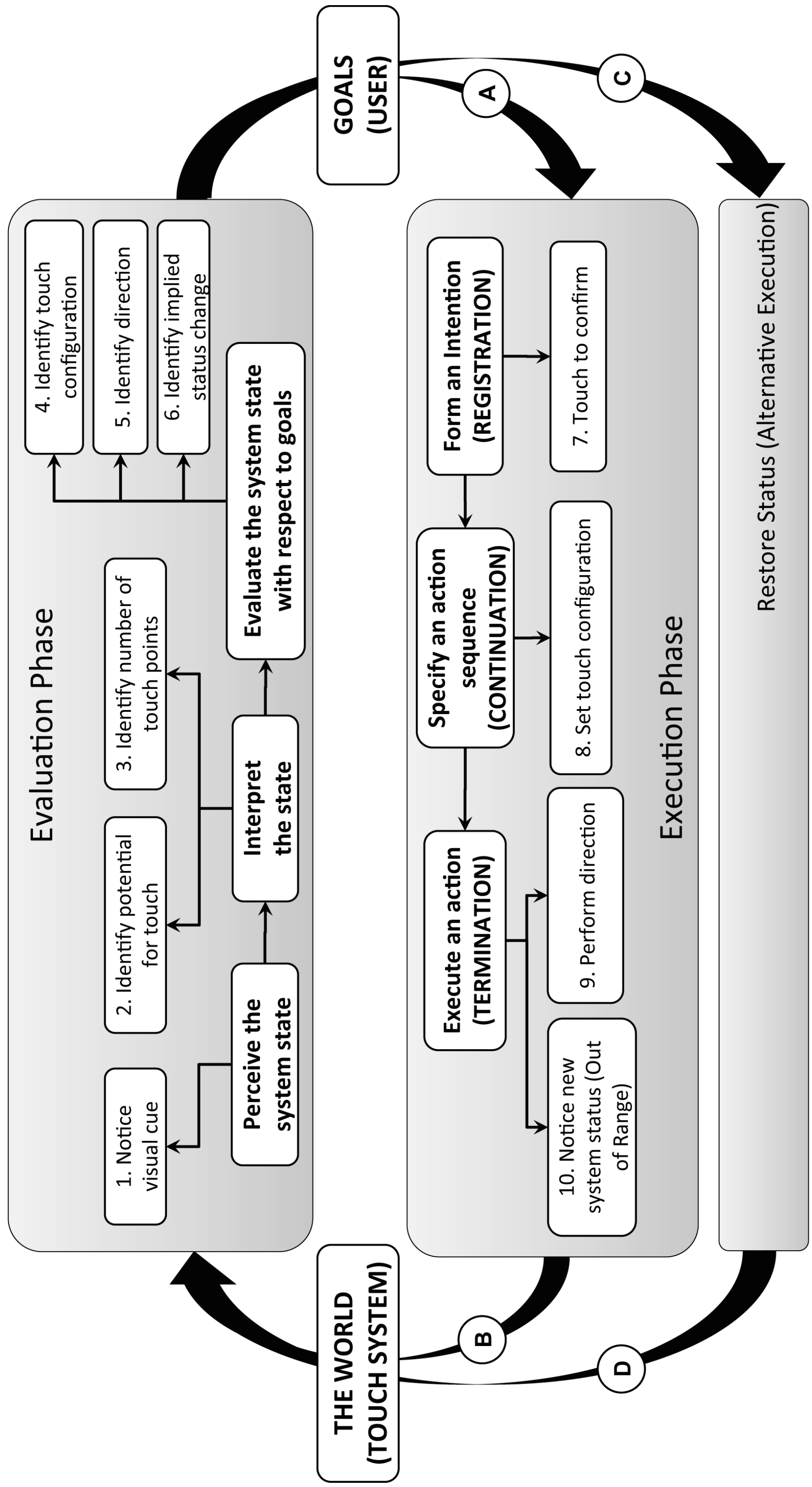


Figure 95: gesture-and-effect model.

APPENDIX D - RECRUITMENT POSTER (ST 1)

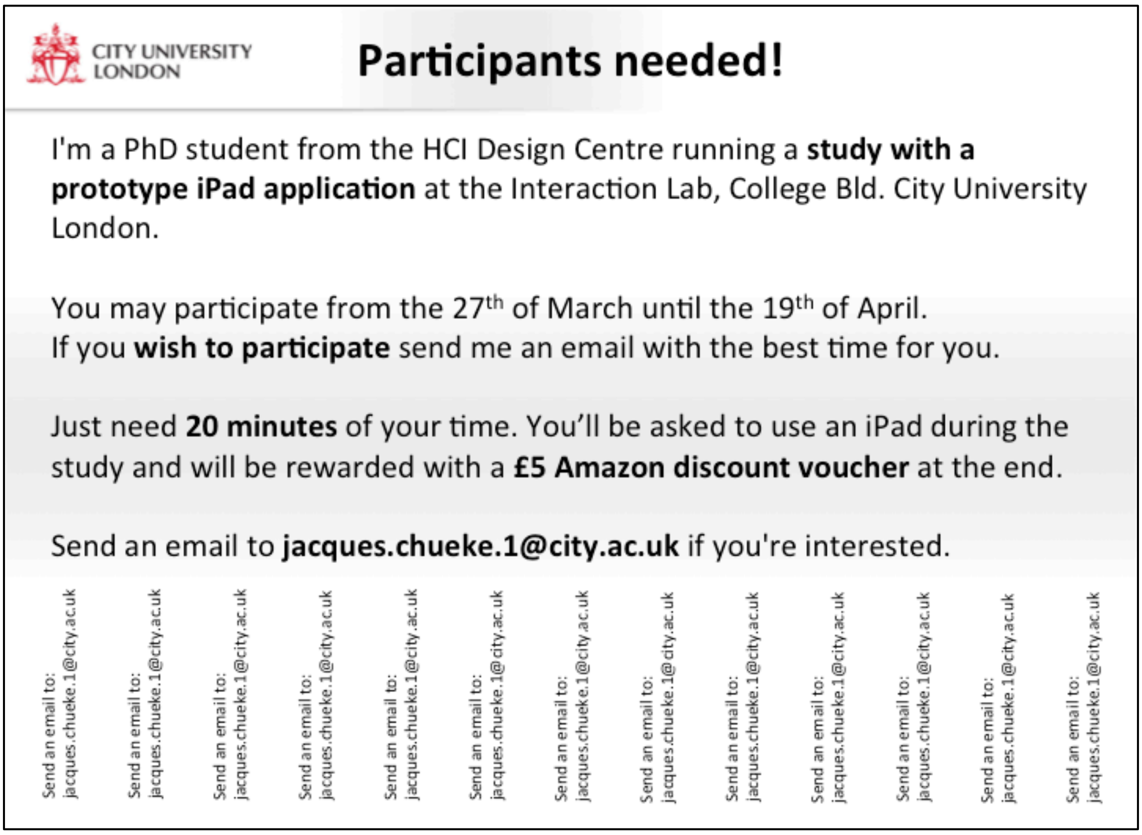


Figure 96: Recruitment poster for Study 1.

APPENDIX E - CONSENT FORM (STUDY 1)

This research investigates visual cues for interaction with emerging technologies, especially touch-based devices. If you agree to participate in the test, first you will be asked to answer to a few questions about yourself, then to observe an iPad application and describe what you see on the screen. After that you will be asked to interact with the program and answer to a few more questions. You will be asked to do this for different versions of the iPad application, all in presence of the facilitator.

Your participation will take approximately 20-25 minutes and no risk from participation is anticipated. There are no right or wrong answers and this session is to evaluate the system and is not about testing your skills. Any information you share will be kept confidential and your name will not be associated with your data (you will be referred to as "participant"). However, highlight video prints along with findings will be used in presentations, the PhD thesis and the production of papers. Your privacy is protected to the maximum extent allowable by UK Law.

Your participation is completely voluntary. You may choose not to participate at all, may refuse to participate in certain procedures or answer certain questions, or may discontinue your participation at any time without penalty. Your decision to participate will not affect your relationship with City University London or the person who identified you as a potential participant. Agreeing to participate and signing this form does not waive any of your legal rights. If you have any questions about this study, please contact Jacques Chueke, PhD Researcher within the Centre for HCI Design by phone: (0) 797575 5544, or email: jacques.chueke.1@city.ac.uk

If you voluntarily agree to participate in this research, having your comments video recorded, and have had all questions answered, please sign below.

Participant's Signature Date

Researcher's Signature Date

APPENDIX F - PRE-TEST QUEST. (STUDY 1)

1. Name: ____

2. Email: ____

3. Nationality: ____

4. Occupation: ____

5. Age: ____

6. Gender

☐ Male ☐ Female ☐ Other

7. Do you have a laptop with trackpad?

☐ Yes ☐ No If yes, which one?

____

8. Do you have a touch-based phone?

☐ Yes ☐ No If yes, which one?

____

9. Do you have a tablet/PDA?

☐ Yes ☐ No If yes, which one?

____

10. How often do you use your tablet/PDA?

☐ Daily

☐ 1-4 times a week

☐ 1-3 times a month

☐ Never

APPENDIX G- RANDOMIZATION SET (STUDY 1)

Random 01: I4-S7-I3-S8-I2-S5-I1-S6-I8-S3-I7-S4-I6-S1-I5-S2

ICONS04 ZOOM IN/OUT ZOOM IN/OUT	SMUDGE07 TASK SWITCHER	Participants
ICONS03 DISPLAY OPTIONS DISPLAY OPTIONS	SMUDGE08 MINIMISE APP	
ICONS02 DRAG PICTURE DRAG PICTURE	SMUDGE05 FLIP PAGE	
ICONS01 UNVEIL MAIN MENU UNVEIL MAIN MENU	SMUDGE06 SWIPE APPS	
ICONS08 MINIMISE APP MINIMISE APP	SMUDGE03 DISPLAY OPTIONS	
ICONS07 TASK SWITCHER TASK SWITCHER	SMUDGE04 ZOOM IN/OUT	
ICONS06 SWIPE APPS SWIPE APPS	SMUDGE01 UNVEIL MAIN MENU	
ICONS05 FLIP PAGE FLIP PAGE	SMUDGE02 DRAG PICTURE	

Random 02: I1-S6-I2-S5-I3-S8-I4-S7-I5-S2-I6-S1-I7-S4-I8-S3

ICONS01 UNVEIL MAIN MENU UNVEIL MAIN MENU	SMUDGE06 SWIPE APPS	Participants
ICONS02 DRAG PICTURE DRAG PICTURE	SMUDGE05 FLIP PAGE	
ICONS03 DISPLAY OPTIONS DISPLAY OPTIONS	SMUDGE08 MINIMISE APP	
ICONS04 ZOOM IN/OUT ZOOM IN/OUT	SMUDGE07 TASK SWITCHER	
ICONS05 FLIP PAGE FLIP PAGE	SMUDGE02 DRAG PICTURE	
ICONS06 SWIPE APPS SWIPE APPS	SMUDGE01 UNVEIL MAIN MENU	
ICONS07 TASK SWITCHER TASK SWITCHER	SMUDGE04 ZOOM IN/OUT	
ICONS08 MINIMISE APP MINIMISE APP	SMUDGE03 DISPLAY OPTIONS	

Random 03: I2-S5-I1-S6-I4-S7-I3-S8-I6-S1-I5-S2-I8-S3-I7-S4

ICONS02 DRAG PICTURE DRAG PICTURE	SMUDGE05 FLIP PAGE	Participants
ICONS01 UNVEIL MAIN MENU UNVEIL MAIN MENU	SMUDGE06 SWIPE APPS	
ICONS04 ZOOM IN/OUT ZOOM IN/OUT	SMUDGE07 TASK SWITCHER	
ICONS03 DISPLAY OPTIONS DISPLAY OPTIONS	SMUDGE08 MINIMISE APP	
ICONS06 SWIPE APPS SWIPE APPS	SMUDGE01 UNVEIL MAIN MENU	
ICONS05 FLIP PAGE FLIP PAGE	SMUDGE02 DRAG PICTURE	
ICONS08 MINIMISE APP MINIMISE APP	SMUDGE03 DISPLAY OPTIONS	
ICONS07 TASK SWITCHER TASK SWITCHER	SMUDGE04 ZOOM IN/OUT	

Random 04: I3-S8-I4-S7-I1-S6-I2-S5-I7-S4-I8-S3-I5-S2-I6-S1

ICONS03 DISPLAY OPTIONS DISPLAY OPTIONS	SMUDGE08 MINIMISE APP	Participants
ICONS04 ZOOM IN/OUT ZOOM IN/OUT	SMUDGE07 TASK SWITCHER	
ICONS01 UNVEIL MAIN MENU UNVEIL MAIN MENU	SMUDGE06 SWIPE APPS	
ICONS02 DRAG PICTURE DRAG PICTURE	SMUDGE05 FLIP PAGE	
ICONS07 TASK SWITCHER TASK SWITCHER	SMUDGE04 ZOOM IN/OUT	
ICONS08 MINIMISE APP MINIMISE APP	SMUDGE03 DISPLAY OPTIONS	
ICONS05 FLIP PAGE FLIP PAGE	SMUDGE02 DRAG PICTURE	
ICONS06 SWIPE APPS SWIPE APPS	SMUDGE01 UNVEIL MAIN MENU	

APPENDIX H- INDEPENDENT SAMPLES TEST - (STUDY 1)

Test of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
identify_potential_touch	.450	900	0.000	.584	900	.000
identify_touch_points	.493	900	0.000	.475	900	.000
identify_touch_config	.480	900	0.000	.511	900	.000
identify_direction	.537	900	0.000	.246	900	.000
identify_system_status	.475	900	0.000	.520	900	.000
tap_to_preview	.385	540	0.000	.632	540	.000
touch_to_confirm	.524	540	0.000	.356	540	.000
perform_swipe	.491	540	0.000	.482	540	.000
perform_direction	.538	540	0.000	.149	540	.000
system_status	.496	540	0.000	.477	540	.000

Interaction 1

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	.418	.520	-.336	66	.738	-.0147	.0438	-.1022	.0728
			-.336	65.360	.738	-.0147	.0438	-.1022	.0728
identify_touch_config	4.297	.042	-1.097	66	.276	-.0735	.0670	-.2073	.0602
			-1.097	62.043	.277	-.0735	.0670	-.2075	.0604
identify_touch_points	4.453	.039	-1.024	66	.310	-.0588	.0575	-.1736	.0559
			-1.024	53.800	.311	-.0588	.0575	-.1741	.0564
identify_type_of_gesture	7.972	.006	-1.380	66	.172	-.1029	.0746	-.2519	.0460
			-1.380	57.017	.173	-.1029	.0746	-.2523	.0464
identify_direction	7.972	.006	-1.380	66	.172	-.1029	.0746	-.2519	.0460
			-1.380	57.017	.173	-.1029	.0746	-.2523	.0464
identify_system_status	8.634	.005	-1.509	66	.136	-.0882	.0585	-.2050	.0285
			-1.509	57.552	.137	-.0882	.0585	-.2053	.0289
touch_to_confirm	4.254	.043	1.000	66	.321	.0294	.0294	-.0293	.0881
			1.000	33.000	.325	.0294	.0294	-.0304	.0893
set_type_of_gesture	4.254	.043	1.000	66	.321	.0147	.0147	-.0147	.0441
			1.000	33.000	.325	.0147	.0147	-.0152	.0446
system_status	4.254	.043	1.000	66	.321	.0294	.0294	-.0293	.0881
			1.000	33.000	.325	.0294	.0294	-.0304	.0893
restore_status	4.254	.043	1.000	66	.321	.0294	.0294	-.0293	.0881
			1.000	33.000	.325	.0294	.0294	-.0304	.0893

Interaction 2

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test					
	F	Sig.	t	df	Sig. (2-	Mean Difference	Std. Error Difference	95% Confidence Interval of the

					tailed)			Difference Lower	Difference Upper
identify_potential	4.254	.043	1.000	66	.321	.0294	.0294	-.0293	.0881
			1.000	33.000	.325	.0294	.0294	-.0304	.0893
identify_touch_config	.851	.360	.447	66	.656	.0147	.0329	-.0509	.0804
			.447	48.529	.657	.0147	.0329	-.0514	.0808
identify_touch_points	.000	1.000	0.000	66	1.000	0.0000	.0416	-.0830	.0830
			0.000	66.000	1.000	0.0000	.0416	-.0830	.0830
identify_type_of_gesture	.418	.520	-.336	66	.738	-.0147	.0438	-.1022	.0728
			-.336	65.360	.738	-.0147	.0438	-.1022	.0728
identify_direction	.418	.520	-.336	66	.738	-.0147	.0438	-.1022	.0728
			-.336	65.360	.738	-.0147	.0438	-.1022	.0728
identify_system_status	1.388	.243	-.583	66	.562	-.0294	.0504	-.1301	.0713
			-.583	59.884	.562	-.0294	.0504	-.1303	.0715
touch_to_confirm	4.254	.043	1.000	66	.321	.0147	.0147	-.0147	.0441
			1.000	33.000	.325	.0147	.0147	-.0152	.0446
set_type_of_gesture	9.387	.003	-1.436	66	.156	-.0294	.0205	-.0703	.0115
			-1.436	33.000	.160	-.0294	.0205	-.0711	.0123
restore_status	0.000	1.000	0.000	66	1.000	0.0000	.0208	-.0415	.0415
			0.000	66.000	1.000	0.0000	.0208	-.0415	.0415

Interaction 3

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	38.147	.000	-2.795	66	.007	-.2059	.0737	-.3530	-.0588
			-2.795	45.083	.008	-.2059	.0737	-.3542	-.0575
identify_touch_config	3.415	.069	-1.973	66	.053	-.1912	.0969	-.3847	.0023
			-1.973	64.651	.053	-.1912	.0969	-.3847	.0024
identify_touch_points	8.191	.006	-1.368	66	.176	-.1176	.0860	-.2893	.0540
			-1.368	59.146	.176	-.1176	.0860	-.2897	.0544
identify_type_of_gesture	1.413	.239	-2.102	66	.039	-.2353	.1119	-.4588	-.0118
			-2.102	65.668	.039	-.2353	.1119	-.4588	-.0118
identify_direction	15.484	.000	-1.806	66	.076	-.1471	.0814	-.3097	.0155
			-1.806	53.050	.077	-.1471	.0814	-.3104	.0163
identify_system_status	15.311	.000	-2.141	66	.036	-.1912	.0893	-.3695	-.0129
			-2.141	58.645	.036	-.1912	.0893	-.3699	-.0125
touch_to_confirm	.197	.658	.194	66	.846	.0147	.0756	-.1363	.1657
			.194	65.351	.846	.0147	.0756	-.1363	.1658
set_type_of_gesture	.070	.793	-.282	66	.779	-.0294	.1044	-.2379	.1791
			-.282	66.000	.779	-.0294	.1044	-.2379	.1791
perform_direction	.033	.856	-.147	66	.883	-.0147	.0997	-.2138	.1844
			-.147	65.999	.883	-.0147	.0997	-.2138	.1844
system_status	0.000	1.000	0.000	66	1.000	0.0000	.1086	-.2168	.2168
			0.000	66.000	1.000	0.0000	.1086	-.2168	.2168
restore_status	.360	.550	-.400	66	.690	-.0441	.1102	-.2641	.1759
			-.400	65.946	.690	-.0441	.1102	-.2641	.1759

Interaction 4

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	6.132	.016	-1.239	66	.220	-.1029	.0831	-.2688	.0629
			-1.239	60.767	.220	-.1029	.0831	-.2691	.0632
identify_touch_config	31.429	.000	-3.139	66	.003	-.2794	.0890	-.4571	-.1017
			-3.139	52.922	.003	-.2794	.0890	-.4580	-.1009
identify_touch_points	25.303	.000	-2.367	66	.021	-.2206	.0932	-.4066	-.0345
			-2.367	55.356	.021	-.2206	.0932	-.4073	-.0339
identify_type_of_gesture	34.469	.000	-2.714	66	.008	-.2794	.1029	-.4849	-.0739

			-2.714	57.469	.009	-.2794	.1029	-.4855	-.0733
identify_direction	23.779	.000	-2.204	66	.031	-.2059	.0934	-.3924	-.0193
			-2.204	55.236	.032	-.2059	.0934	-.3931	-.0187
identify_system_status	29.366	.000	-2.313	66	.024	-.1765	.0763	-.3288	-.0242
			-2.313	44.183	.025	-.1765	.0763	-.3302	-.0227
touch_to_confirm	2.282	.136	.745	66	.459	.0588	.0790	-.0989	.2165
			.745	62.993	.459	.0588	.0790	-.0990	.2167
set_type_of_gesture	.000	1.000	0.000	66	1.000	0.0000	.0872	-.1741	.1741
			0.000	66.000	1.000	0.0000	.0872	-.1741	.1741
perform_direction	.000	1.000	0.000	66	1.000	0.0000	.0793	-.1584	.1584
			0.000	66.000	1.000	0.0000	.0793	-.1584	.1584
system_status	.000	1.000	0.000	66	1.000	0.0000	.0872	-.1741	.1741
			0.000	66.000	1.000	0.0000	.0872	-.1741	.1741
restore_status	.371	.545	-.304	66	.762	-.0294	.0967	-.2226	.1637
			-.304	65.772	.762	-.0294	.0967	-.2226	.1637

Interaction 5

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	10.279	.002	1.477	66	.144	.1029	.0697	-.0362	.2421
			1.477	50.010	.146	.1029	.0697	-.0370	.2429
identify_touch_config	2.251	.138	.715	66	.477	.0441	.0617	-.0791	.1673
			.715	58.693	.477	.0441	.0617	-.0794	.1676
identify_touch_points	2.425	.124	.746	66	.458	.0441	.0591	-.0739	.1621
			.746	57.058	.458	.0441	.0591	-.0742	.1625
identify_type_of_gesture	1.724	.194	.625	66	.534	.0441	.0706	-.0969	.1851
			.625	61.776	.534	.0441	.0706	-.0971	.1853
identify_direction	2.984	.089	.847	66	.400	.0588	.0695	-.0798	.1975
			.847	60.405	.400	.0588	.0695	-.0801	.1977
identify_system_status	2.435	.123	.698	66	.488	.0588	.0843	-.1095	.2271
			.698	62.410	.488	.0588	.0843	-.1096	.2273
touch_to_confirm	9.387	.003	1.436	66	.156	.0588	.0410	-.0230	.1406
			1.436	33.000	.160	.0588	.0410	-.0245	.1422
set_type_of_gesture	9.387	.003	1.436	66	.156	.0588	.0410	-.0230	.1406
			1.436	33.000	.160	.0588	.0410	-.0245	.1422
perform_direction	9.387	.003	1.436	66	.156	.0588	.0410	-.0230	.1406
			1.436	33.000	.160	.0588	.0410	-.0245	.1422
system_status	9.387	.003	1.436	66	.156	.0588	.0410	-.0230	.1406
			1.436	33.000	.160	.0588	.0410	-.0245	.1422
restore_status	4.453	.039	1.024	66	.310	.0588	.0575	-.0559	.1736
			1.024	53.800	.311	.0588	.0575	-.0564	.1741

Interaction 6

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	10.427	.002	1.782	66	.079	.1029	.0578	-.0124	.2183
			1.782	61.782	.080	.1029	.0578	-.0125	.2184
identify_touch_config	4.512	.037	1.308	66	.195	.1029	.0787	-.0542	.2601
			1.308	64.183	.196	.1029	.0787	-.0543	.2601
identify_touch_points	4.871	.031	1.978	66	.052	.2059	.1041	-.0020	.4137
			1.978	64.312	.052	.2059	.1041	-.0021	.4139
identify_type_of_gesture	1.526	.221	.642	66	.523	.0294	.0458	-.0620	.1208
			.642	64.039	.523	.0294	.0458	-.0621	.1209
identify_direction	.003	.958	0.000	66	1.000	0.0000	.0358	-.0716	.0716
			0.000	58.909	1.000	0.0000	.0358	-.0717	.0717
identify_system_status	10.882	.002	2.189	66	.032	.1618	.0739	.0142	.3093
			2.189	59.257	.033	.1618	.0739	.0139	.3096
touch_to_confirm	11.737	.001	2.478	66	.016	.2206	.0890	.0429	.3983

			2.478	58.558	.016	.2206	.0890	.0424	.3987
set_type_of_gesture	10.774	.002	1.635	66	.107	.1029	.0630	-.0228	.2287
			1.635	54.151	.108	.1029	.0630	-.0233	.2292
perform_direction	4.016	.049	.976	66	.333	.0588	.0603	-.0615	.1791
			.976	56.153	.333	.0588	.0603	-.0619	.1795
system_status	31.341	.000	2.608	66	.011	.2647	.1015	.0621	.4674
			2.608	57.313	.012	.2647	.1015	.0615	.4679
restore_status	34.436	.000	3.003	66	.004	.2941	.0980	.0986	.4897
			3.003	55.411	.004	.2941	.0980	.0979	.4904

Interaction 7

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	5.036	.028	1.199	66	.235	.1029	.0859	-.0685	.2744
			1.199	62.481	.235	.1029	.0859	-.0687	.2746
identify_touch_config	7.882	.007	1.497	66	.139	.1324	.0884	-.0442	.3089
			1.497	61.176	.140	.1324	.0884	-.0444	.3092
identify_touch_points	2.372	.128	.755	66	.453	.0735	.0974	-.1210	.2681
			.755	64.655	.453	.0735	.0974	-.1211	.2682
identify_type_of_gesture	27.129	.000	2.270	66	.026	.1765	.0777	.0213	.3317
			2.270	46.365		.1765	.0777	.0200	.3329
identify_direction	40.879	.000	2.734	66	.008	.2206	.0807	.0595	.3816
			2.734	45.311		.2206	.0807	.0581	.3830
identify_system_status	10.883	.002	2.456	66	.017	.2353	.0958	.0441	.4265
			2.456	61.560		.2353	.0958	.0438	.4268
touch_to_confirm	47.919	.000	3.170	66	.002	.2647	.0835	.0980	.4314
			3.170	46.541		.2647	.0835	.0967	.4327
set_type_of_gesture	18.336	.000	1.915	66	.060	.1176	.0614	-.0050	.2403
			1.915	41.123		.1176	.0614	-.0064	.2417
perform_direction	31.085	.000	2.455	66	.017	.1912	.0779	.0357	.3466
			2.455	46.317		.1912	.0779	.0345	.3479
system_status	46.862	.000	3.914	66	.000	.3824	.0977	.1873	.5774
			3.914	53.263		.3824	.0977	.1865	.5783
restore_status	36.506	.000	3.310	66	.002	.3382	.1022	.1342	.5422
			3.310	57.000		.3382	.1022	.1336	.5428

Interaction 8

Independent Samples Test

	Levene's Test for Equality of Variances		Mann-Whitney U test						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
identify_potential	6.626	.012	1.254	66	.214	.0735	.0587	-.0436	.1906
			1.254	52.921	.216	.0735	.0587	-.0441	.1912
identify_touch_config	38.920	.000	2.687	66	.009	.2059	.0766	.0529	.3589
			2.687	44.073		.2059	.0766	.0515	.3603
identify_touch_points	21.084	.000	2.129	66	.037	.1618	.0760	.0101	.3135
			2.129	49.677		.1618	.0760	.0091	.3144
identify_type_of_gesture	20.900	.000	2.026	66	.047	.1471	.0726	.0021	.2920
			2.026	45.483		.1471	.0726	.0009	.2932
identify_direction	20.900	.000	2.026	66	.047	.1471	.0726	.0021	.2920
			2.026	45.483		.1471	.0726	.0009	.2932
identify_system_status	4.385	.040	1.047	66	.299	.0735	.0702	-.0667	.2138
			1.047	59.868	.299	.0735	.0702	-.0670	.2141
touch_to_confirm	10.596	.002	1.550	66	.126	.1029	.0664	-.0297	.2355
			1.550	55.363	.127	.1029	.0664	-.0301	.2360
set_type_of_gesture	17.943	.000	1.960	66	.054	.1176	.0600	-.0022	.2375
			1.960	45.897		.1176	.0600	-.0032	.2385
perform_direction	15.577	.000	1.811	66	.075	.1029	.0568	-.0105	.2164
			1.811	42.632		.1029	.0568	-.0117	.2176
system_status	116.016	.000	3.447	66	.001	.2647	.0768	.1114	.4180

			3.447	33.000	.002	.2647	.0768	.1085	.4210
restore_status	.774	.382	3.188	66	.002	.3529	.1107	.1319	.5740
			3.188	65.891		.3529	.1107	.1319	.5740

Table 55: Independent samples test for Evaluation and Execution phases (Study 1).

APPENDIX I - QUALITATIVE DATA ANALYSIS (STUDY 1)

ID	Code	Circles	Smudge	Theme
1.1.	Clear and visible (several)	27	0	1. Clear Visibility
	Total	27	0	
2.1.	Unclear touch and hold quality: interaction 03	6	0	2. Affordance issues for Interaction 03 'Touch and Hold for Options'
	Total	6	0	
3.1.	Incorrect about touch method: interaction 03 Pinch issue	3	1	3. Pinch issue for interaction 03 'Touch and Hold for Options'
3.2.	Issues with implied status change: interaction 03	4	0	
	Total	7	1	
4.1.	Incorrect about touch method: interaction 04 Pinch issue	5	1	4. Pinch issue for interaction 04 'Double tap to zoom in'
	Total	5	1	
5.1.	Unclear implied directionality (several)	4	0	5. Unclear Directionality of interactions 01, 06, 07 and 08
	Total	4	0	
6.1.	Incorrect touch method: non-dominant hand (several)	5	2	6. Non-dominant hand issue for Interaction 08 'Minimize App'
	Total	5	2	
7.1.	Unclear & blurry (several)	0	11	7. Unclear and Blurry issue
	Total	0	11	
8.1.	Incorrect about touch method: interaction 04 Thumb issue	0	5	8. Issues to identify Affordances
8.2.	Incorrect about touch method: interaction 08 Lion paw issue	0	6	
8.3.	Uncertainty about type of gesture (several)	0	10	
8.4.	Uncertainty about status change (several)	2	8	
8.5.	Incorrect touch method (several)	3	6	
8.6.	Incorrect touch method: use of thumb	0	9	
	Total	5	44	
9.1.	Clear touch and hold quality: interaction 03	0	17	9. Clear perception of Interaction 03 'Touch and Hold for Options'
	Total	0	17	
10.1.	Issues with multi-touch: interaction 06	4	6	10. Uncertainty about number of fingers for Interaction 06
	Total	4	6	
11.1.	Uncertainty about status change: interaction 06	1	2	11. Feedforward issue for Interaction 06 'Swipe Apps'
11.2.	Issues with implied status change: interaction 06	2	3	
	Total	3	5	
12.1.	Clear implied directionality (several)	0	7	12. Clear Perception of Directionality for Interaction 01 'Unveil Menu' and 06 'Swipe Apps'
	Total	0	7	
13.1.	Unclear implied directionality: interaction 07 water drop issue	0	3	13. Unclear & Incorrect Directionality of interaction 07
13.2.	Incorrect touch method: interaction 07 wrong direction	0	4	
	Total	0	7	
14.1.	Issues with multi-touch: interaction 07	2	5	14. Feedforward issue for Interaction 07 'Unveil Task Switcher'
14.2.	Uncertainty about status change: interaction 07	0	4	
	Total	2	9	
15.1.	Issues with implied status change: interaction 05	7	2	15. Feedforward issue for Interaction 05 'Flip pages'
	Total	7	2	

16.1.	Insight from implied status change: interaction 08	4	10	16. Insight from Feedforward for Interaction 08 'Minimize App'
16.2.	Insight from Feedback: interaction 08	6	9	
	Total	10	19	
17.1.	Incorrect gesture to restore: interaction 08: accidental	0	2	17. Incorrect gesture to restore for Interaction 08 'Minimize App'
17.2.	Incorrect gesture to restore: interaction 08	5	5	
	Total	5	7	
18.1.	Issues with multi-touch: Little finger issue	4	1	18. Issues with Multi-Touch and Three fingers preference
18.2.	Uncertainty about number of fingers (several)	4	4	
18.3.	Incorrect about touch method (several)	6	6	
18.4.	Issues with multi-touch: Preference to touch with 3 fingers	3	3	
	Total	17	14	

Table 56: Qualitative data analysis (Study 1).

APPENDIX J - DESCRIPTION OF THEMES (STUDY 1)

ID	Code	Description	Theme
1.1	Observation: Clear and visible	Participant's description of gesture design suggesting easiness to identify	VISIBILITY
1.2	Observation: Unclear and blurry	Participant's description of gesture design suggesting hardship to identify	
2.1	Observation: Clear implied directionality	Participant's description of gesture design suggesting clear understanding of directionality	DIRECTIONALITY
2.2	Observation: Unclear implied directionality	Participant's description of gesture design suggesting unclear understanding of directionality	
3.1	Observation: Clear touch and hold quality: int 03	Participant's description of gesture design suggesting clear understanding of touch and hold style	TOUCH AND HOLD
3.2	Observation: Unclear touch and hold quality: int 03	Participant's description of gesture design suggesting unclear understanding of touch and hold	
4.1	Observation: Uncertainty about type of gesture	Participant's description of gesture design suggesting uncertainty on how to perform gesture	UNCERTAINTY
4.2	Observation: Uncertainty about n of fingers	Participant's description of gesture design suggesting uncertainty about n of fingers	
4.3	Observation: Uncertainty about status change	Participant's description of UI elements design indicating uncertainty about status change	
5.1	Observation: Incorrect about touch method	Participant's description of gesture design suggesting incorrect assessment on gesture	INCORRECT ASSESSMENT
5.2	Observation: Incorrect about touch: Pinch issue	Participant's description of gesture design suggesting incorrect assessment on pinch gesture	
5.3	Observation: Issues with implied status change	Participant's description of UI elements design indicating incorrect assessment on status change	
5.4	Interaction: Issues with multi-touch	Participant's description of gesture design suggesting incorrect assessment about n of fingers	
5.5	Interaction: Issues with new status	Participant's description of UI elements design suggesting incorrect assessment of new status	
6.1	Interaction: Incorrect touch method	Participant's incorrect performance of touch style	INCORRECT INTERACTION
6.2	Interaction: Incorrect direction	Participant's incorrect performance of gesture direction	
6.3	Interaction: Incorrect gesture to restore	Participant's incorrect performance of gesture to restore or undo previous status	
7.1	Observation: Insight from implied status change	Participant's expressed learning from system previewing UI elements new status	INSIGHT/ LEARNING
7.2	Interaction: Insight from feedback: int 08	Participant's expressed learning from system previewing new status of 'minimizing application'	

Table 57: Description of themes from qualitative data analysis (Study 1).

APPENDIX K - TRANSCRIPTIONS (STUDY 1)

N	Gen	Age	Int	Design	Comment/ < Facilitator comments/questions>	Code	Theme
1	F	41	G	Circles	Smudge 03: I'll touch and this will slect the entire image. I prefer the white circle, to be honest with you.	Visible & number of fingers	Observation: Fingers and visibility
1	F	41	G	Smudge	Circles 06: I prefer the shades.	Clear touch and hold quality	Observation: Touch and hold quality
1	F	41	G	Smudge	Circles 07: If you touch like this you'll see a menu come from the bottom, I'll prefer the shades and not the circles.	Clear touch and hold quality	Observation: Touch and hold quality
1	F	41	2	Smudge	Smudge 02: I touch there and I move there and I prefer the shady and not the circle.	Clear touch and hold quality	Observation: Touch and hold quality
1	F	41	4	Smudge	Smudge 04: If you touch it the image would become bigger, you can zoom into the image. In this case I'd prefer this one and not the white circle, I don't know why.	Clear touch and hold quality	Observation: Touch and hold quality
1	F	41	8	Smudge	Smudge 08: I saw a menu with applications. With this kind of movement, I expect the image to go down there.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
1	F	41	6	Smudge	Smudge 06: the image of a page, something else will come out...maybe the main menu or another image I don't know.	Uncertainty about status change	Observation: Uncertainty
1	F	41	6	Smudge	Smudge 06: <touched with 3 fingers first.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
1	F	41	6	Circles	Circles 06: Ah, this four fingers thing.! I prefer to use 3 and not 4, these 3 fingers are longer...	Issues with multi-touch: Little finger issue	Interaction: Issues with multi-touch
1	F	41	7	Circles	Circles 07: I'm using four but I can't, these fingers are longer than this!	Issues with multi-touch: Little finger issue	Interaction: Issues with multi-touch
2	F	29	G	Circles	General: I think the circles give me a better idea of how many fingers I should use.	Visible & number of fingers	Observation: Fingers and visibility
2	F	29	7	Circles	Circles 07: Circles give the idea of how many fingers should I use...	Visible & number of fingers	Observation: Fingers and visibility
2	F	29	G	Circles	General: I think the circles give me a better idea of how many fingers I should use.	Visible & number of fingers	Observation: Fingers and visibility
2	M	26	G	Smudge	Circles 07: I think it's important to be consistent, the first made me think touch <Cirles>, the second made me think swipe <Smudge>. Still prefers the circles, they're clearer.	Clear implied directionality	Observation: Implied directionality
2	F	29	3	Smudge	Smudge 03: Prefer this one because the finger size is similar to mine.	Clear touch and hold quality	Observation: Touch and hold quality
2	F	29	7	Smudge	Smudge 07: Familiar with some of this gestures being a Mac user.	Previous knowledge	Interaction: Insight from feedback
2	F	29	5	Circles	Circles 05: <Was surprised with the page flip, didn't expect that.>	Issues with implied status	Observation: Issues with

						change: interaction 05	implied status change
2	F	29	5	Circles	Circles 05: I've seen the circle move but nothing happened to the page. <Expected to see an animation of the page flipping, similar to the previous.>	Issues with implied status change: interaction 05	Observation: Issues with implied status change
2	F	29	6	Smudge	Smudge 06: I think he slides the images but putting his finger above the picture.	Issues with implied status change: interaction 06	Observation: Issues with implied status change
2	F	29	6	Smudge	Smudge 06: <Trouble to touch with 4 fingers. Used the thumb as a fourth finger contact.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
2	F	29	8	Smudge	Smudge 08: <Opened the task switcher with a 4 finger pinch gesture outwards, by accident.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
3	F	25	G	Circles	General: Not really. The raindrops just appear on one place but they already look like a movement whereas the circles/bubbles appear and move themselves. I think the circles are a bit more visible than the raindrops...	Visible & number of fingers	Observation: Fingers and visibility
3	F	25	G	Smudge	General: Not really. The raindrops just appear on one place but they already look like a movement whereas the circles/bubbles appear and move themselves. I think the circles are a bit more visible than the raindrops…	Clear implied directionality	Observation: Implied directionality
3	F	25	8	Circles	Circles 08: It was closed but if I wanted to open again I'll find it there.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
3	F	25	8	Smudge	Smudge 08: the application goes to the bottom right.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
3	F	25	6	Circles	Circles 06: maybe the next page or maybe the menu, I don't know.	Uncertainty about status change	Observation: Uncertainty
3	F	25	6	Smudge	Smudge 06: something else appeared on the right side.	Uncertainty about status change	Observation: Uncertainty
3	F	25	7	Smudge	Smudge 07: Something came from the bottom, I didn't see.	Uncertainty about status change	Observation: Uncertainty
3	F	25	5	Circles	Circles 05: Bubble for the index finger appears on and is dragged to the middle of the screen but nothing really happens...	Issues with implied status change: interaction 05	Observation: Issues with implied status change
3	F	25	2	Circles	Circles 02: <Did you expect that?> Will bring the menu first.	Mental model/bias to restore: menu first	Mental model/bias to restore
4	M	53	5	Circles	Circles 05: <Did you expect that?> I wasn't expecting this particular thing to happen.	Insight from implied status change	Observation: Insight from implied status change
4	M	53	8	Circles	Circles 08: Symbolically is telling that will store into the right side hand corner.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change

4	M	53	7	Smudge	Smudge 07: Four balls symbols in the middle but I'm not sure why is showing me this...	Uncertainty about type of gesture	Observation: Uncertainty
4	M	53	1	Circles	Circles 01: I was expecting that I will bring the middle picture to the board.	Issues with implied status change	Observation: Issues with implied status change
4	M	53	5	Smudge	Smudge 05: <Explained that will move the picture and not the page.>	Issues with implied status change: interaction 05	Observation: Issues with implied status change
4	M	53	6	Smudge	Smudge 06: four cues show how the picture is going to move...	Issues with implied status change: interaction 06	Observation: Issues with implied status change
4	M	53	3	Smudge	Smudge 03: <Showed how to zoom from the central area.>	Incorrect touch method	Interaction: Incorrect touch method
4	M	53	4	Smudge	Smudge 04: <Tried a pinch outwards gesture.>	Incorrect touch method	Interaction: Incorrect touch method
4	M	53	7	Circles	Circles 07: I was thinking that only the image would move up.	Issues with new status	Interaction: Issues with new status
5	M	26	1	Smudge	Smudge 01: Looks more like sliding from the left, different from the previous. I would say to some extent this one is better than the previous. But I expected this to happen this time...	Clear touch and hold quality	Observation: Touch and hold quality
5	M	26	G	Smudge	General: Preferred the water drops. <Design 02 Smudge>. Allows more flexibility. The dots imply you have to be more precise.	Clear touch and hold quality	Observation: Touch and hold quality
5	M	26	G	Circles	General: Preferred the water drops. <Design 02 Smudge>. Allows more flexibility. The dots imply you have to be more precise.	Unclear touch and hold quality	Observation: Touch and hold quality
5	M	26	1	Smudge	Smudge 01: looks more like sliding from the left, different from the previous. I would say to some extent this one is better than the previous. But I expected this to happen this time...	Insight from implied status change	Observation: Insight from implied status change
5	M	26	7	Smudge	Smudge 07: I don't have an iPad but used a few times but I have a cellphone and maybe a little bit from it - from that I get some intuition maybe.	Previous knowledge	Interaction: Insight from feedback
5	M	26	1	Circles	Circles 01: maybe shake or tap on this corner <left bezel.>	Incorrect about touch method	Observation: Incorrect about touch method
5	M	26	8	Smudge	Smudge 08: Put your fingers, shape of a paw.	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
5	M	26	5	Circles	Circles 05: put your fingers but nothing happens. <expected to see some feedforward like the previous cases.>	Issues with implied status change: interaction 05	Observation: Issues with implied status change
5	M	26	8	Smudge	Smudge 08: <Tried several times with the right hand without success, despite utilising the right combination fingers.>	Incorrect touch method	Interaction: Incorrect touch method
5	M	26	8	Circles	Circles 08: I guess I was doing too quickly or maybe it's about	Incorrect touch method: non-	Interaction: Incorrect touch

					persistante.<Tried several times with the right hand without success, despite utilising the right combination fingers. Only managed with his left hand.>	dominant hand	method
6	M	57	G	Circles	General: <Do you prefer one design above the other or it's all the same for you?> Circles are easier to understand, better than the raindrops.	Visible & number of fingers	Observation: Fingers and visibility
6	M	57	6	Smudge	Smudge 06: swipe across, no I didn't know in advance.	Insight from implied status change	Observation: Insight from implied status change
6	M	57	8	Smudge	Smudge 08: I'm getting the hand because of what I knew...the selection...	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
6	M	57	8	Circles	Circles 08: There's a difference but I prefer the one I'm used to.	Insight from Feedback	Interaction: Insight from feedback
6	M	57	8	Circles	Circles 08: <Knew this gesture in advance.>	Previous knowledge	Interaction: Insight from feedback
6	M	57	7	Smudge	Smudge 07: Some drops, I couldn't know what it is.	Uncertainty about type of gesture	Observation: Uncertainty
6	M	57	7	Smudge	Smudge 07: <erroneous direction: downwards.>	Incorrect touch method: interaction 07 wrong direction	Interaction: Incorrect touch method
6	M	57	8	Smudge	Smudge 08: <Manage to bring the task switcher up by accident with a reverse pinch.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
7	F	30	G	Circles	General: <Did you learn anything?> I didn't know about the 4 fingers…I don't use them, maybe because I have nails (laughs). <Do you prefer one design above the other or it's all the same for you?> This shows the movement more <referring to design 02 smudge> and the other <design 01 circles> shows the number of fingers that you need more. The first shows the motion more whereas the second doesn't show the movement so well.	Visible & number of fingers	Observation: Fingers and visibility
7	F	30	G	Smudge	General: <Did you learn anything?> I didn't know about the 4 fingers…I don't use them, maybe because I have nails (laughs). <Do you prefer one design above the other or it's all the same for you?> This shows the movement more <referring to design 02 smudge> and the other <design 01 Circles> shows the number of fingers that you need more. The first <design 02 smudge> shows the motion more whereas the second doesn't show the movement so well.	Clear implied directionality	Observation: Implied directionality
7	F	30	1	Circles	General: <Did you learn anything?> I didn't know about the 4 fingers…I don't use them, maybe because I have nails (laughs). <Do you prefer one design above the other or it's all the same for you?> This shows the	Unclear implied directionality	Observation: Implied directionality

					movement more <referring to design 02 smudge> and the other <design 01 Circles> shows the number of fingers that you need more. The first <design 02 smudge> shows the motion more whereas the second <design 01 circles> doesn't show the movement so well.		
7	F	30	8	Smudge	Smudge 08: Don't have an iPad but used one before. You almost do it without thinking, don't you?	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
7	F	30	3	General	Circles 03: I guess subconsciously I knew that to select I had to hold to get it.	Previous knowledge	Interaction: Insight from feedback
7	F	30	6	Circles	Circles 06: I'd probably just use two fingers but looks like four…	Uncertainty about number of fingers	Observation: Uncertainty
7	F	30	7	Smudge	Smudge 07: <3 fingers only and then a 90 degree wrist rotation.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
7	F	30	7	Smudge	Smudge 07: <3 fingers only.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
7	F	30	G	General	General: <Did you learn anything?> I didn't know about the 4 fingers…I don't use them, maybe because I have nails (laughs). <Do you prefer one design above the other or it's all the same for you?> This shows the movement more <referring to design 02 smudge> and the other <design 01 Circles> shows the number of fingers that you need more. The first shows the motion more whereas the second doesn't show the movement so well.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
8	M	25	8	Smudge	Smudge 08: <Did you expect that?> It showed how to put the application in there below, I like it.	Insight from Feedback	Interaction: Insight from feedback
8	M	25	7	Smudge	Smudge 07: <You knew this gestures before or it's the first time?> Some are very common. With more than one finger is not so frequent...but maybe because I don't have a tablet. I think the majority of tablets use only one finger because it's more comfortable.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
8	M	25	1	Smudge	Smudge 01: <Decided to use his thumb to activate and restore status.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
8	M	25	2	Smudge	Smudge 02: <Decided to use his thumb to activate.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
8	M	25	3	Smudge	Smudge 03: <Decided to use his thumb to activate.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
9	M	26	7	Circles	Circles 07: I think it's important to be consistent, the first made me think touch, the second made me think swipe. Still prefers the circles, they're clearer.	Visible & number of fingers	Observation: Fingers and visibility
9	M	26	G	Circles	General: The circle are much clearer than the fingerprint. The edges you won't miss that. I suppose the fingerprint and the hybrid ones would	Visible & number of fingers	Observation: Fingers and visibility

					look nicer…these you have to interpret where your fingers should go. I'm curious how people will automatically assossiate these cues in these touch-based interactions, in your research.		
9	M	26	G	Circles	Circles 07: I think it's important to be consistent, the first made me think touch, the second made me think swipe. Still prefers the circles, they're clearer.	Visible & number of fingers	Observation: Fingers and visibility
9	M	26	7	Circles	Circles 07: I think it's important to be consistent, the first made me think touch, the second made me think swipe. Still prefers the circles, they're clearer.	Visible & number of fingers	Observation: Fingers and visibility
9	M	26	1	Smudge	Sumdge 01: I don't feel the actual fingerprint is very clear…the action itself.	Unclear & blurry	Observation: Fingers and visibility
9	M	26	5	Circles	Circles 05: Different from before, this one you have to touch and move, before it was more like a bigger movement. <Did a large swipe.> Felt more 'natural'.	Insight from implied status change	Observation: Insight from implied status change
9	M	26	8	Smudge	Smudge 08: I'm not sure if I should just touch it or drag it like that <in direction of the task switcher as the animation suggests.>	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
9	M	26	8	Smudge	Smudge 08: As opposed to what actually happens it shows it's still available somewhere.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
9	M	26	8	Smudge	Smudge 08: Ah, shall I drag down as well? <made this comment based on the animation.> <What do you think of this?> As opposed to what actually happened? I think is nice showing that it's not just gone, it's still there and available, it wasn't just shut down.	Insight from Feedback	Interaction: Insight from feedback
9	M	26	1	Smudge	Sumdge 01: I don't feel the actual fingerprint is very clear…the action itself.	Uncertainty about type of gesture	Observation: Uncertainty
9	M	26	8	Smudge	Smudge 08: I'm not sure if I should just touch it or drag it like that <in direction of the task switcher as the animation suggests.>	Uncertainty about type of gesture	Observation: Uncertainty
9	M	26	5	Circles	Circles 05: Expected to see an animation, like the others for the page flipping.	Issues with implied status change: interaction 05	Observation: Issues with implied status change
9	M	26	2	Smudge	Smudge 02: <Did you expect that?> Would try to bring the menu back first and then move the picture.	Mental model/bias to restore: menu first	Mental model/bias to restore
10	M	28	G	Smudge	General: <Did you know this gestures beforehand?> I knew pinch <minimise app> and swipe up and down <unveil task switcher> with four fingers.<Do you prefer one design over the other?> I think the four fingers is very unnatural. think the blurry one is quite explanatory.	Clear touch and hold quality	Observation: Touch and hold quality
10	M	28	G	General	General: <Did you know this gestures beforehand?> I knew pinch	Previous knowledge	Interaction: Insight from

					<minimise app> and swipe up and down <unveil task switcher> with four fingers. <Do you prefer one design above the other?> I think the four fingers is very unnatural. think the blurry one is quite explanatory.		feedback
10	M	28	G	General	General: <Did you know this gestures beforehand?> I knew pinch <minimise app> and swipe up and down <unveil task switcher> with four fingers. <Do you prefer one design above the other?> I think the four fingers is very unnatural. think the blurry one is quite explanatory.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
10	M	28	8	Circles	Circles 08: <Tried to bring back first with the same pinch inwards gesture. Then outwards. Then remembered the correct gesture.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
10	M	28	8	Smudge	Smudge 08: <Tried to bring back first with the same pinch inwards gesture.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
10	M	28	2	Circles	Circles 02: <Tried to bring the menu first.>	Mental model/bias to restore: menu first	Mental model/bias to restore
11	F	27	G	Circles	General: Circles are clearer, the shadys you can't figure sometimes how to use it. Shows you exactly how many fingers you're supposed to be using. The other seems to be crying.	Visible & number of fingers	Observation: Fingers and visibility
11	F	27	G	Circles	General: Circles are clearer, the shadys you can't figure sometimes how to use it. Shows you exactly how many fingers you're supposed to be using. The other seems to be crying.	Visible & number of fingers	Observation: Fingers and visibility
11	F	27	G	Smudge	General: Circles are clearer, the shadys you can't figure sometimes how to use it. Shows you exactly how many fingers you're supposed to be using. The other seems to be crying.	Unclear implied directionality: Water drop issue	Observation: Implied directionality
11	F	27	2	Circles	Circles 02: <Did you expect that?> I wasn't expecting the menu to take the picture back.	Insight from Feedback	Interaction: Insight from feedback
11	F	27	8	Smudge	Smudge 08: <Is different from the animation, isn't it?> Yes, I prefer seeing where it's gone.	Insight from Feedback	Interaction: Insight from feedback
11	F	27	6	Smudge	Smudge 06: By using your hand. <Imprecise about number of fingers.>	Incorrect about touch method: interaction 06	Observation: Incorrect about touch method
11	F	27	2	Circles	Circles 02: <Did you expect that?> I wasn't expecting the menu to take the picture back.	Issues with implied status change	Observation: Issues with implied status change
11	F	27	6	Smudge	Smudge 06: <Touched with five fingers.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
11	F	27	7	Smudge	Smudge 07: <Touched with five fingers.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
11	F	27	6	Circles	Circles 06: I don't have four equal lenghts <referring to her finger's size> to do it.	Issues with multi-touch: Little finger issue	Interaction: Issues with multi-touch
11	F	27	1	Circles	Circles 01: <How can you make this	Mental	Mental

					menu disappear?> I was expecting to find a cross up there. <referring to the top-right hand corner.> 1:<Did you expect that?>. No, I wasn't sure if it would be smaller again or perhaps an 'undo' function.	model/bias to restore	model/bias to restore
12	M	27	G	Circles	General: <Any comments, any feedback?> In the beginning I wasn't sure I had to use four fingers at once. After some time it was quite easy to get what I was supposed to do. Then you can use the previous knowledge…moving pages and trying the same with pictures...<Do you prefer one design above the other?> I do prefer the circles because the first time I couldn't see the blurry one. Easier to get because you can just identify them.	Visible & number of fingers	Observation: Fingers and visibility
12	M	27	G	Circles	General: <Any comments, any feedback?> In the beginning I wasn't sure I had to use four fingers at once. After some time it was quite easy to get what I was supposed to do. Then you can use the previous knowledge…moving pages and trying the same with pictures...<Do you prefer one design above the other?> I do prefer the circles because the first time I couldn't see the blurry one. Easier to get because you can just identify them.	Visible & number of fingers	Observation: Fingers and visibility
12	M	27	G	Smudge	General: <Any comments, any feedback?> In the beginning I wasn't sure I had to use four fingers at once. After some time it was quite easy to get what I was supposed to do. Then you can use the previous knowledge…moving pages and trying the same with pictures...<Do you prefer one design above the other?> I do prefer the circles because the first time I couldn't see the blurry one. Easier to get because you can just identify them.	Unclear & blurry	Observation: Fingers and visibility
12	M	27	6	Smudge	Smudge 06: Not sure if I have to use four or maybe just one…	Uncertainty about number of fingers	Observation: Uncertainty
12	M	27	G	General	General: <Any comments, any feedback?> In the beginning I wasn't sure I had to use four fingers at once. After some time it was quite easy to get what I was supposed to do. Then you can use the previous knowledge…moving pages and trying the same with pictures...<Do you prefer one design above the other?> I do prefer the circles because the first time I couldn't see the blurry one. Easier to get because you can just identify them.	Uncertainty about number of fingers	Observation: Uncertainty
12	M	27	7	Smudge	Smudge 07: Will scroll the whole book up and down or just the picture?	Uncertainty about status change	Observation: Uncertainty
12	M	27	5	Circles	Circles 05: Probably the way to	Issues with	Observation:

					change pages even though I don't see the result.	implied status change: interaction 05	Issues with implied status change
12	M	27	6	Smudge	Smudge 06: will show me some other options, like what's behind the book or something.	Issues with implied status change: interaction 06	Observation: Issues with implied status change
12	M	27	G	General	General: <Any comments, any feedback?> In the beginning I wasn't sure I had to use four fingers at once. After some time it was quite easy to get what I was supposed to do. Then you can use the previous knowledge…moving pages and trying the same with pictures...<Do you prefer one design above the other?> I do prefer the circles because the first time I couldn't see the blurry one. Easier to get because you can just identify them.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
12	M	27	3	Smudge	Smudge 03: <Managed only with his left hand after several attempts.>	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
13	M	27	G	Smudge	General: <Do you prefer one design over the other?> The shady are overall easier. The circles are a bit baffling.	Clear touch and hold quality	Observation: Touch and hold quality
13	M	27	G	Circles	General: <Do you prefer one design over the other?> The shady are overall easier. The circles are a bit baffling.	Unclear touch and hold quality	Observation: Touch and hold quality
13	M	27	5	Smudge	Smudge 05: Might be a refresh button.	Uncertainty about type of gesture	Observation: Uncertainty
13	M	27	7	Smudge	Smudge 06: probably with three fingers.	Uncertainty about number of fingers	Observation: Uncertainty
13	M	27	4	Circles	Circles 04: I'd try to pinch it…	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
13	M	27	4	Smudge	Smudge 04: to zoom, double tap with your thumb.	Incorrect about touch method: Thumb issue	Observation: Incorrect about touch method
13	M	27	7	Smudge	Smudge 07: I saw paws.	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
13	M	27	4	Smudge	Smudge 04: <Tried a pinch.>	Incorrect touch method	Interaction: Incorrect touch method
13	M	27	8	Smudge	Smudge 08: <Where did it go?> Here. <Pointing to the center of the sreen.> <Performed a pinch out gesture (4 fingers) with the intent to bring the app back.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
14	F	34	G	Circles	General: <Did you prefer any visual cues over the other?> Some are bigger implying you have to press. Some have got the direction already. Probably prefer the one that shows the direction as well. I think the circles are easier to see. The blurry you might think is part of the picture though. When you see the raindrops it might imply you have to go down because they fall...the ones you have	Visible & number of fingers	Observation: Fingers and visibility

					to move is better to have the raindrops, the ones you have to press is better to have the circles.		
14	F	34	G	Smudge	General: <Did you prefer any visual cues over the other?> Some are bigger implying you have to press. Some have got the direction already. Probably prefer the one that shows the direction as well. I think the circles are easier to see. The blurry you might think is part of the picture though. When you see the raindrops it might imply you have to go down because they fall...the ones you have to move is better to have the raindrops, the ones you have to press is better to have the circles.	Unclear & blurry	Observation: Fingers and visibility
14	F	34	G	Smudge	General: <Did you prefer any visual cues over the other?> Some are bigger implying you have to press. Some have got the direction already. Probably prefer the one that shows the direction as well. I think the circles are easier to see. The blurry you might think is part of the picture though. When you see the raindrops it might imply you have to go down because they fall...the ones you have to move is better to have the raindrops, the ones you have to press is better to have the circles.	Clear implied directionality	Observation: Implied directionality
14	F	34	G	Smudge	General: <Did you prefer any visual cues over the other?> Some are bigger implying you have to press. Some have got the direction already. Probably prefer the one that shows the direction as well. I think the circles are easier to see. The blurry you might think is part of the picture though. When you see the raindrops it might imply you have to go down because they fall...the ones you have to move is better to have the raindrops, the ones you have to press is better to have the circles.	Unclear implied directionality: Water drop issue	Observation: Implied directionality
14	F	34	6	Smudge	Smudge 06: Something telling you to go like this on the screen <performed a one finger swipe from right to left, imitating the curvature suggested by the fingerprints.>	Uncertainty about number of fingers	Observation: Uncertainty
14	F	34	6	Circles	Circles 06: <Tried the curved one finger gesture and then three fingers.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
14	F	34	8	Circles	Circles 08: I think at first my fingers were too close together but when I spread them I got it.	Incorrect touch method	Interaction: Incorrect touch method
15	F	50	G	Smudge	General: I prefer the shades, the teardrop shapes. Which do suggest, once learned, that you should place the finger and move towards the direction suggested. The circels made me think I had to actually position my fingers on the exact spot. The tear drop shapes which look like finger marks in a sense replicate that seemed	Clear implied directionality	Observation: Implied directionality

					easier.		
15	F	50	8	Smudge	Smudge 08: Wheter it was minimised or closed it I' not sure.	Uncertainty about status change	Observation: Uncertainty
15	F	50	3	Circles	Circles 03: I would touch around the edges expecting those blue markers to appear.	Incorrect about touch method: interaction 03	Observation: Incorrect about touch method
15	F	50	4	Circles	Circles 04: I'd try pinching it…	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
15	F	50	7	Circles	Circles 07: <Was touching with three fingers only for several times.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
15	F	50	2	Circles	Circles 02:<Did you expect that?> I would try to bring the menu first and then drag the picture.	Mental model/bias to restore: menu first	Mental model/bias to restore
16	F	42	7	Smudge	Smudge 07: Oh, stamp? I've seen some thing up there…but I missed the bit down here <referring to the task switcher.> Look like footprints in the middle. Or water dripping down.	Unclear implied directionality: Water drop issue	Observation: Implied directionality
16	F	42	8	Smudge	Smudge 08: It disappears, goes into the 'laptop.'	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
16	F	42	8	Smudge	Smudge 08: Yes, because it went straight away…it didn't go down there.	Insight from Feedback	Interaction: Insight from feedback
16	F	42	7	Smudge	Smudge 07: Oh, stamp? I've seen some thing up there…but I missed the bit down here <referring to the task switcher.> Look like footprints in the middle. Or water dripping down.	Uncertainty about status change	Observation: Uncertainty
16	F	42	1	Circles	Circles 01: <Showed a double tap on the left hand side.>	Incorrect about touch method	Observation: Incorrect about touch method
16	F	42	3	Smudge	Smudge 03: You touch the edges and sometimes touch in the center to scroll it. <Showed a pinch gesture.>	Incorrect about touch method: interaction 03	Observation: Incorrect about touch method
16	F	42	1	Circles	Circles 01: <Did you expect that?> I thought that just the picture or page would come over.	Issues with new status	Interaction: Issues with new status
16	F	42	2	Circles	Circles 02: <Did you expect that?> <She would bring the menu first and then slide over the picture back.>	Mental model/bias to restore: menu first	Mental model/bias to restore
17	F	32	8	Circles	Circles 08: I prefer the drag marks but they're not so visually distinctive. Specially over images they don't show up so well. The circle is more visible.	Visible & number of fingers	Observation: Fingers and visibility
17	F	32	G	Smudge	Circles 08: I prefer the drag marks but they're not so visually distinctive. Specially over images they don't show up so well. The circle is more visible.	Unclear & blurry	Observation: Fingers and visibility
17	F	32	G	Smudge	General: I prefer the drag marks but they're not so visually distinctive. I'm not sure how can you make them show better. And perhaps three fingers is more natural, the short finger doesn't seem to reach the screen.	Unclear & blurry	Observation: Fingers and visibility
17	F	32	8	Circles	Circles 08: <Did you know this	Previous	Interaction:

					interactions before?> Minimize an app I think.	knowledge	Insight from feedback
17	F	32	6	Circles	Circles 06: I think will go to the main screen.	Issues with implied status change: interaction 06	Observation: Issues with implied status change
17	F	32	6	Circles	Circles 06: <Described four fingers but was touching with 3 at the beginning.> I'm not used to use my little finger for anything…just too short.	Issues with multi-touch: Little finger issue	Interaction: Issues with multi-touch
17	F	32	G	General	General: I prefer the drag marks but they're not so visually distinctive. I'm not sure how can you make them show better. And perhaps three fingers is more natural, the short finger doesn't seem to reach the screen.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
17	F	32	2	Circles	Circles 02: <She would bring the menu first.>	Mental model/bias to restore: menu first	Mental model/bias to restore
18	F	35	G	Circles	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.	Visible & number of fingers	Observation: Fingers and visibility
18	F	35	G	Smudge	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.	Clear implied directionality	Observation: Implied directionality
18	F	35	G	Circles	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.	Unclear implied directionality	Observation: Implied directionality
18	F	35	G	Smudge	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not	Clear touch and hold quality	Observation: Touch and hold quality

					sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.		
18	F	35	G	Circles	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.	Unclear touch and hold quality	Observation: Touch and hold quality
18	F	35	8	Smudge	Smudge 08: <Did you notice the difference?> Closed completely, it didn't go to the bottom menu as it did on the example.	Insight from Feedback	Interaction: Insight from feedback
18	F	35	G	Smudge	General: <Any more comments?> The different Circles can do different things. The 'swipy' you can see is like an imprint where you can push quite hard. And I wanted to use my thumb with the big round one. And the small ones it didn't show push or swipe. Not sure if I prefer one above the other...the circle is very clear...but the swipe one tells you which direction you should swipe in - but the double tap I prefer the circle.	Incorrect about touch method: Thumb issue	Observation: Incorrect about touch method
18	F	35	3	Smudge	Smudge 03: <Used her thumb.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
18	F	35	4	Smudge	Smudge 04: Probably to tap twice...with your thumb perhaps. <Double tapped with her index finger.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
19	M	56	8	Circles	Circles 08: <Understood where the app went.> <Tried a pich outwards to restore the app.>	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
19	M	56	G	General	General: <Tell me what you think of the test.> First I didn't know what I was doing but then I got it. <What can you remember?> I remember I can bring the program and make it disappear <Int 01: Unveil menu> and 4 finger to make it dispappear and bring back <Int 06: Swipe apps> and drag the picture with one finger <Int 02: Drag picture>.	Able to remember interactions	Interaction: Insight from feedback
19	M	56	5	Smudge	Smudge 05: Some other picture will come.	Issues with implied status change: interaction 05	Observation: Issues with implied status change
19	M	56	3	Circles	Circles 03: <Tried a pinch inwards>	Incorrect touch method	Interaction: Incorrect touch method
19	M	56	6	Smudge	Smudge 06: <Managed to perform the gesture but cannot make sense of what's happening.>	Issues with new status	Interaction: Issues with new status
19	M	56	7	Smudge	Smudge 07: <Managed to perform the	Issues with new	Interaction:

					gesture but couldn't make sense of what's happening.>	status	Issues with new status
19	M	56	4	Circles	Circles 04: <Tried a pinch inwards>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
19	M	56	8	Circles	Circles 08: <Understood where the app went.> <Tried a pich outwards to restore the app.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
20	F	30	G	Circles	General: <Any comments?> I wasn't sure if should be copying or doing my thing… <Which interactions you didn't know?> I didn't know about the menu on the right and the bottom.<Int 06: Swipe apps and Int 07: Unveil task switcher> 16:18: <Do you prefer one design above the other?> I prefer the circles and the swirly one was a bit weird to understand, I didn't realize was telling me to do that.	Visible & number of fingers	Observation: Fingers and visibility
20	F	30	G	Smudge	General: <Any comments?> I wasn't sure if should be copying or doing my thing… <Which interactions you didn't know?> I didn't know about the menu on the right and the bottom.<Int 06: Swipe apps and Int 07: Unveil task switcher> <Do you prefer one design above the other?> I prefer the circles and the swirly <Smudge> one was a bit weird to understand, I didn't realize was telling me to do that.	Unclear & blurry	Observation: Fingers and visibility
20	F	30	G	General	General: <Any comments?> I wasn't sure if should be copying or doing my thing… <Which interactions you didn't know?> I didn't know about the menu on the right and the bottom.<Int 06: Swipe apps and Int 07: Unveil task switcher> <Do you prefer one design above the other?> I prefer the circles and the swirly one was a bit weird to understand, I didn't realize was telling me to do that.	Able to remember interactions	Interaction: Insight from feedback
20	F	30	8	Circles	Circles 08: I'll try with two…but it says four.	Uncertainty about number of fingers	Observation: Uncertainty
20	F	30	4	Smudge	Smudge 04: I'd use two fingers. <Showed a pinch gesture with two fingers outwards.>	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
20	F	30	6	Circles	Circles 06: That's not how I would do it…<How would you do that?> Just like that <one finger only.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
20	F	30	1	Smudge	Smudge 01: <Touched the erroneous spot, too far away from the bezel.>	Incorrect touch method	Interaction: Incorrect touch method
20	F	30	8	Circles	Circles 08: <First tried a pinch with 2 fingers, then managed to restore by accident with a pinch outwards brought the task switcher up.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
20	F	30	5	Smudge	Smudge 05: <Just touched the bent corner.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
21	M	27	G	Circles	General: <Which gesture do you remember?> <Straight away showed	Visible & number of	Observation: Fingers and

					me Int 08: Minimise app> <Any comments?> I find easy to handle. <Prefer one design over the other?> I prefer the one I can drag/swipe. The circles is better to touch.	fingers	visibility
21	M	27	G	Smudge	General: <Which gesture do you remember?> <Straight away showed me Int 08: Minimise app> <Any comments?> I find easy to handle. <Prefer one design over the other?> I prefer the one I can drag/swipe. The circles is better to touch.	Clear touch and hold quality	Observation: Touch and hold quality
21	M	27	G	General	General: <Which gesture do you remember?> <Straight away showed me Int 08: Minimise app> <Any comments?> I find easy to handle. <Prefer one design over the other?> I prefer the one I can drag/swipe. The circles is better to touch.	Able to remember interactions	Interaction: Insight from feedback
21	M	27	3	Circles	Circles 03: <Simulated a double tap without touching the screen.>	Incorrect about touch method: interaction 03	Observation: Incorrect about touch method
21	M	27	3	Circles	Circles 03: <Did you expect that?> I only expected to see the blue dots.	Issues with implied status change: interaction 03	Observation: Issues with implied status change
21	M	27	8	Smudge	Smudge 08: <Wasn't pressing hard enough or starting the gesture with a wider pinch ratio.>	Incorrect touch method	Interaction: Incorrect touch method
21	M	27	8	Circles	Circles 08: <Could only perform the gesture with the left hand.>	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
21	M	27	7	Circles	Circles 07: <when asked to restore status used one finger only sliding down and was unable to make the bar disappear.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
21	M	27	7	Smudge	Smudge 07: <The participant used a reverse gesture to restore status.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
21	M	27	2	Smudge	Smudge 02: <First tried to bring the menu and then dragged the picture within.>	Mental model/bias to restore: menu first	Mental model/bias to restore
22	F	29	G	Circles	General: <Do you remember how to minimise?> Think is four fingers straight down <Int 08: Minmise app. She tried to perform the gesture towards where the animation showed the app being minimised to, in diagonal towards the bottom right corner.> To bring that bar up <Int 07: Task switcher> I don't remeber I'd need to see the cue... <Any other comments?> I guess I felt a little bit scared because I've never used it, if I used everyday I'd feel more confident to try things out. <Did you notice that two different designs and which one do you prefer?> I thought I preferred the blurred ones first but the circles are more neat.	Visible & number of fingers	Observation: Fingers and visibility
22	F	29	G	General	General: <Do you remember how to minimise?> Think is four fingers straight down <Int 08: Minmise app.	Able to remember interactions	Interaction: Insight from feedback

					She tried to perform the gesture towards where the animation showed the app being minimised to, in diagonal towards the bottom right corner.> To bring that bar up <Int 07: Task switcher> I don't remeber I'd need to see the cue... <Any other comments?> I guess I felt a little bit scared because I've never used it, if I used everyday I'd feel more confident to try things out. <Did you notice that two different designs and which one do you prefer?> I thought I preferred the blurred ones first but the circles are more neat.		
22	F	29	7	Smudge	Smudge 07: I'm familiar with some of this gestures being a Mac user.	Previous knowledge	Interaction: Insight from feedback
22	F	29	1	Smudge	Smudge 01: Looks like all you have to do is that <showed me a touch only with no swipe involved.>	Incorrect about touch method	Observation: Incorrect about touch method
22	F	29	6	Smudge	Smudge 06: Looks like with your left hand you can point and drag.	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
22	F	29	7	Smudge	Smudge 07: <Touched with four but performed a swipe downwards.>	Incorrect touch method: interaction 07 wrong direction	Interaction: Incorrect touch method
23	F	41	G	Circles	General: <Do you prefer one design over the other?> I guess I'm a circles persons, more defined, more obvious.	Visible & number of fingers	Observation: Fingers and visibility
23	F	41	2	Circles	Circles 02: If I was touching I'd have done it, you know. Was pretty much like the picture has read your mind...as if you were moving and then you changed your mind…	Insight from implied status change	Observation: Insight from implied status change
23	F	41	3	Circles	Circles 03: Holders of the picture telling me I'm here if you want to click on me...without touching it, I so want to touch it now.	Insight from implied status change	Observation: Insight from implied status change
23	F	41	8	Smudge	Smudge 08: Disappeared completely and I didn't see the 'journey'. <Do you know where ot goes now?> I don't think is closed, probably minimised.	Insight from Feedback	Interaction: Insight from feedback
23	F	41	7	Smudge	Smudge 07: Now I'm thinking in a different way...I think I forgot already did it go up or down?...the paw print shuffled it...	Uncertainty about type of gesture	Observation: Uncertainty
23	F	41	2	Smudge	Smudge 02: Another way to move the finger...something big, a fist, knob…bigger.	Incorrect about touch method: Thumb issue	Observation: Incorrect about touch method
23	F	41	7	Smudge	Smudge 07: Now I'm thinking in a different way...I think I forgot already did it go up or down?...the paw print shuffled it...	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
23	F	41	5	Circles	Circles 05: I'd have expected the page to turn but nothing happened...	Issues with implied status change: interaction 05	Observation: Issues with implied status change
23	F	41	6	Circles	Circles 06: Not my natural way, touching with 4 fingers…	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
23	F	41	7	Smudge	Smudge 07: <She tried with 3 fingers only, almost as she could not reach the screen with the small finger.>	Issues with multi-touch: Little finger	Interaction: Issues with multi-touch

						issue	
23	F	41	8	Circles	Circles 08: <Only managed with her left hand.>	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
23	F	41	4	Smudge	Smudge 04: For me is like different tools to do the movement...the thumb selecting the picture.	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
24	M	37	G	Circles	General: <Do you prefer one design above the other?> The fingerprint is logical but is temporaly damaging the picture...or the screen. The circles is more understandable than the drop, but still is not a finger.	Visible & number of fingers	Observation: Fingers and visibility
24	M	37	G	Smudge	General: <Do you prefer one design above the other?> The fingerprint is logical but is temporaly damaging the picture...or the screen. The circles is more understandable than the drop, but still is not a finger.	Unclear & blurry	Observation: Fingers and visibility
24	M	37	8	Circles	Circles 08: If you do it like this you don't expect to go to that place, goes to the center <referring to the animation that shows the app going to the bottom right within the task switcher bar.>	Insight from Feedback	Interaction: Insight from feedback
24	M	37	6	Smudge	Smudge 06: I'm not sure of this kind of navigation---It's some kind of facility...I can move right-left, left-right but you don't have to change the original picture.	Uncertainty about type of gesture	Observation: Uncertainty
24	M	37	4	Circles	Circles 04: If I put these two finger together I can enlarge the picture. <Showed me index and thumb pinching outwards.>	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
24	M	37	6	Smudge	Smudge 06: <Wasn't touching the fourth finger appropriately.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
24	M	37	8	Circles	Circles 08:<Tried a pinch first. Didn't manage with the right hand but did with the left hand.>	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
24	M	37	7	Smudge	Smudge 07: <Swiped downwards.>	Incorrect touch method: interaction 07 wrong direction	Interaction: Incorrect touch method
25	F	24	G	Smudge	General: <Which design do you prefer?> The smudgy is more light to the eyes, I find bteer than the circles.	Clear touch and hold quality	Observation: Touch and hold quality
25	F	24	7	Circles	Circles 07: <Showed less fingers than before.>	Uncertainty about number of fingers	Observation: Uncertainty
25	F	24	6	Circles	Circles 06: <Thought was 3 fingers at first, then on the 3rd time managed with four.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
25	F	24	7	Circles	Circles 07: <Three fingers only.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
25	F	24	6	Smudge	Smudge 06: <Three fingers only.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
25	F	24	7	Smudge	Smudge 07: <Swiped downwards.>	Incorrect touch method: interaction 07 wrong direction	Interaction: Incorrect touch method
26	F	31	3	Smudge	Smudge 03: Looks blurry, not sure if you have to tap it or do something	Unclear & blurry	Observation: Fingers and

					else.		visibility
26	F	31	8	Smudge	Smudge 08: And I didn't know about this beforehand.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
26	F	31	6	Smudge	Smudge 06: <Did you expect that to happen?> No.	Insight from Feedback	Interaction: Insight from feedback
26	F	31	4	Circles	Circles 04: <And you've seen that on your iPhone?> Yes.	Previous knowledge	Interaction: Insight from feedback
26	F	31	3	Smudge	Smudge 03: Looks blurry, not sure if you have to tap it or do something else.	Uncertainty about type of gesture	Observation: Uncertainty
26	F	31	7	Circles	Circles 07: Looks like three fingers and then you push up.	Uncertainty about number of fingers	Observation: Uncertainty
26	F	31	G	General	General: <Any other comments?> Pretty straightforward. Once you start playing with it it's much easier then the first time, pretty clear. <You noticed that are different designs?> I'm used to use 3 finger rather than four but obviously one you get used to it…I think it's quite weird using the little finger.	Issues with multi-touch: Preference to touch with 3 fingers	Interaction: Issues with multi-touch
27	F	40	1	Circles	Circles 01: Seems a bit random hint of some hinges that I couldn't see what they were, not giving me a lot...	Unclear implied directionality	Observation: Implied directionality
27	F	40	G	Smudge	General: <You noticed the different designs, right? Do you prefer one over the other?> I think is all the same...when that kind of hazy area comes up, makes you feel like hold it, is not that quick suggesting to hold it, whereas the other is more ambiguous...	Clear touch and hold quality	Observation: Touch and hold quality
27	F	40	G	Circles	General: <You noticed the different designs, right? Do you prefer one over the other?> I think is all the same...when that kind of hazy area comes up, makes you feel like hold it, is not that quick suggesting to hold it, whereas the other is more ambiguous...	Unclear touch and hold quality	Observation: Touch and hold quality
27	F	40	3	Circles	Circles 03: <Are you familiar with this one?> Yes.	Previous knowledge	Interaction: Insight from feedback
27	F	40	8	Smudge	Smudge 08: Some cue that shows that you can minimise this…<Are you familiar with this gesture?> Yes, I am.	Previous knowledge	Interaction: Insight from feedback
27	F	40	2	Circles	Circles 02: It hasn't show any result of that..looks like moving something to the left…maybe the image or the page?	Uncertainty about status change	Observation: Uncertainty
27	F	40	5	Smudge	Smudge 05: Don't know, quite subtle...unless I press it wouldn't even know what to expect from it I think.	Uncertainty about status change	Observation: Uncertainty
27	F	40	1	Circles	Circles 01: I'd probably touch on the side, see if it will come again…	Incorrect about touch method	Observation: Incorrect about touch method
27	F	40	3	Circles	Circles 03: Didn't expect these options <edit/copy, etc.> to come out.	Issues with implied status change:	Observation: Issues with implied status

						interaction 03	change
27	F	40	7	Smudge	Smudge 07: <Couldn't do it because was using three fingers only.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
27	F	40	8	Smudge	Smudge 08: <Couldn't do it because was using only two fingers on the top in conjunction with thumb.>	Issues with multi-touch	Interaction: Issues with multi-touch
27	F	40	6	Circles	Circles 06: Should I press there? <referring to the home-button>. <It was hard for her tho swipe back with four fingers, took her 5x.>	Incorrect touch method	Interaction: Incorrect touch method
27	F	40	8	Circles	Circles 08: <Only managed with her left hand after 6x.> It's a wider gesture, perhaps?	Incorrect touch method: non-dominant hand	Interaction: Incorrect touch method
27	F	40	3	Circles	Circles 03:<Tried to de-select by holding again.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
27	F	40	6	Circles	Circles 06: Should I press there? <referring to the home-button>. <It was hard for her tho swipe back with four fingers, took her 5x.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore
28	F	29	G	Circles	General: <Any other comments? Do you prefer the blurry or the circles?> I prefer the circles because they're clearer. The blurry one makes me feel the screen is soft and squishy.	Visible & number of fingers	Observation: Fingers and visibility
28	F	29	G	Smudge	General: <Any other comments? Do you prefer the blurry or the circles?> I prefer the circles because they're clearer. The blurry one makes me feel the screen is soft and squishy.	Unclear & blurry	Observation: Fingers and visibility
28	F	43	4	Smudge	Smudge 04: <What did you learn do far?> I've learned: the sideways <Smudge 06> and the shrink to put in the task bar. <Smudge 08>	Insight from implied status change	Observation: Insight from implied status change
28	F	43	8	Smudge	Smudge 08: I've never seen this before. I didn't know though that it goes to the task switcher.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
28	F	43	G	General	Smudge 04: <What did you learn do far?> I've learned: the sideways <Int 06: Swipe apps> and the shrink to put in the task bar. <Int 08: Minimise app>	Able to remember interactions	Interaction: Insight from feedback
28	F	29	8	Circles	Circles 08: I did that on the trackpad, on my laptop…	Previous knowledge	Interaction: Insight from feedback
28	F	29	3	Circles	Circles 03: I wouldn't expect to see the menu with options…	Issues with implied status change: interaction 03	Observation: Issues with implied status change
29	F	43	G	Circles	General: <Did you learn anything?> If you keep doing it it is easily done. I just got an iPhone 5 and now I've learned new things. Didn't know about the double tap, for instance. <Int 04: Zoom in> When I'm stuck somewhere I always press the home screen, now I know about the minimise gesture <Int 08: Minimise app>. 20:50:<Which design do you prefer?> I prefer the circles, better than this one - circles are precise and you can do exactly as they say.	Visible & number of fingers	Observation: Fingers and visibility

29	F	43	8	Circles	Circles 08: For someone that doesn't use many applications this is really good!	Insight from Feedback	Interaction: Insight from feedback
29	F	29	8	Smudge	Smudge 08: It completed disappeared.	Insight from Feedback	Interaction: Insight from feedback
29	F	43	G	General	General: <Did you learn anything?> If you keep doing it it is easily done. I just got an iPhone 5 and now I've learned new things. Didn't know about the double tap, for instance. <Int 04: Zoom in> When I'm stuck somewhere I always press the home screen, now I know about the minimise gesture <Int 08: Minimise app>. <Which design do you prefer?> I prefer the circles, better than this one - circles are precise and you can do exactly as they say.	Able to remember interactions	Interaction: Insight from feedback
29	F	29	7	Smudge	Smudge 07: Maybe I'll see a video of what happens to the picture?	Uncertainty about status change	Observation: Uncertainty
29	F	43	4	Circles	Circles 04: <Showed me a pinch gesture, index and thumb.>	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
29	F	29	8	Smudge	Smudge 08: I've been thinking of lions and zebras...that looks like a lion's paw disappearing…	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
29	F	29	6	Smudge	Smudge 06: <Didn't use four fingers.>	Issues with multi-touch: interaction 06	Interaction: Issues with multi-touch
29	F	29	2	Circles	Circles 02: First I would try tho bring the menu back.	Mental model/bias to restore: menu first	Mental model/bias to restore
30	F	31	G	Smudge	General: <Do you prefer the shady/blurry design over the circles or not?> I think for me was more obvious what should I do with the blurry one. With the dots I wasn't sure if I should focus on one dot or all the dots… <Would you use these gestures/combinations of fingers?> Yeah I think so, I have an iPad, barely use it. I think I'd do the swipping <Int 06: Swipe apps>…If I paging through something I'd sweep.	Clear touch and hold quality	Observation: Touch and hold quality
30	F	31	G	Circles	General: <Do you prefer the shady/blurry design over the circles or not?> I think for me was more obvious what should I do with the blurry one. With the dots I wasn't sure if I should focus on one dot or all the dots… <Would you use these gestures/combinations of fingers?> Yeah I think so, I have an iPad, barely use it. I think I'd do the swipping <Int 06: Swipe apps>…If I paging through something I'd sweep.	Unclear touch and hold quality	Observation: Touch and hold quality
30	F	31	8	Circles	Circles 08: Can I open like that? <Tried a reverse pinch with 4 fingers.> <Where did the app go?> Down here. <Do you remember how to bring that menu up from the bottom?> No…	Insight from Feedback	Interaction: Insight from feedback

30	F	31	G	General	General: <Do you prefer one design over the other?> I think for me was more obvious what should I do with the blurry one. With the dots I wasn't sure if I should focus on one dot or all the dots… <Would you use these gestures/combinations of fingers?> Yeah I think so, I have an iPad, barely use it. I think I'd do the swipping <Int 06: Swipe apps>…If I paging through something I'd sweep.	Able to remember interactions	Interaction: Insight from feedback
30	F	31	3	Circles	Circles 03: If I use my finger anywhere in the picture will highlight that dot…or maybe double tap it…	Incorrect about touch method: interaction 03	Observation: Incorrect about touch method
30	F	31	8	Circles	Circles 08: Can I open like that? <Tried a reverse pinch with 4 fingers.> <Where did the app go?> Down here. <Do you remember how to bring that menu up from the bottom?> No…	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
30	F	31	8	Smudge	Smudge 08: <Tried a reverse pinch with all her fingers.> maybe like that? <tried to press the home-buttton.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
31	M	20	G	Smudge	General: <Do you prefer one design over the other?> I prefer the circles…well, it's three designs. The drop shape is a bit confusing… <Did you notice there are two different designs?> The one which is blurred indicates that I have to use my fingers, there's no point on the screen, they spread out. I would prefer to use the one wich is smudged, it shows me the direction the way better than the dots. I was unaware of the object selection <hold> and I didn't know how to deselect but these gestures were easy to learn and I did better the second time.	Unclear & blurry	Observation: Fingers and visibility
31	M	20	G	Circles	General: <Do you prefer one design over the other?> I prefer the circles…well, it's three designs. The drop shape is a bit confusing… <Did you notice there are two different designs?> The one which is blurred indicates that I have to use my fingers, there's no point on the screen, they spread out. I would prefer to use the one wich is smudged, it shows me the direction the way better than the dots. I was unaware of the object selection <hold> and I didn't know how to deselect but these gestures were easy to learn and I did better the second time.	Unclear implied directionality	Observation: Implied directionality
31	M	20	G	Smudge	General: <Do you prefer one design over the other?> I prefer the circles…well, it's three designs. The drop shape is a bit confusing… <Did you notice there are two different designs?> The one which is blurred indicates that I have to use my fingers, there's no point on the screen, they spread out. I would prefer to use the one wich is smudged, it shows me	Clear touch and hold quality	Observation: Touch and hold quality

					the direction the way better than the dots. I was unaware of the object selection <hold> and I didn't know how to deselect but these gestures were easy to learn and I did better the second time.		
31	M	20	8	Circles	Circles 08: I know is down there, in that bar below. Can't remember. <Tried a four finger pinch again.>	Insight from Feedback	Interaction: Insight from feedback
31	M	20	8	Smudge	Smudge 08: <You knew about this gesture before?> That specific gesture I've never done before. <Did you notice the difference from what you saw and what actually happened?> Before it went to bar but now it just disappeared…	Insight from Feedback	Interaction: Insight from feedback
31	M	20	G	General	Smudge 08: <You knew about this gesture before?> That specific gesture I've never done before. <Did you notice the difference from what you saw and what actually happened?> Before it went to bar but now it just disappeared…	Able to remember interactions	Interaction: Insight from feedback
31	M	20	G	General	General: <Do you prefer one design over the other?> I prefer the circles…well, it's three designs. The drop shape is a bit confusing… <Did you notice there are two different designs?> The one which is blurred indicates that I have to use my fingers, there's no point on the screen, they spread out. I would prefer to use the one wich is smudged, it shows me the direction the way better than the dots. I was unaware of the object selection <Int 03: Touch and hold> and I didn't know how to deselect but these gestures were easy to learn and I did better the second time.	Able to remember interactions	Interaction: Insight from feedback
31	M	20	2	Smudge	Smudge 02: I'm not sure, just move it with your thumb.	Uncertainty about type of gesture	Observation: Uncertainty
31	M	20	2	Smudge	Smudge 02: I'm not sure, just move it with your thumb.	Incorrect about touch method: Thumb issue	Observation: Incorrect about touch method
31	M	20	4	Smudge	Smudge 04: Click twice with your thumb and it zooms in.	Incorrect about touch method: Thumb issue	Observation: Incorrect about touch method
31	M	20	3	Circles	Circles 03: I thought I'd just copy it, didn't expect this options.	Issues with implied status change: interaction 03	Observation: Issues with implied status change
31	M	20	7	Smudge	Smudge 07: <Tried with three fingers.>	Issues with multi-touch: interaction 07	Interaction: Issues with multi-touch
31	M	20	2	Smudge	Smudge 02: <Used the thumb to drag the picture across and back>.	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
31	M	20	3	Smudge	Smudge 03: <Used the thumb to hold and deselect.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
31	M	20	4	Smudge	Smudge 04: <Used the thumb to double tap.>	Incorrect touch method: use of thumb	Interaction: Incorrect touch method
31	M	20	8	Circles	Circles 08: I know is down there, in	Incorrect	Interaction:

					that bar below. Can't remember. <Tried a four finger pinch again.>	gesture to restore: interaction 08	Incorrect gesture to restore
31	M	20	8	Smudge	Smudge 08: <Tried the same pinch inwards gesture to bring the app back.>	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
32	M	25	7	Smudge	Smudge 07: <Are you familiar with these interactions?> Yes, I'm familiar with some of this interactions.	Previous knowledge	Interaction: Insight from feedback
32	M	25	8	Smudge	Smudge 08: Somebody showed me some and some I discovered myself, I use everyday. Some of the interactions are similar on Nexus 4. There are similar gestures, tap and hold, similar swipe gestures from left to right…	Previous knowledge	Interaction: Insight from feedback
33	F	22	G	Smudge	General: <Do you prefer one design above the other?> I think the blurry ones are better and the circles are a bit vague, a bit like kindergarden. Although sometimes the blurry just look like a mark/dirt on the screen.	Unclear & blurry	Observation: Fingers and visibility
33	F	22	G	Smudge	General: <Do you prefer one design above the other?> I think the blurry ones are better and the circles are a bit vague, a bit like kindergarden. Although sometimes the blurry just look like a mark/dirt on the screen.	Clear touch and hold quality	Observation: Touch and hold quality
33	F	22	G	Circles	General: <Do you prefer one design above the other?> I think the blurry ones are better and the circles are a bit vague, a bit like kindergarden. Although sometimes the blurry just look like a mark/dirt on the screen.	Unclear touch and hold quality	Observation: Touch and hold quality
33	F	22	7	Circles	Circles 07: <Did you know this gesture before?> No, I think I've just learned this one. I generally just touch the home-button twice to get it. <referring to the task switcher.>	Insight from implied status change	Observation: Insight from implied status change
33	F	22	8	Circles	Circles 08: It tends to go in the middle, not to bottom right...	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
33	F	22	8	Smudge	Smudge 08: Like any iPad or iPhone generally the program goest to right or left but this one went down to the corner and decreased.	Insight from implied status change: Interaction 08	Observation: Insight from implied status change
33	F	22	8	Smudge	Smudge 08: So, this is where it went. <Referring to the 'smudge 8' interaction, finally comprehending how to bring the task switcher up to restore status.>	Insight from Feedback	Interaction: Insight from feedback
33	F	22	G	General	Circles 07: <Did you know this gesture before?> No, I think I've just learned this one <Int 07: Unveil task switcher>. I generally just touch the home-button twice to get it. <referring to the task switcher.>	Able to remember interactions	Interaction: Insight from feedback
33	F	22	4	Smudge	Smudge 04: I knew this <the double tap>.	Previous knowledge	Interaction: Insight from feedback
33	F	22	3	Smudge	Smudge 03: I'm not sure about this, seems to be the harder one.	Uncertainty about type of gesture	Observation: Uncertainty

33	F	22	4	Circles	Circles 04: You can have it larger <showed me a pinch gesture using her two hands index fingers.>	Incorrect about touch method: interaction 04	Observation: Incorrect about touch method
33	F	22	8	Smudge	Smudge 08: There's a paw there, maybe that's the next move of the lion...	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
33	F	22	8	Smudge	Smudge 08: <Tried a reverse pinch, brought the 'notification tab' from the top but couldn't remember about how to bring the task switcher>.	Incorrect gesture to restore: interaction 08	Interaction: Incorrect gesture to restore
33	F	22	2	Circles	Circles 02: <During interaction her expectation was to bring the menu first and then drag the pic back to it.>	Mental model/bias to restore: menu first	Mental model/bias to restore
34	F	32	G	Circles	General: <What can you remember?> I can push sideways, upwards, minimise. <Which design do you prefer?> I think I prefer the one with dots. It's just a pointer and there's no connection with the animal. The blurry one shows more movement though.	Visible & number of fingers	Observation: Fingers and visibility
34	F	32	G	Smudge	General: <What can you remember?> I can push sideways, upwards, minimise. <Which design do you prefer?> I think I prefer the one with dots. It's just a pointer and there's no connection with the animal. The blurry one shows more movement though.	Clear implied directionality	Observation: Implied directionality
34	F	32	G	General	General: <What can you remember?> I can push sideways <Int 06: Swipe apps>, upwards <Int 07: Unveil task switcher>, minimise <Int 08: Minimise app>. <Which design do you prefer?> I think I prefer the one with dots. It's just a pointer and there's no connection with the animal. The blurry one shows more movement though.	Able to remember interactions	Interaction: Insight from feedback
34	F	32	6	Smudge	Smudge 06: <Showed me an all fingers pinch outwards.>	Incorrect about touch method: interaction 06	Observation: Incorrect about touch method
34	F	32	8	Smudge	Smudge 08: That was a footprint of the lion...	Incorrect about touch method: Lion paw issue	Observation: Incorrect about touch method
34	F	32	6	Circles	Circles 06: There will be a next page and this is gonna disappear.	Issues with implied status change: interaction 06	Observation: Issues with implied status change
34	F	32	4	Circles	Circles 04: <Just touched and held, then touched and dragged around with two fingers.>	Issues with multi-touch	Interaction: Issues with multi-touch
34	F	32	5	Smudge	Smudge 05: <Just touched the corners, didn't do the swipe gesture for flipping the page back.>	Incorrect gesture to restore	Interaction: Incorrect gesture to restore

Table 58: Transcriptions from all test sessions (Study 1). 'G' stands for general comments.

APPENDIX L - SOFTWARE SOLUTION (ST 2)

Language: QML + QtQuick [1][2] rapid

Framework: Qt C++ framework [3]. The system was developed on Linux and OS/X using Xcode, and run on iOS 7. Implemented in JavaScript.

Timings (in ms):

- fadeIn: 600 (the time it takes for an item to fade in)
- fadeOut: 400 (the time it takes for an item to fade out)
- springBack: 1000 (time taken for an object dragged and released outside the target zone to go back)
- moveOut: 800 (when automatically moving something out, e.g. Feedforward component, the time it takes to go out)
- moveBack: 1000 (when automatically moving something out and released outside the target zone, e.g. Feedforward component, the time it takes to come back)
- tapDelay: 300 (the limit between press and release event when tapping)
- tapAndHoldDelay: 600 (the amount of time a press must be held to generate a tap-and-hold-event)
- tripleTapDelay: 1000 (the maximum of time allowed to the happening of three taps to skip interactions)
- initialDelay: 5000 (the time before the first affordance is displayed)
- intervalDelay: 3 * 1000 (for repeated affordances, the interval between the start of one and the start of the next)
- The maximal travel height of the button of the first interaction is the height of the button itself.
- V1. Static affordances: 5000 delay to display
- V2. Gesture and UI component: 5000 delay to display, 1600 to animate, 2000 to return to original position/state
- V3/4.: same as above but without initial delay (1-tap version)
- V5. same as above but both automatically after 5000 wait, and on tap.

Interaction 3 is an exception with:
- Version 2/5.: - animated icon for 2000, and corner shown for 800ms, starting 200ms before the end of the animated gestural icon.
- Version 3.: animated icon for 2000ms
- Version 4.: animated corner (immediately) for 800ms

Pause screen:
- Opacity: 0.6
- Tap/release to activate next interaction

[1] http://qt-project.org/doc/qt-5/qtqml-index.html
[2] http://qt-project.org/doc/qt-5/qtquick-index.html
[3] http://en.wikipedia.org/wiki/Qt_%28software%29

Description of gesture and effect times per versions

	Gesture			Effect		
	Evaluation		Execution	Evaluation		Execution
	Affordance	Feedforward	Feedback	Affordance	Feedforward	Feedback
Version 1 (gesture STATIC)	5000 delay to display: shows static gestural symbol. Fade in 600, delay of 1000 and Fade out 400	-	-	-	-	-
Version 2 (gesture and ANIMATED effect)	5000 delay to display: shows static gestural symbol. Fade in 600	Touch points move in the appropriate direction: 1600 and Fade out 400	-	Shows control Fade in 600 Animation time: 1600	moveOut: 800 Control moves into position and returns to original position or state (moveBack): 1000 and Fade out 400	-
Version 3 (gesture feedback only)	-	-	1-tap brief touch over 'control' displays ANIMATED gesture: Fade in 600, delay of 800 and fade out 400 springBack: 1000	-	-	-
Version 4 (UI component feedback only)	-	-	-	-	-	1-tap brief touch over 'control' displays ANIMATED UI component Fade in 600, moveOut: 800 moveBack: 1000 and Fade out 400
Version 5 (complete):	5000 delay to display: shows static gestural symbol. Fade in 600	Touch points move in the appropriate direction: 1600 and Fade out 400	1-tap brief touch over 'control' displays ANIMATED gesture: Fade in 600, delay of 800 and fade out 400 springBack: 1000	Shows control Fade in 600 Animation time: 1600	moveOut: 800 Control moves into position and returns to original position or state: 2000	1-tap brief touch over 'control' displays ANIMATED UI component Fade in 600, moveOut: 800 moveBack: 1000 and Fade out 400
- A pause screen is displayed after every interaction (successful or triggered by facilitator): tripleTapDelay: 1000 - The maximal travel height of the button of the first interaction is the height of the button itself. - Tap and hold interaction: tapAndHoldDelay: 600 (the amount of time a press must be held to generate a tap-and-hold-event) / animated corner (immediately) for 800ms						

Table 59: Description of times per prototype version (Study 2).

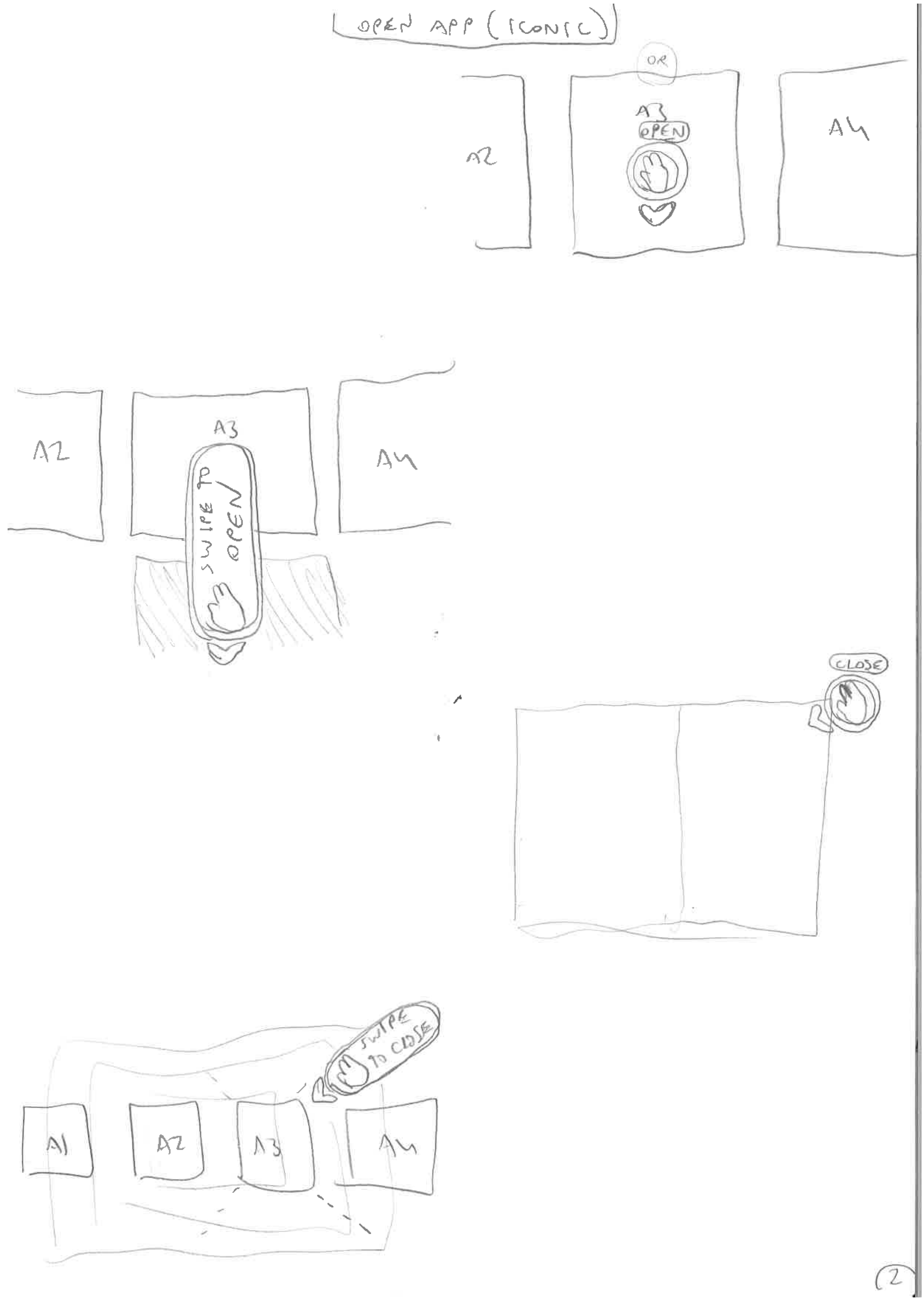
Description of gesture and effect times per interactions

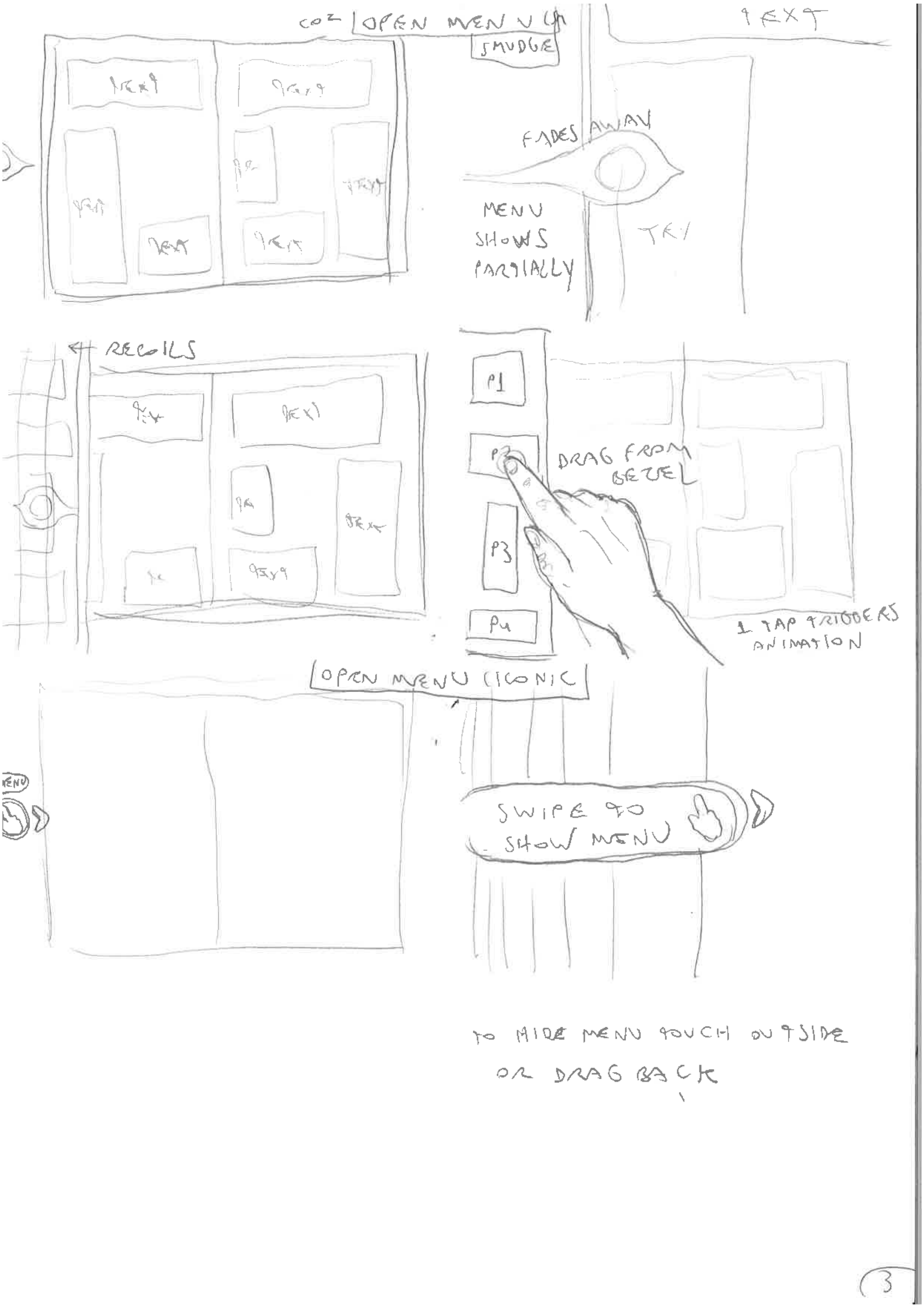
	Gesture			**Effect**		
	Evaluation		**Execution**	**Evaluation**		**Execution**
	Affordance	**Feedforward**	**Feedback**	**Affordance**	**Feedforward**	**Feedback**
Int 1: Open app	initialDelay: 5000 fadeIn: 600 Touch points (located over button) with implied directionality (vertical downward) over button are displayed **	moveOut: 800 02 touch points move downwards once and returns to previous position each time. springBack:1000 fadeOut: 400	tapDelay: 300 1-tap brief touch over button displays SPG	4 buttons	1 button ghost moves downward along with gesture affordance and returns to previous position. **	02 touch points moving the button downwards and releasing after threshold is reached opens the app.
Int 2: Unveil menu	initialDelay: 5000 fadeIn: 600 Touch-point (close to left bezel) with implied directionality (horizontal toward right)	moveOut: 800 Touch-point with implied directionality move towards the centre of the screen and return to previous position springBack:1000 fadeOut: 400	tapDelay: 300 1-tap brief touch over anywhere proximal to left bezel displays SPG	Hidden away from sight	initialDelay: 3 1000 Menu partially moves and returns to initial position (hidden away from sight)	Touch-point swiping towards the centre of the screen unveils the menu (after threshold is reached).
Int 3-3.1: Multiple selection	initialDelay: 5000 fadeIn: 600 Touch-point with implied touch and hold over the picture is displayed	Animation of touch and hold is displayed fadeOut: 400 Animation time: 2000	tapDelay: 300 1-tap brief touch over button displays SPG for selecting picture. tapAndHoldDelay: 600	fadeIn: 600 Picture top right corner appears 'flagged' with corner that show for 800 (200 after gesture affordance)	'Flagged' top right corner fades out fadeOut: 400	Animated for 800 Touch and hold to de-select picture: tapAndHoldDelay: 600
Interaction 3-3.1: Drag pictures	Deemed unnecessary to display	Deemed unnecessary to display	Deemed unnecessary to display	The picture itself (user drags towards the centre of the screen)	Deemed unnecessary to display	moveBack:1000 In case the user releases before reaching threshold within target zone

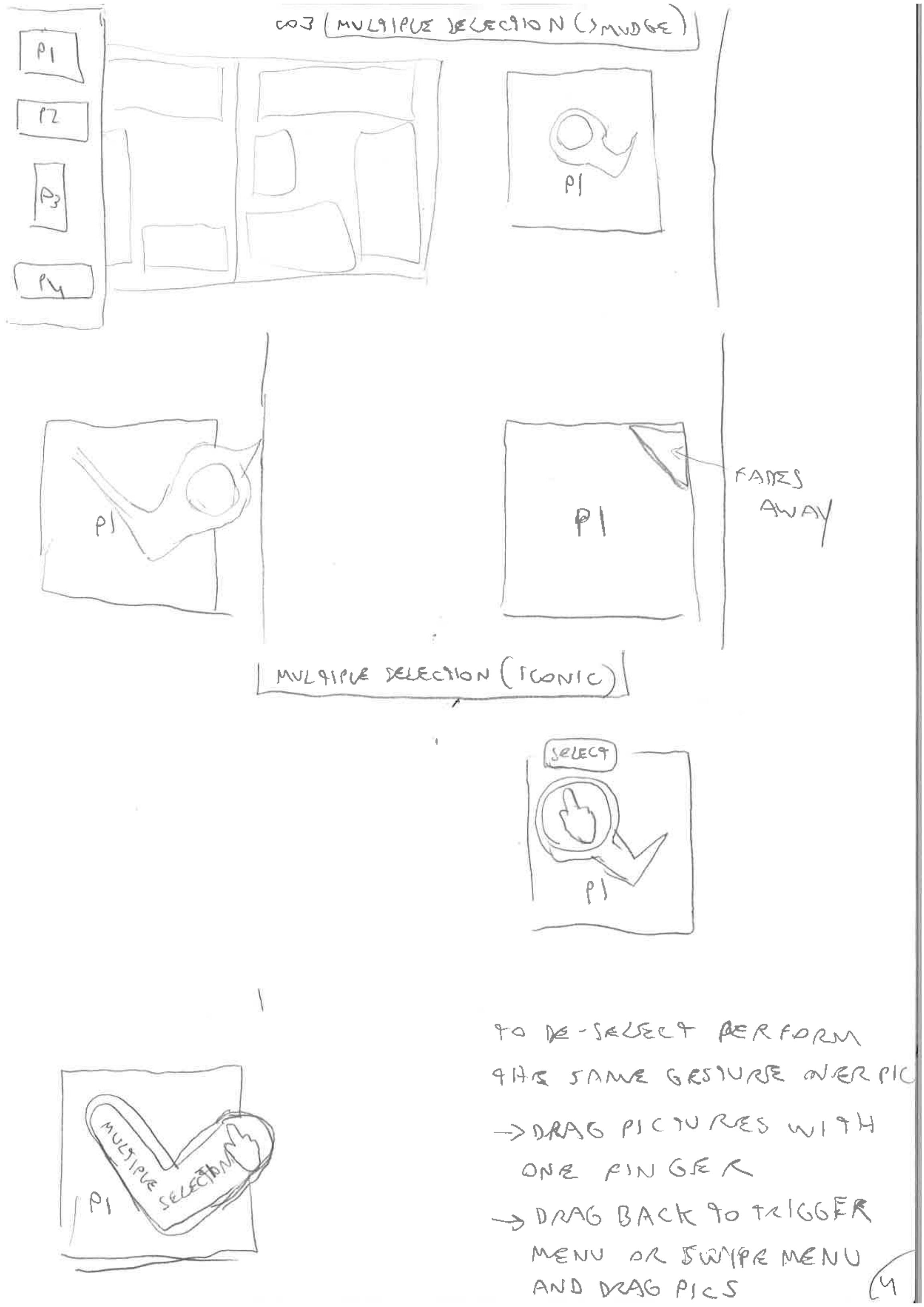
All animations are played once unless stated otherwise.
All animations fade away after played unless stated otherwise.
UI components are displayed immediately after gestures affordances unless stated otherwise.
A pause screen is displayed after every interaction (successful or triggered by facilitator).
** The maximal travel height of the button of the first interaction is the height of the button itself.

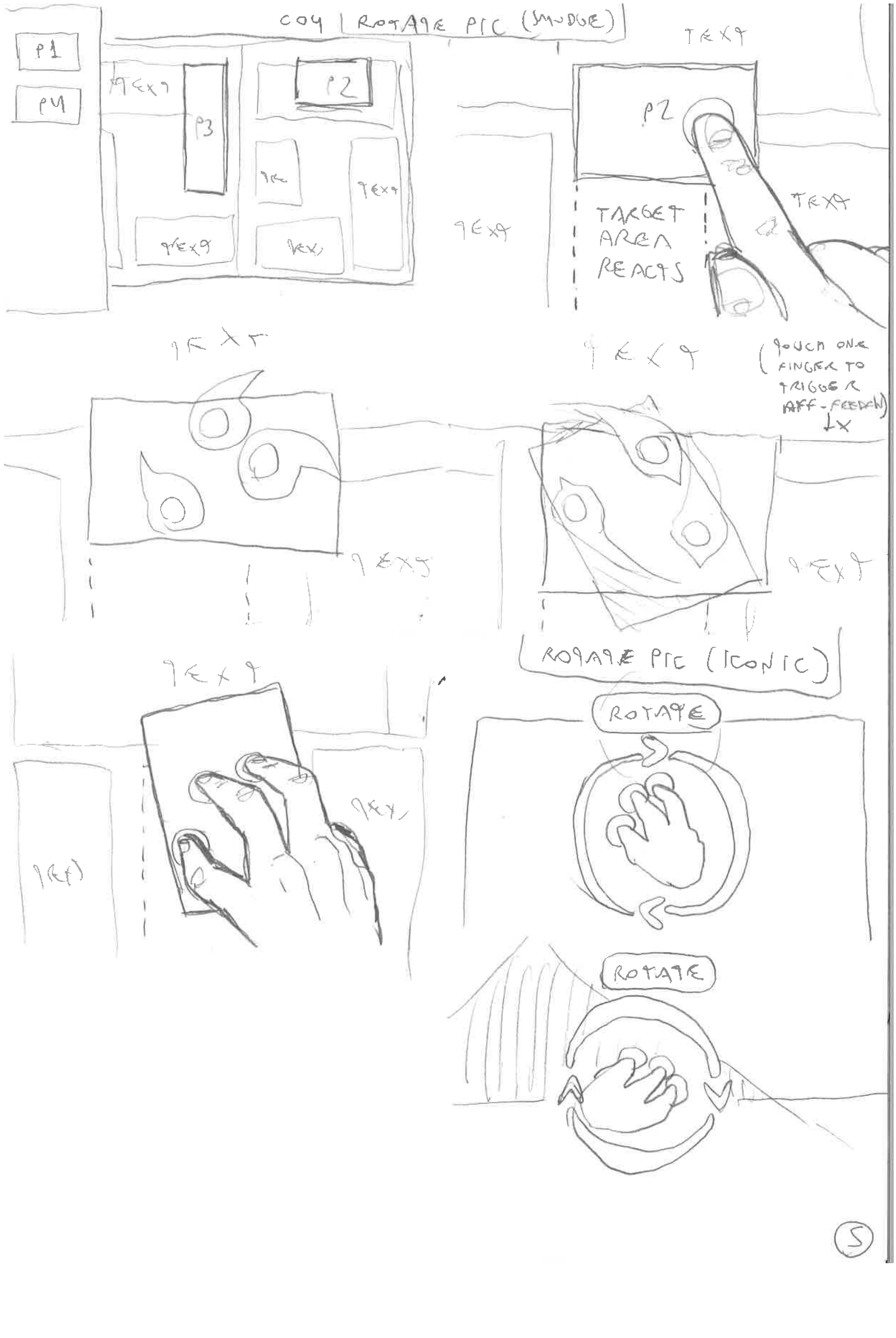
Table 60: Description of times per interaction (Study 2).

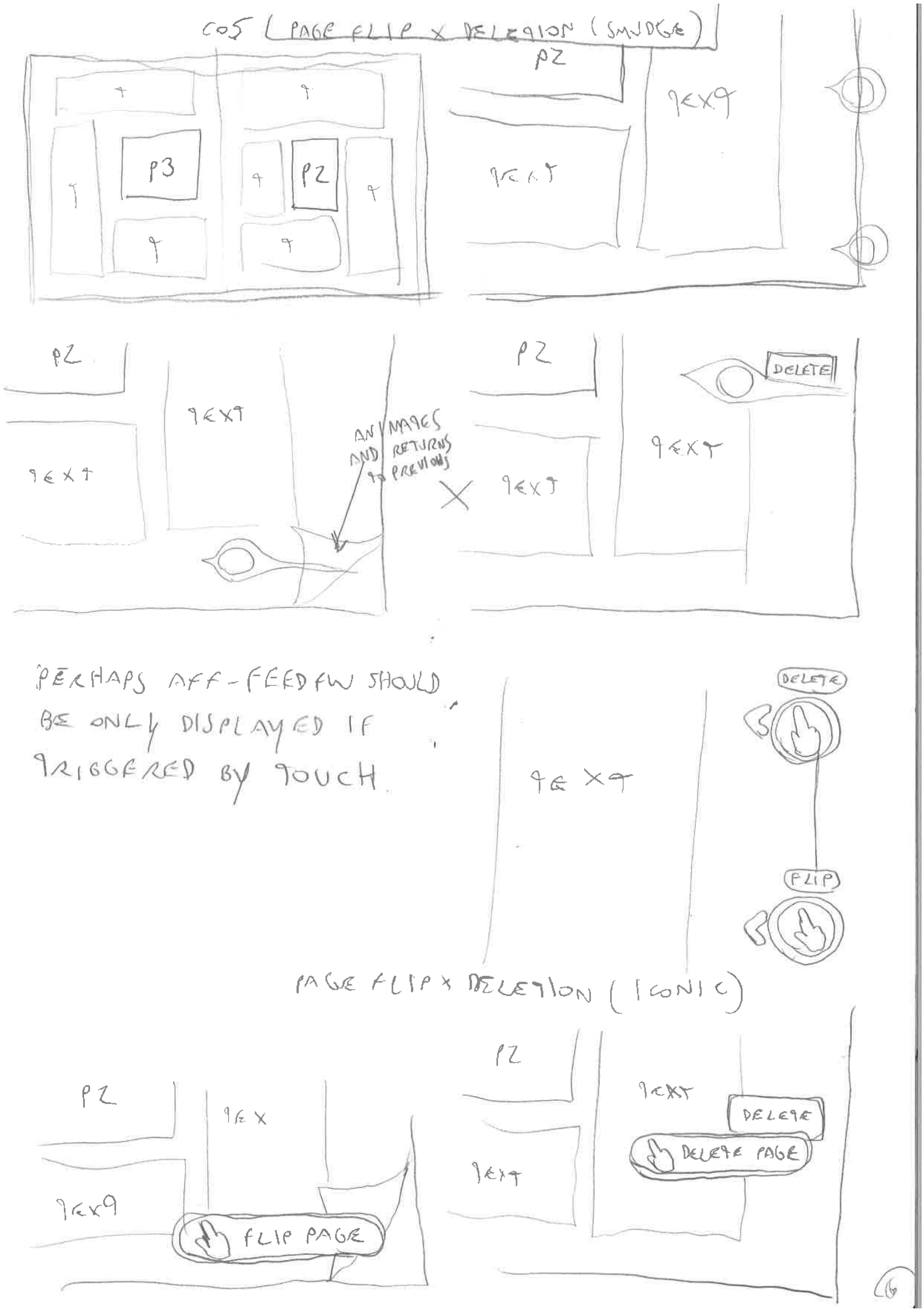
APPENDIX M - SKETCHES FOR SPG (STUDY 2)


OPEN APP (ICONIC)
OR
A2
A3
OPEN
A4
A2
A3
SWIPE TO OPEN
A4
CLOSE
SWIPE TO CLOSE
A1
A2
A3
A4
(2)


OPEN MENU
SMUDGE
TEXT
FADES AWAY
MENU SHOWS PARTIALLY
RECOILS
P1
P2
P3
P4
DRAG FROM BEZEL
1 TAP TRIGGERS ANIMATION
OPEN MENU (ICONIC
MENU
SWIPE TO SHOW MENU
TO HIDE MENU TOUCH OUTSIDE OR DRAG BACK
3


MULTIPLE SELECTION (SMUDGE)
P1
P2
P3
P4
P1
P1
FADES AWAY
P1
MULTIPLE SELECTION (ICONIC)
SELECT
P1
MULTIPLE SELECTION
P1
TO DE-SELECT PERFORM THE SAME GESTURE OVER PIC
-> DRAG PICTURES WITH ONE FINGER
-> DRAG BACK TO TRIGGER MENU OR SWIPE MENU AND DRAG PICS


ROTATE PIC (SMUDGE)
P1
P4
P3
P2
TEXT
TARGET AREA REACTS
TOUCH ONE FINGER TO TRIGGER AFF-FEEDBACK
ROTATE PIC (ICONIC)
ROTATE
ROTATE


CO5 (PAGE FLIP X DELETION (SMUDGE))
P3
P2
TEXT
ANIMATES AND RETURNS TO PREVIOUS
DELETE
PERHAPS AFF-FEEDFW SHOULD BE ONLY DISPLAYED IF TRIGGERED BY TOUCH
FLIP
PAGE FLIP X DELETION (ICONIC)
FLIP PAGE
DELETE PAGE

APPENDIX N - RECRUITMENT POSTER (ST 2)

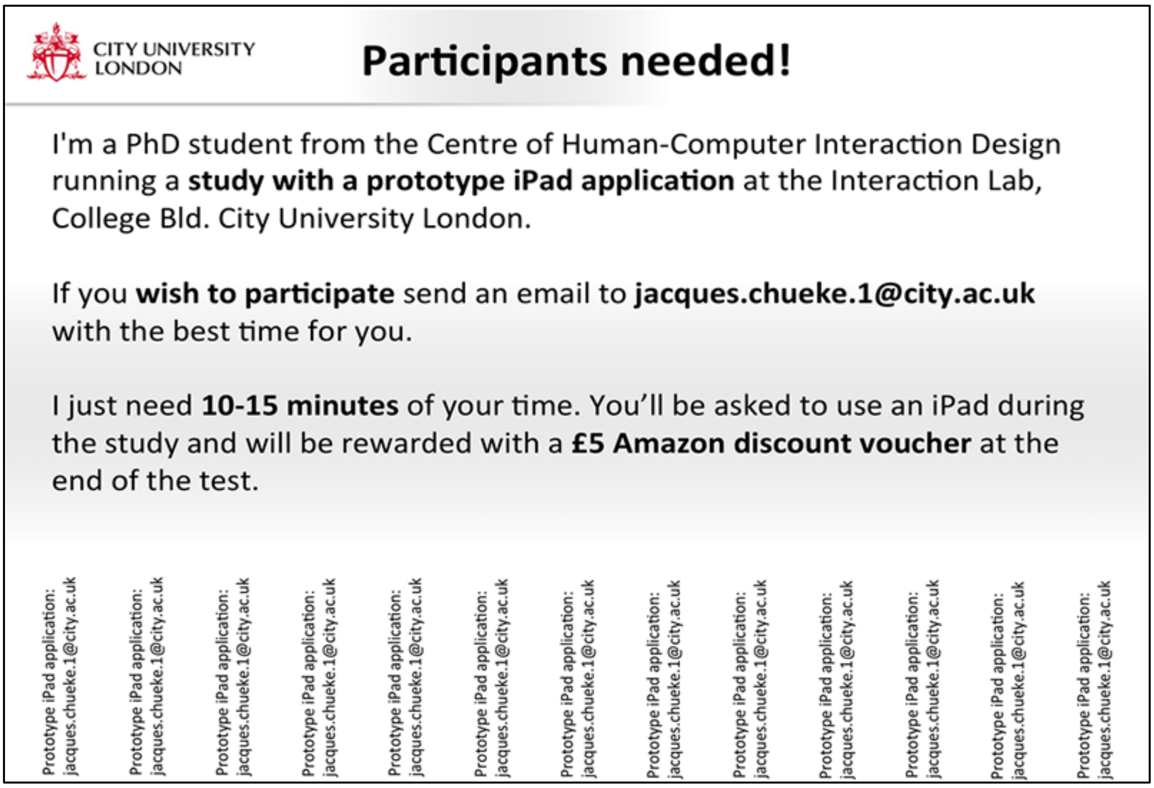


Figure 97: Recruitment poster for study 2.

APPENDIX O - CONSENT FORM (STUDY 2)

We would like to invite you to take part in a research study. Before you decide whether you would like to take part it is important that you understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and discuss it with the principal researcher. Ask if there is anything that is not clear or if you would like more information.

What is the purpose of the study?

This research will investigate novel interfaces designed for touch-based devices such as tablets. You will be shown new interface designs and your feedback will help us improve the designs. We welcome participants regardless their skill levels with touch-based technology, acknowledging that any feedback on the design and software behaviours will prove insightful.

Do I have to take part?

Your participation is completely voluntary. You may choose not to participate at all, may refuse to participate in certain procedures or answer certain questions, or may discontinue your participation at any time without penalty. Your decision not to participate will not affect your relationship with City University London or the person who identified you as a potential participant. Agreeing to participate and signing this form does not waive any of your legal rights. UK Law protects your privacy to the maximum extent allowable.

What will happen if I take part?

Your participation will take approximately 10-15 minutes and no risk from participation is anticipated. There are no right or wrong answers and the purpose of this session is to evaluate the system and not your skills. No further contacts or additional visits to the lab will be necessary after this session. The conversation between you and the facilitator and your interactions with the screen will be recorded with a small camera mounted on the mobile stand to ensure the accuracy of the research and to assist in the confirmation of the findings.

What do I have to do?

If you agree to participate in the test, first you will be asked to fill in a questionnaire about yourself. After that you will be asked to sit in front of a tablet mounted on a special stand used for user-testing sessions with mobile devices. Then you will be asked to observe and interact with a prototype application running on the tablet. The facilitator will ask you to think-aloud about your impressions of the screen and the interactions. You will be asked to perform three short tasks across twenty different designs of the application, all in presence of the facilitator. After that you will be asked to fill in a questionnaire about the application characteristics. The study will take place at the Focus Room located at A222 College building within the Interaction Lab, Centre for HCID.

What are the possible benefits of taking part?

Your assessment of the application and the data accumulated from your interactions can help improving personal gestural interface design. We believe its findings and design recommendations can be used by manufacturers e.g. Microsoft, Apple, Samsung in designing better responsive software in mobile devices and tablets; and in the future could also be extrapolated to the design of multiple-users large-scale devices e.g. interactive walls, tables and live-size screens.

What will happen at the end of the study?

You will receive a copy of this information sheet and consent form. The principal investigator will offer to share any findings from the study, after data from all participants' sessions was organised. You will be able to contact the principal investigator by email or phone (informed at the end of this information sheet).

Will my taking part in the study be kept confidential?

Any information you share will be kept confidential and your name will not be associated with your data (you will be referred to as "participant number, age, gender"). If a participant decides not to participate at any time his/her video recording will be deleted and his/her personal details will be excluded from further data analysis. Recordings of participants that signed the consent form will be kept in the principal investigator's laptop.

What will happen to results of the research study?
Highlight videos clips, stills and transcription of verbalisations along with findings will be used in presentations, the PhD thesis and the production of papers; however rest assured that your name will not be associated to any of the aforementioned materials.

If you have any questions about this study, please contact the principal researcher: Jacques Chueke, PhD Candidate within the Centre for HCI Design. Phone: +44 (0) 20 7040 8166, or email: Jacques.Chueke.1@city.ac.uk

If you have any complains you could also write to the Secretary at:

Anna Ramberg
Secretary to Senate Research Ethics Committee

Research Office, E214
City University London
Northampton Square
London
EC1V 0HB

Email: Anna.Ramberg.1@city.ac.uk

City University London holds insurance policies, which apply to this study. If you feel you have been harmed or injured by taking part in this study you may be eligible to claim compensation.

This does not affect your legal rights to seek compensation. If you are harmed due to someone's negligence, then you may have grounds for legal action.

Who has reviewed the study?

City University London Informatics and Research Ethics Committee have approved this study.

Consent Form

Please check boxes

1. I agree to take part in the above City University London research project. I have had the project explained to me, and I have read the participant information sheet, which I may keep for my records. ☐

   I understand this will involve:

   be interviewed by the researcher

   allow the interview to be videotaped/audiotaped

   complete questionnaires asking me about myself

   use a tablet to undertake the tasks necessary for the study

   complete questionnaires asking me about the subject of the study / task

---

2. This information will be held and processed for the following purpose(s): ☐

   I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party. No identifiable personal data will be published. The identifiable data will not be shared with any other organisation.

   I consent to the videotapes being shown to other researchers and interested professionals.

   I consent to the use of sections of the videotapes in publications.

---

3. I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalized or disadvantaged in any way. ☐

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4. I agree to City University London recording and processing this information about me. I understand that this information will be used only for the ☐

purpose(s) set out in this statement and my consent is conditional on the University complying with its duties and obligations under the Data Protection Act 1998.

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5. If you voluntarily agree to participate in this research, having comments and video recorded, and have had all questions answered, please sign below.

Participant's Signature Date

Researcher's Signature Date

Thank you for taking the time to read the information sheet and the consent form.

APPENDIX P - PRE-TEST QUEST. (STUDY 2)

1. Name: ____

2. Email: ____

3. Nationality: ____

4. Occupation: ____

5. Age: ____

6. Gender

☐ Male ☐ Female ☐ Other

7. Do you have a laptop with trackpad?

☐ Yes ☐ No If yes, which one?

____

8. Do you have a touch-based phone?

☐ Yes ☐ No If yes, which one?

____

9. Do you have a tablet/PDA?

☐ Yes ☐ No If yes, which one?

____

10. How often do you use your tablet/PDA?

☐ Daily

☐ 1-4 times a week

☐ 1-3 times a month

☐ Never

APPENDIX Q - RANDOMIZATION SET (ST 2)

SEQUENCE 01			SEQUENCE 02			SEQUENCE 03		
INT	DES	VER	INT	DES	VER	INT	DES	VER
1	2	1	3	1	2	3	2	4
2	1	2	2	2	5	1	1	2
3	2	3	1	1	1	2	1	5
3	1	4	2	2	4	1	1	1
2	1	5	1	1	3	3	2	3
1	2	5	3	2	3	2	1	3
1	2	4	2	1	4	1	2	1
3	1	3	3	2	1	2	2	2
2	2	2	1	1	5	3	2	5
2	1	1	3	2	2	1	1	4
3	1	2	1	2	4	3	2	1
1	1	5	2	1	2	2	1	2
3	2	1	1	2	5	2	2	3
1	1	4	2	2	1	3	1	4
2	2	3	3	1	3	1	2	5
2	1	4	1	2	3	3	1	5
1	2	3	3	1	1	2	1	4
3	1	1	2	1	5	1	2	3
2	2	5	1	1	2	3	1	2
1	2	2	3	2	4	2	2	1
I#1=7x I#2=7x I#3=6x	D#1=10x D#2=10x	V#1=4x V#2=4x V#3=4x V#4=4x V#5=4x	I#1=7x I#2=6x I#3=7x	D#1=10x D#2=10x	V#1=4x V#2=4x V#3=4x V#4=4x V#5=4x	I#1=6x I#2=7x I#3=7x	D#1=10x D#2=10x	V#1=4x V#2=4x V#3=4x V#4=4x V#5=4x

Table 61: Three sequences randomised - internally balanced order (Study 2).

APPENDIX R - SUMMARY SCREEN (STUDY 2)

Results: sequence 1

No.	I.	D.	V.	Time	Success
1	1	2	1	42s	no
2	2	1	2	46s	yes
3	3	2	3	55s	no
4	3	1	4	39s	no
5	2	1	5	14s	yes
6	1	2	5	17s	yes
7	1	2	4	4s	yes
8	3	1	3	31s	yes
9	2	2	2	6s	yes
10	2	1	1	8s	yes
11	3	1	2	10s	yes
12	1	2	5	6s	yes
13	3	1	1	22s	yes
14	1	1	4	13s	yes
15	2	2	3	14s	yes
16	2	1	3	2s	yes
17	1	2	4	14s	yes
18	3	1	1	21s	yes
19	2	2	5	5s	yes
20	1	2	2	3s	yes

Total: 17/20, time: 372s

End time: Wed Feb 5 18:05:16 2014 GMT

Figure 98: Example of summary screen at the end of a test (Study 2).

APPENDIX S - BETWEEN SUBJECTS EFFECT - ALL VERSIONS (STUDY 2)

Test of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Estatística	df	Sig.	Estatística	df	Sig.
identify_potential_touch	.450	900	0.000	.584	900	.000
identify_touch_points	.493	900	0.000	.475	900	.000
identify_touch_config	.480	900	0.000	.511	900	.000
identify_direction	.537	900	0.000	.246	900	.000
identify_system_status	.475	900	0.000	.520	900	.000
tap_to_preview	.385	540	.000	.632	540	.000
touch_to_confirm	.524	540	0.000	.356	540	.000
perform_swipe	.491	540	0.000	.482	540	.000
perform_direction	.538	540	0.000	.149	540	.000
system_status	.496	540	0.000	.477	540	.000

Evaluation phase

Version 1

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	identify_potential_touch	14,583[b]	5	2.917	9.766	.000
	identify_touch_points	39,097[c]	5	7.819	17.070	.000
	identify_touch_config	25,996[d]	5	5.199	9.523	.000
	identify_direction	31,881[e]	5	6.376	19.026	.000
	identify_system_status	12,092[f]	5	2.418	8.608	.000
Intercept	identify_potential_touch	431.784	1	431.784	1445.736	.000
	identify_touch_points	383.619	1	383.619	837.474	.000
	identify_touch_config	384.850	1	384.850	704.897	.000
	identify_direction	457.301	1	457.301	1364.523	.000
	identify_system_status	482.808	1	482.808	1718.460	.000
design	identify_potential_touch	1.048	1	1.048	3.509	.063
	identify_touch_points	.040	1	.040	.088	.767
	identify_touch_config	1.274	1	1.274	2.334	.128
	identify_direction	.038	1	.038	.113	.738
	identify_system_status	1.865	1	1.865	6.639	.011
interaction	identify_potential_touch	11.682	2	5.841	19.558	.000
	identify_touch_points	37.848	2	18.924	41.312	.000
	identify_touch_config	18.998	2	9.499	17.398	.000
	identify_direction	31.166	2	15.583	46.498	.000
	identify_system_status	8.515	2	4.257	15.153	.000
design * interaction	identify_potential_touch	.777	2	.388	1.301	.275
	identify_touch_points	.003	2	.001	.003	.997
	identify_touch_config	3.933	2	1.966	3.602	.029
	identify_direction	.030	2	.015	.044	.957
	identify_system_status	.808	2	.404	1.438	.240
Error	identify_potential_touch	51.967	174	.299		
	identify_touch_points	79.703	174	.458		
	identify_touch_config	94.998	174	.546		
	identify_direction	58.314	174	.335		
	identify_system_status	48.886	174	.281		
Total	identify_potential_touch	537.000	180			

	identify_touch_points	542.000	180			
	identify_touch_config	523.000	180			
	identify_direction	607.000	180			
	identify_system_status	588.000	180			
Corrected Total	identify_potential_touch	66.550	179			
	identify_touch_points	118.800	179			
	identify_touch_config	120.994	179			
	identify_direction	90.194	179			
	identify_system_status	60.978	179			

a. version = V1
b. R Squared = ,219 (Adjusted R Squared = ,197)
c. R Squared = ,329 (Adjusted R Squared = ,310)
d. R Squared = ,215 (Adjusted R Squared = ,192)
e. R Squared = ,353 (Adjusted R Squared = ,335)
f. R Squared = ,198 (Adjusted R Squared = ,175)

Version 2

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	identify_potential_touch	3,930[b]	5	.786	4.431	.001
	identify_touch_points	12,479[c]	5	2.496	6.464	.000
	identify_touch_config	6,067[d]	5	1.213	3.369	.006
	identify_direction	1,617[e]	5	.323	2.416	.038
	identify_system_status	3,142[f]	5	.628	2.641	.025
Intercept	identify_potential_touch	466.826	1	466.826	2631.316	.000
	identify_touch_points	427.103	1	427.103	1106.187	.000
	identify_touch_config	449.209	1	449.209	1247.384	.000
	identify_direction	540.502	1	540.502	4037.368	.000
	identify_system_status	474.887	1	474.887	1995.533	.000
design	identify_potential_touch	.022	1	.022	.124	.726
	identify_touch_points	.814	1	.814	2.109	.148
	identify_touch_config	.038	1	.038	.105	.747
	identify_direction	.170	1	.170	1.269	.261
	identify_system_status	.291	1	.291	1.223	.270
interaction	identify_potential_touch	3.148	2	1.574	8.872	.000
	identify_touch_points	6.988	2	3.494	9.049	.000
	identify_touch_config	5.676	2	2.838	7.881	.001
	identify_direction	.934	2	.467	3.488	.033
	identify_system_status	2.431	2	1.216	5.108	.007
design * interaction	identify_potential_touch	.690	2	.345	1.945	.146
	identify_touch_points	1.910	2	.955	2.474	.087
	identify_touch_config	.536	2	.268	.744	.477
	identify_direction	.084	2	.042	.313	.732
	identify_system_status	.741	2	.371	1.557	.214
Error	identify_potential_touch	30.870	174	.177		
	identify_touch_points	67.182	174	.386		
	identify_touch_config	62.661	174	.360		
	identify_direction	23.294	174	.134		
	identify_system_status	41.408	174	.238		
Total	identify_potential_touch	618.000	180			
	identify_touch_points	617.000	180			
	identify_touch_config	627.000	180			
	identify_direction	690.000	180			
	identify_system_status	617.000	180			
Corrected Total	identify_potential_touch	34.800	179			
	identify_touch_points	79.661	179			
	identify_touch_config	68.728	179			
	identify_direction	24.911	179			
	identify_system_status	44.550	179			

a. version = V2

b. R Squared = ,113 (Adjusted R Squared = ,087)
c. R Squared = ,157 (Adjusted R Squared = ,132)
d. R Squared = ,088 (Adjusted R Squared = ,062)
e. R Squared = ,065 (Adjusted R Squared = ,038)
f. R Squared = ,071 (Adjusted R Squared = ,044)

Version 3

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	identify_potential_touch	31,190[b]	5	6.238	34.176	.000
	identify_touch_points	9,135[c]	5	1.827	5.423	.000
	identify_touch_config	51,606[d]	5	10.321	39.756	.000
	identify_direction	,590[e]	5	.118	1.692	.139
	identify_system_status	32,044[f]	5	6.409	35.117	.000
Intercept	identify_potential_touch	437.180	1	437.180	2395.149	.000
	identify_touch_points	448.841	1	448.841	1332.387	.000
	identify_touch_config	442.991	1	442.991	1706.368	.000
	identify_direction	577.144	1	577.144	8273.790	.000
	identify_system_status	466.864	1	466.864	2558.113	.000
design	identify_potential_touch	1.416	1	1.416	7.759	.006
	identify_touch_points	.783	1	.783	2.324	.129
	identify_touch_config	6.733	1	6.733	25.937	.000
	identify_direction	.021	1	.021	.298	.586
	identify_system_status	2.330	1	2.330	12.766	.000
interaction	identify_potential_touch	9.223	2	4.612	25.266	.000
	identify_touch_points	5.313	2	2.656	7.885	.001
	identify_touch_config	15.187	2	7.594	29.250	.000
	identify_direction	.318	2	.159	2.280	.105
	identify_system_status	8.950	2	4.475	24.519	.000
design * interaction	identify_potential_touch	12.233	2	6.116	33.510	.000
	identify_touch_points	5.094	2	2.547	7.560	.001
	identify_touch_config	14.834	2	7.417	28.570	.000
	identify_direction	.042	2	.021	.298	.742
	identify_system_status	11.435	2	5.718	31.328	.000
Error	identify_potential_touch	31.760	174	.183		
	identify_touch_points	58.615	174	.337		
	identify_touch_config	45.172	174	.260		
	identify_direction	12.138	174	.070		
	identify_system_status	31.756	174	.183		
Total	identify_potential_touch	553.000	180			
	identify_touch_points	619.000	180			
	identify_touch_config	564.000	180			
	identify_direction	705.000	180			
	identify_system_status	584.000	180			
Corrected Total	identify_potential_touch	62.950	179			
	identify_touch_points	67.750	179			
	identify_touch_config	96.778	179			
	identify_direction	12.728	179			
	identify_system_status	63.800	179			

a. version = V3
b. R Squared = ,495 (Adjusted R Squared = ,481)
c. R Squared = ,135 (Adjusted R Squared = ,110)
d. R Squared = ,533 (Adjusted R Squared = ,520)
e. R Squared = ,046 (Adjusted R Squared = ,019)
f. R Squared = ,502 (Adjusted R Squared = ,488)

Version 4

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.

Corrected Model	identify_potential_touch	21,380[b]	5	4.276	17.432	.000
	identify_touch_points	14,830[c]	5	2.966	6.929	.000
	identify_touch_config	53,983[d]	5	10.797	28.116	.000
	identify_direction	,982[e]	5	.196	2.700	.022
	identify_system_status	22,391[f]	5	4.478	21.298	.000
Intercept	identify_potential_touch	433.940	1	433.940	1769.053	.000
	identify_touch_points	462.427	1	462.427	1080.310	.000
	identify_touch_config	384.540	1	384.540	1001.390	.000
	identify_direction	627.589	1	627.589	8624.221	.000
	identify_system_status	479.902	1	479.902	2282.347	.000
design	identify_potential_touch	.053	1	.053	.214	.644
	identify_touch_points	3.117	1	3.117	7.282	.008
	identify_touch_config	.373	1	.373	.972	.325
	identify_direction	.078	1	.078	1.076	.301
	identify_system_status	.012	1	.012	.057	.811
interaction	identify_potential_touch	17.674	2	8.837	36.025	.000
	identify_touch_points	8.043	2	4.021	9.395	.000
	identify_touch_config	48.955	2	24.478	63.742	.000
	identify_direction	.688	2	.344	4.727	.010
	identify_system_status	19.865	2	9.933	47.238	.000
design * interaction	identify_potential_touch	1.743	2	.871	3.553	.031
	identify_touch_points	1.446	2	.723	1.689	.188
	identify_touch_config	1.868	2	.934	2.432	.091
	identify_direction	.163	2	.082	1.122	.328
	identify_system_status	1.521	2	.760	3.616	.029
Error	identify_potential_touch	42.681	174	.245		
	identify_touch_points	74.481	174	.428		
	identify_touch_config	66.817	174	.384		
	identify_direction	12.662	174	.073		
	identify_system_status	36.586	174	.210		
Total	identify_potential_touch	541.000	180			
	identify_touch_points	596.000	180			
	identify_touch_config	544.000	180			
	identify_direction	702.000	180			
	identify_system_status	586.000	180			
Corrected Total	identify_potential_touch	64.061	179			
	identify_touch_points	89.311	179			
	identify_touch_config	120.800	179			
	identify_direction	13.644	179			
	identify_system_status	58.978	179			

a. version = V4
b. R Squared = ,334 (Adjusted R Squared = ,315)
c. R Squared = ,166 (Adjusted R Squared = ,142)
d. R Squared = ,447 (Adjusted R Squared = ,431)
e. R Squared = ,072 (Adjusted R Squared = ,045)
f. R Squared = ,380 (Adjusted R Squared = ,362)

Version 5

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	identify_potential_touch	8,044[b]	5	1.609	10.343	.000
	identify_touch_points	11,361[c]	5	2.272	7.011	.000
	identify_touch_config	24,622[d]	5	4.924	25.070	.000
	identify_direction	,689[e]	5	.138	1.625	.156
	identify_system_status	7,611[f]	5	1.522	5.561	.000
Intercept	identify_potential_touch	448.164	1	448.164	2881.052	.000
	identify_touch_points	464.485	1	464.485	1433.269	.000
	identify_touch_config	423.766	1	423.766	2157.403	.000
	identify_direction	565.335	1	565.335	6666.530	.000
	identify_system_status	434.005	1	434.005	1585.377	.000
design	identify_potential_touch	2.200	1	2.200	14.143	.000
	identify_touch_points	.768	1	.768	2.370	.125

	identify_touch_config	7.766	1	7.766	39.535	.000
	identify_direction	.018	1	.018	.214	.644
	identify_system_status	5.568	1	5.568	20.340	.000
interaction	identify_potential_touch	4.326	2	2.163	13.903	.000
	identify_touch_points	8.594	2	4.297	13.259	.000
	identify_touch_config	11.182	2	5.591	28.464	.000
	identify_direction	.453	2	.226	2.669	.072
	identify_system_status	1.970	2	.985	3.599	.029
design * interaction	identify_potential_touch	2.406	2	1.203	7.732	.001
	identify_touch_points	.738	2	.369	1.138	.323
	identify_touch_config	10.741	2	5.370	27.341	.000
	identify_direction	.118	2	.059	.696	.500
	identify_system_status	1.568	2	.784	2.863	.060
Error	identify_potential_touch	27.067	174	.156		
	identify_touch_points	56.389	174	.324		
	identify_touch_config	34.178	174	.196		
	identify_direction	14.756	174	.085		
	identify_system_status	47.633	174	.274		
Total	identify_potential_touch	604.000	180			
	identify_touch_points	619.000	180			
	identify_touch_config	642.000	180			
	identify_direction	696.000	180			
	identify_system_status	610.000	180			
Corrected Total	identify_potential_touch	35.111	179			
	identify_touch_points	67.750	179			
	identify_touch_config	58.800	179			
	identify_direction	15.444	179			
	identify_system_status	55.244	179			

a. version = V5
b. R Squared = ,229 (Adjusted R Squared = ,207)
c. R Squared = ,168 (Adjusted R Squared = ,144)
d. R Squared = ,419 (Adjusted R Squared = ,402)
e. R Squared = ,045 (Adjusted R Squared = ,017)
f. R Squared = ,138 (Adjusted R Squared = ,113)

Execution phase

Version 1

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	touch_to_confirm	39,941[b]	5	7.988	21.236	.000
	perform_swipe	24,567[c]	5	4.913	9.062	.000
	perform_direction	32,694[d]	5	6.539	19.250	.000
Intercept	touch_to_confirm	411.780	1	411.780	1094.676	.000
	perform_swipe	389.238	1	389.238	717.875	.000
	perform_direction	460.810	1	460.810	1356.571	.000
design	touch_to_confirm	.003	1	.003	.008	.927
	perform_swipe	.093	1	.093	.172	.679
	perform_direction	.087	1	.087	.256	.614
interaction	touch_to_confirm	38.657	2	19.328	51.383	.000
	perform_swipe	19.910	2	9.955	18.360	.000
	perform_direction	31.319	2	15.660	46.100	.000
design * interaction	touch_to_confirm	.190	2	.095	.252	.777
	perform_swipe	2.891	2	1.445	2.666	.072
	perform_direction	.191	2	.095	.281	.755
Error	touch_to_confirm	65.453	174	.376		
	perform_swipe	94.344	174	.542		
	perform_direction	59.106	174	.340		
Total	touch_to_confirm	563.000	180			
	perform_swipe	536.000	180			
	perform_direction	612.000	180			

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Total	touch_to_confirm	105.394	179			
	perform_swipe	118.911	179			
	perform_direction	91.800	179			

a. version = V1
b. R Squared = ,379 (Adjusted R Squared = ,361)
c. R Squared = ,207 (Adjusted R Squared = ,184)
d. R Squared = ,356 (Adjusted R Squared = ,338)

Version 2

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	touch_to_confirm	9,717[b]	5	1.943	5.693	.000
	perform_swipe	7,064[c]	5	1.413	3.921	.002
	perform_direction	1,620[d]	5	.324	2.613	.026
Intercept	touch_to_confirm	459.519	1	459.519	1346.197	.000
	perform_swipe	456.064	1	456.064	1265.907	.000
	perform_direction	554.002	1	554.002	4466.943	.000
design	touch_to_confirm	1.305	1	1.305	3.824	.052
	perform_swipe	.341	1	.341	.946	.332
	perform_direction	.491	1	.491	3.960	.048
interaction	touch_to_confirm	4.900	2	2.450	7.177	.001
	perform_swipe	5.573	2	2.786	7.734	.001
	perform_direction	.361	2	.180	1.454	.237
design * interaction	touch_to_confirm	.954	2	.477	1.397	.250
	perform_swipe	.425	2	.212	.590	.556
	perform_direction	.361	2	.180	1.454	.237
Error	touch_to_confirm	59.394	174	.341		
	perform_swipe	62.686	174	.360		
	perform_direction	21.580	174	.124		
Total	touch_to_confirm	638.000	180			
	perform_swipe	621.000	180			
	perform_direction	696.000	180			
Corrected Total	touch_to_confirm	69.111	179			
	perform_swipe	69.750	179			
	perform_direction	23.200	179			

a. version = V2
b. R Squared = ,141 (Adjusted R Squared = ,116)
c. R Squared = ,101 (Adjusted R Squared = ,075)
d. R Squared = ,070 (Adjusted R Squared = ,043)

Version 3

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	tap_to_preview	56,760[b]	5	11.352	16.489	.000
	touch_to_confirm	7,444[c]	5	1.489	6.935	.000
	perform_swipe	38,155[d]	5	7.631	23.979	.000
	perform_direction	,912[e]	5	.182	2.031	.077
Intercept	tap_to_preview	135.603	1	135.603	196.970	.000
	touch_to_confirm	497.649	1	497.649	2318.019	.000
	perform_swipe	451.641	1	451.641	1419.198	.000
	perform_direction	564.986	1	564.986	6286.652	.000
design	tap_to_preview	4.966	1	4.966	7.213	.008
	touch_to_confirm	1.464	1	1.464	6.818	.010
	perform_swipe	5.553	1	5.553	17.449	.000
	perform_direction	.012	1	.012	.135	.714
interaction	tap_to_preview	28.305	2	14.152	20.557	.000
	touch_to_confirm	6.156	2	3.078	14.338	.000
	perform_swipe	13.111	2	6.556	20.600	.000
	perform_direction	.854	2	.427	4.749	.010
design * interaction	tap_to_preview	21.321	2	10.661	15.485	.000
	touch_to_confirm	2.584	2	1.292	6.019	.003

	perform_swipe	8.944	2	4.472	14.053	.000
	perform_direction	.024	2	.012	.135	.873
Error	tap_to_preview	119.790	174	.688		
	touch_to_confirm	37.356	174	.215		
	perform_swipe	55.373	174	.318		
	perform_direction	15.638	174	.090		
Total	tap_to_preview	339.000	180			
	touch_to_confirm	672.000	180			
	perform_swipe	577.000	180			
	perform_direction	701.000	180			
Corrected Total	tap_to_preview	176.550	179			
	touch_to_confirm	44.800	179			
	perform_swipe	93.528	179			
	perform_direction	16.550	179			

a. version = V3
b. R Squared = ,321 (Adjusted R Squared = ,302)
c. R Squared = ,166 (Adjusted R Squared = ,142)
d. R Squared = ,408 (Adjusted R Squared = ,391)
e. R Squared = ,055 (Adjusted R Squared = ,028)

Version 4

Tests of Between-Subjects Effects[a]

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	tap_to_preview	45,879[b]	5	9.176	13.434	.000
	touch_to_confirm	9,374[c]	5	1.875	6.682	.000
	perform_swipe	34,038[d]	5	6.808	15.645	.000
	perform_direction	2,471[e]	5	.494	3.519	.005
Intercept	tap_to_preview	90.015	1	90.015	131.785	.000
	touch_to_confirm	536.813	1	536.813	1913.252	.000
	perform_swipe	412.910	1	412.910	948.940	.000
	perform_direction	608.712	1	608.712	4333.735	.000
design	tap_to_preview	.065	1	.065	.096	.758
	touch_to_confirm	.887	1	.887	3.160	.077
	perform_swipe	.522	1	.522	1.200	.275
	perform_direction	.221	1	.221	1.570	.212
interaction	tap_to_preview	30.884	2	15.442	22.607	.000
	touch_to_confirm	6.669	2	3.334	11.884	.000
	perform_swipe	30.383	2	15.192	34.913	.000
	perform_direction	1.406	2	.703	5.005	.008
design * interaction	tap_to_preview	11.247	2	5.624	8.233	.000
	touch_to_confirm	1.343	2	.672	2.393	.094
	perform_swipe	2.124	2	1.062	2.441	.090
	perform_direction	.780	2	.390	2.776	.065
Error	tap_to_preview	118.849	174	.683		
	touch_to_confirm	48.820	174	.281		
	perform_swipe	75.712	174	.435		
	perform_direction	24.440	174	.140		
Total	tap_to_preview	263.000	180			
	touch_to_confirm	645.000	180			
	perform_swipe	561.000	180			
	perform_direction	692.000	180			
Corrected Total	tap_to_preview	164.728	179			
	touch_to_confirm	58.194	179			
	perform_swipe	109.750	179			
	perform_direction	26.911	179			

a. version = V4
b. R Squared = ,279 (Adjusted R Squared = ,258)
c. R Squared = ,161 (Adjusted R Squared = ,137)
d. R Squared = ,310 (Adjusted R Squared = ,290)
e. R Squared = ,092 (Adjusted R Squared = ,066)

Version 5

Multivariate Tests[a,b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.987	3195,731[c]	4.000	171.000	.000
	Wilks' Lambda	.013	3195,731[c]	4.000	171.000	.000
	Hotelling's Trace	74.754	3195,731[c]	4.000	171.000	.000
	Roy's Largest Root	74.754	3195,731[c]	4.000	171.000	.000
design	Pillai's Trace	.061	2,786[c]	4.000	171.000	.028
	Wilks' Lambda	.939	2,786[c]	4.000	171.000	.028
	Hotelling's Trace	.065	2,786[c]	4.000	171.000	.028
	Roy's Largest Root	.065	2,786[c]	4.000	171.000	.028
interaction	Pillai's Trace	.397	10.645	8.000	344.000	.000
	Wilks' Lambda	.632	11,021[c]	8.000	342.000	.000
	Hotelling's Trace	.536	11.395	8.000	340.000	.000
	Roy's Largest Root	.430	18,475[d]	4.000	172.000	.000
design * interaction	Pillai's Trace	.118	2.686	8.000	344.000	.007
	Wilks' Lambda	.884	2,723[c]	8.000	342.000	.006
	Hotelling's Trace	.130	2.759	8.000	340.000	.006
	Roy's Largest Root	.116	4,990[d]	4.000	172.000	.001

a. version = V5

b. Design: Intercept + design + interaction + design * interaction

c. Exact statistic

d. The statistic is an upper bound on F that yields a lower bound on the significance level.

Table 62: Tests for between-subjects effects - Evaluation and Execution phases (Study 2).

APPENDIX T - QUALITATIVE DATA ANALYSIS (STUDY 2)

Code	Sum	Theme	Definition	Examples
Expectation: drag and drop picture	31	BIAS FROM DESKTOP	It was observed in #int3 'Touch and Hold to select picture' participants expressing will or dragging pictures from menu towards the booklet.	"Well, it doesn't come". 9P42, F, 56) "I saw the triangle..a bookmark maybe?" (P3, M, 49)
Incorrect gesture: double tap to select picture	15	BIAS FROM DESKTOP	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to select pictures by double tapping them.	"Will these buttons will just sit there until I tried something?" (P34, F, 35) (P23, F, 19), (P29, M, 48), (P17, F, 33), (P22, M, 24)
Incorrect gesture: tap target area and then picture	12	BIAS FROM DESKTOP	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to select the target picture drop area and then the picture itself.	"Still tempted to drag these pictures across, simply because there is a gap in there". (P46, M, 54) "Maybe I could touch it here first". (P24, F, 26)
Criticism: should be simlar to desktop OS	4	BIAS FROM DESKTOP	It was observed across the 3 interactions participants criticizing touch and multi-touch as non-equivalent to desktop OS traditional interface and interactions.	"See, this why I got rid of the smartphone". "I'm looking for an equivalent to a lelt click on a mouse or a right click but I cannot find anything". (P34, F, 35) "I wouldn't know how, would look for the settings somewhere". (P34, F, 35) "Generally I don't like the iPad interface". (P39, F, 56) "I have a MacOSX, laptop, and the finger pad I use two fingers". (P1, M, 34)
Incorrect gesture: double tap to activate button	3	BIAS FROM DESKTOP	It was observed in Int #1 'Open app with 2 fingers' participants trying to activate buttons by double tapping them.	"Will these buttons will just sit there until I tried something?" (P34, F, 35) "It's unclear to me". (P40, M, 42)
Accidental activation: 2 fingers to select picture	39	BIAS FROM PREVIOUS GESTURES	It was observed in Int #3 'Touch and Hold to select picture' participants successfully selecting pictures with two fingers by accident.	"Oh, what did I do?" (P27, F, 23) "I think is two fingers and slighly moving…" (P32, F, 27) "I'm still not quite sure how I did it…" (P33, F, 40)
Incorrect gesture: 2 fingers to select picture	17	BIAS FROM PREVIOUS GESTURES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to select pictures with two fingers.	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P8, M, 38), (P12, M, 20), (P30, F, 27), (P35, F, 29), (P44, M, 53)
Incorrect gesture: touch and hold to activate button	14	BIAS FROM PREVIOUS GESTURES	It was observed in Int #1 'Open app with 2 fingers' participants trying to activate buttons by touching and holding into them.	"Gave me the caption to hold it and slide it down". (P18, F, 21) "So the previous one was with holding". (P6, M, 25) "My impression is it says to press the circle and hold it down to move it". (P1, M, 34)
Incorrect gesture: 2 fingers to swipe horizontally	5	BIAS FROM PREVIOUS GESTURES	It was observed in Int #2 'Swipe from bezel to unveil menu' and Int #3 'Touch and Hold to select picture' participants incorrectly trying to perform the interaction with an	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P1, M, 34), (P8, M, 38), (P19, F, 34)

			unnecessary horizontal swipe with 2 fingers.	
Incorrect gesture: 2 fingers to drag picture	4	BIAS FROM PREVIOUS GESTURES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to drag pictures by dragging them with 2 fingers.	"Think I have to do this with my hand". (P41, F, 55) (P8, M, 38), (P19, F, 34), ((P12, M, 20)
Expectation: tap button to open	28	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #1 'Open app with 2 fingers' participants expressing will or activating buttons by tapping on them.	"Something showed and disappeared..two circles...maybe zoom perhaps? Ah, that was two dots, guess had to bring down". (P43, F, 35) (P1, M, 34), (P21, F, 31), (P39, F, 56)
Previous experience helped executing: smartphones & tablets	7	BIAS FROM TOUCH-BASED DEVICES	It was observed across the 3 interactions participants expressing or interacting demonstrating previous experience with other smartphone and tablets as an enabling factor.	"Sometimes with iPads you have gestures where you can bring things down...it's a normal thing to do on a tablet I think". (P44, M, 53) "Maybe written instructions would be easier to know what to do next. Some sort of instruction. When I first used my tablet instructions said pull this, hold on to this". (P23, F, 19) "From my previous knowledge...I've never used an iPad before but I've seen people doing it before". (P18, F, 21) "The menu is something similar to Android". (P6, M, 25)
Accidental activation: pinch to select picture	6	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #3 'Touch and Hold to select picture' participants successfully selecting pictures with a pinch gesture by accident.	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P15, F, 43), (P45, M, 24), (P39, F, 56)
Accidental activation: rotate to select picture	4	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #3 'Touch and Hold to select picture' participants successfully selecting pictures by incorrectly trying to rotate them.	"I'd like to rotate them". (P6, M, 25) (P32, F, 27)
Criticism: system does not respond to basic gestures	4	BIAS FROM TOUCH-BASED DEVICES	It was observed across the 3 interactions participants criticizing unnatural gestures.	"I find a bit irritating, don't see the purpose of using 2 fingers to drag it down". (P46, M, 54) "I don't know what that function means...instinctively I feel like just pushing that button but nothing happens". (P1, M, 34)
Incorrect gesture: pinch to select picture	4	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to drag pictures by pinching them with 2 fingers.	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P10, M, 33), (P15, F, 43), (P45, M, 34)
Accidental activation: correct but unplanned gesture	3	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #3 'Touch and Hold to select picture' participants successfully selecting and dragging pictures towards the booklet by accidentally holding over them for the adequate amount of time.	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P21, F, 31), (P23, F, 19)
Incorrect gesture: rotate to select picture	3	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly trying to select pictures by rotating them.	"I'd like to rotate them". (P6, M, 25) (P22, M, 24), (P27, F, 23)

Accidental activation: pinch to select button	2	BIAS FROM TOUCH-BASED DEVICES	It was observed in Int #1 'Open app with 2 fingers' participants successfully activating buttons by incorrectly pinching them.	<Facilitator: No utterances, assessment made based on observing participants interacting.> (P17, F, 36), (P39, F, 56)
Incorrect understanding of feedforward: picture bent top corner	21	DESIGN ISSUES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly describing or interacting with pictures through its bent top corner.	"Something to do with the corner...but I don't know what it means". (P4, F, 23) "I wanna cut it…it seems like sometihng that will lead me to cutting it" (P10, M, 33) "I saw the white corner thing...I felt the need to pull that out". (P13, F, 20) "There's something on top right corner but I'm not familiar with what would that be". (P46, M, 54)
Incorrect gesture: select picture by top corner	19	DESIGN ISSUES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly interacting with pictures through its bent top corner.	"I guess I could put the photo away by the corner". 9P24, F, 26) "I understand that first I have to do a small touch for the corner to fade…then I have to hold it and drag it". (P9, F, 39) "It's not working?" (P31, M, 33)
Incorrect understanding of affordance: loading	18	DESIGN ISSUES	It was observed in Int #3 'Touch and Hold to select picture' participants wrongly describing the 'Symbolic' affordance as a loading icon.	"Ah, it's kinda like it's gonna open big. It's asking me to wait, I thought was gonna load the image in the main view. This is the standard wait icon, you see on flash and JS pages...so what am I waiting for now?" (P3, M, 49) "The circle…it's like you're loading something or buffering?" (P35, F, 29) "Because it said hold…and before there was a counter, I thought it was loading". (P36, F, 24)
Incorrect understanding of aff-feedforward: page turn	12	DESIGN ISSUES	It was observed in Int #2 'Swipe from bezel to unveil menu' participants wrongly describing the feedforward as a page turn visual cue.	"It's an e-Book, it told me I should turn the pages". (P25, F, 27) "I did notice something happening othe book, like to move the pages". (P28, M, 34) "It showed me to go into that direction, in order to turn the page, maybe?" (P17, F, 33) "I think if I do like this I'll turn the page". (P24, F, 26)
Incorrect understanding of affordance: smiley face	4	DESIGN ISSUES	It was observed in Int #1 'Open app with 2 fingers' during design 2 'Symbolic' display, participants incorrectly describing the two figers requirement as a 'smiley face'.	"Something like a smiley face appeared on the book". (P1, M, 34) "There was a smiley face it just appeared. I guess touching it will make something happen". (P7, M, 28) "I don't understand what is this trying to say...the two circles...smiley face?" (P18, F, 21)
Partial assessment: correct gesture but incorrect outcome	4	DESIGN ISSUES	It was observed across the 3 interactions participants expressing correct understanding of required gesture but incorrect antecipation of action-consequences.	"I saw a finger pointing to a rotating circle and I think it will allow me to pause the image roll". (P29, M, 48) "I think if I hold on to the picture will make it larger". (P14, F, 19) "You hold on to the picture and drag it. I thought it would maximise the picture". (P41, F, 55)
Unable to perceive directionality: static affordance gesture	4	DESIGN ISSUES	It was observed in Int #1 'Open app with 2 fingers' participants expressing the need of animated events to better convey gesture directionality (version 1).	"Now I saw it. Now I saw it coming down. The previous should have moved as well, better when it moves down". (P43, F, 35) (P14, F, 19), (P24, F, 26)
Unable to	3	DESIGN	It was observed in Int #3	"Yeah, I don't know". (P24, F, 26)

perceive feedback: picture selected		ISSUES	'Touch and Hold to select picture' participants being unable to perceive the visual cue that indicated picture already selected (top bent corner).	(P8, M, 38), (P45, M, 24)
Correct understanding of affordance: textual aid	7	DESIGN FEATURE	It was observed across the 3 interactions participants describing the text label as a fundamental aid to relay function or purpose of visual cue.	"This time it said 'hold', that's easier". (P4, F, 23) "Ah, that's better. Much easier when you have a little command as well as the image". (P34, F, 35) "Need to use to fingers to open the little icon. It said in the little animation the little 'open'" (P36, F, 24) "But wasn't written 'hold' beforehand". (P40, M, 42)
Correct understanding of affordance: non-aligned dots simulate touch points	3	DESIGN FEATURE	It was observed in Int #1 'Open app with 2 fingers' during design 2 'Symbolic' display, participants correctly describing the two figers requirement specially because its uneven characteristic.	"I think is clear because it shows two circles...perhaps if they were side by side I'd be confused but it approximates the direction fingers touch". (P20, M, 28) "I think if I put two fingers, not in the same line, one lower than the other I can move down". (P32, F, 27) "It tells me uneven fingers in uneven points…" (P35, F, 29)
Correct understanding of feedforward: purpose of picture bent top corner	3	DESIGN FEATURE	It was observed in Int #3 'Touch and Hold to select picture' participants correctly describing the bent top corner over pictures.	"What have I done? I would say I selected it but I'm distracted with this thing on the corner". (P30, F, 27) (P36, F, 24), (P19, F, 34)
Correct understanding of affordance: general purpose	25	LEARNED NEW VOCABULARY	It was observed across the 3 interactions participants expressing understanding of self-revealing affordances purpose.	"The graphic told me how to do it". (P7, M, 28) "It's quite nice icon actually, very indicative just by looking at it". (P17, F, 33) "I remember how to bring the menu because I saw the little cue at the beginning". (P38, M, 43) "...but thanks to the interactive description otherwise I wouldn't really try to use 2 fingers". (P2, M, 30) "It's actually easy looking the way you're doing it better than reading the instruction. If you want to show someone things it's better to show someone a picture or video…I know I have to put two fingers and move it down". (P32, F, 27)
Criticism: unavailable 1 Tap-to-preview	14	LEARNED NEW VOCABULARY	It was observed across the 3 interactions participants complaining about unavailability of 1 Tap-to-preview or unsuccessfully trying to trigger it.	"I wanna see it again…" (P9, F, 39) "I'd press the icon like that expecting some text to appear". (P29, M, 48) "How about now that nothing shows up? (P42, F, 56) "I'd like to see that again, if possible". (P40, M, 42) "Nothing is visually changing when I click on it". (P36, F, 24)
Correct understanding of affordance: two fingers	12	LEARNED NEW VOCABULARY	It was observed in Int #1 'Open app with 2 fingers' participants correctly describing the two figers requirement to start the	"I think the symbol looked like two fingers rather than one...and run both over it". (P19, F, 34) "I don't know iPad or Android I'd expect to open it just click on it. Well, I was

			interaction.	more focused on the movement down that the two dots". (P31, M, 33) "To activate it I have to do what the hand is doing". (P29, M, 48) "So the symbol is telling me to drag with 2 fingers....pretty obscure I think". (P46, M, 54)
Correct understanding of affordance: touch and hold	9	LEARNED NEW VOCABULARY	It was observed in Int #3 'Touch and Hold to select picture' participants correctly describing the touch and hold over a picture requirement to start the interaction.	"It was fairly intuitive, took a couple of goes and then I notice there was a countdown, it needs to recognise my finger over the image…yeah it seems quite clever". (P28, M, 34) "Can't remember if it was 2 fingers or holding longer...I think was holding it". (P15, F, 43) "I'm supposed to hold it then drag". (P33, F, 40)
Criticism: unavailable visual cue for gesture	6	LEARNED NEW VOCABULARY	It was observed in Int #1 'Open app with 2 fingers' and Int #2 'Swipe from bezel to unveil menu' participants complaining about the lack of visual cues for gesture or touch points (versions 2 and 4).	"Doesn't seem to have much point in that. Doesn't tell you anything". (P34, F, 35) "Similar to the one before but with no dots…still unclear". (P40, M, 42) "I'd try to see if the sign comes back". (P46, M, 54) "Got the corner this time but not the circle…" (P36, F, 24) "This time I got the same symbol but without the fingers circles". (P46, M, 54)
Accidental activation: 1 Tap-to-preview	35	NOVELTY ISSUES	It was observed across the 3 interactions participants triggering by accident preview with one tap.	"It wasn't intuitive, it wasn't clear". (P39, F, 56) "Oh my God, what am I doing?" (P30, F, 27) "Eh, what was that?" (P31, M, 33)
Incorrect gesture: tapped affordance as button	23	NOVELTY ISSUES	It was observed across the 3 interactions participants tapping over self-revealing affordances & feedforward or activated by 1 Tap-to-preview.	"I think I'd press right there but nothing is happening". (P1, M, 34) "No idea, am I supposed to edit it?" (P34, F, 35)
Unable to assess: affordance displayed for short time	18	NOVELTY ISSUES	It was observed across the 3 interactions participants uable to make sense or complaining about affordances short display time.	"There was something displaying but I couldn't read it". 9P5, F, 22) "I saw something moving there, not sure what". (P16, F, 19) "Something popped up with the book...but to be honest I didn't concentrate on it, maybe is to click here first, to find out what it is". (P23, F, 19) "Better, but the command should stay for a few more seconds. Looks great but it then just vanishes". (P34, F, 35) "I think is telling me there's a menu over there but disappeared very quickly". (P39, F, 56)
Incorrect gesture: hardship to hit target area	17	NOVELTY ISSUES	It was observed in Int #2 'Swipe from bezel to unveil menu' participants correctly swiping from left to right to unveil the hidden menu but incorrectly hitting far away from the bezel.	"Ah, this will give me the menu". (P42, F, 56) (P1, M, 34), (P25, F, 27), (P36, F, 24), (P9, F, 39)
Incorrect understanding of 1 tap: mandatory to	8	NOVELTY ISSUES	It was observed across the 3 interactions participants describing or perfoming 1 Tap-to-preview to set the	"I understand that first I have to do a small touch for the corner to fade…then I have to hold it and drag it". (P9, F, 39) (P17, F, 33), (P42, F, 56), (P18, F, 21)

set mode			desired mode to interact.	
Unable to assess: affordances general purpose	6	NOVELTY ISSUES	It was observed across the 3 interactions participants unable to understand the purpose of self-revealing affordance.	"It's obviously providing some help but it's not clear what that help is". (P40, M, 42) "Even thought the icon appeared I wasn't sure if should push it or whatever". (P39, F, 56) "When I tap the pictures I notice the presence of this cue here but I don't know what it the function of this cue". (p45, M, 24) "I didn't know what that meant". (P18, F, 21)
Unable to assess: did not perceive 1 Tap-to-preview	5	NOVELTY ISSUES	It was observed across the 3 interactions participants not demonstrating any awareness of the 1 Tap-to-preview feature.	"Ah, how do I bring this back?" (P43, F, 35) "Did I already did that before? Brought back the cue?" (P47, F, 26) "I don't know how to make the instruction appear again". (P47, F, 26) "How do I present what I saw before?" (P39, F, 56)
Unexpected: surprise with automatic affordance	5	NOVELTY ISSUES	It was observed across the 3 interactions participants expressing surprise in the event of self-revealing affordances being displayed automatically without any interaction from their side.	"It did that because I tapped or would come anyway?" (P36, F, 24) "I didn't touch that". (P39, F, 56) "Will this always appear in the program?" (P43, F, 35) "But I haven't done anything! Feels like it was doing something I didn't ask for". (P43, F, 35)

Table 63: Emerging themes from qualitative data analysis (Study 2).

APPENDIX U - CODE COUNT (STUDY 2)

Code	Sum	Theme
Expectation: drag and drop picture	31	BIAS FROM DESKTOP
Incorrect gesture: double tap to select picture	15	BIAS FROM DESKTOP
Incorrect gesture: tap target area and then picture	12	BIAS FROM DESKTOP
Criticism: should be simlar to desktop OS	4	BIAS FROM DESKTOP
Incorrect gesture: double tap to activate button	3	BIAS FROM DESKTOP
Total	**65**	
Accidental activation: 2 fingers to select picture	39	BIAS FROM PREVIOUS GESTURES
Incorrect gesture: 2 fingers to select picture	17	BIAS FROM PREVIOUS GESTURES
Incorrect gesture: touch and hold to activate button	14	BIAS FROM PREVIOUS GESTURES
Incorrect gesture: 2 fingers to swipe horizontally	5	BIAS FROM PREVIOUS GESTURES
Incorrect gesture: 2 fingers to drag picture	4	BIAS FROM PREVIOUS GESTURES
Incorrect gesture: pinch to select picture	4	BIAS FROM PREVIOUS GESTURES
Total	**83**	
Expectation: tap button to open	28	BIAS FROM TOUCH-BASED DEVICES
Previous experience helped executing: smartphones & tablets	7	BIAS FROM TOUCH-BASED DEVICES
Accidental activation: pinch to select picture	6	BIAS FROM TOUCH-BASED DEVICES
Accidental activation: rotate to select picture	4	BIAS FROM TOUCH-BASED DEVICES
Criticism: system does not respond to basic gestures	4	BIAS FROM TOUCH-BASED DEVICES
Incorrect gesture: pinch to select picture	4	BIAS FROM TOUCH-BASED DEVICES
Accidental activation: correct but unplanned gesture	3	BIAS FROM TOUCH-BASED DEVICES
Incorrect gesture: rotate to select picture	3	BIAS FROM TOUCH-BASED DEVICES
Accidental activation: pinch to select button	2	BIAS FROM TOUCH-BASED DEVICES
Total	**61**	
Incorrect understanding of feedforward: picture bent top corner	21	DESIGN ISSUES
Incorrect gesture: select picture by top corner	19	DESIGN ISSUES
Incorrect understanding of affordance: loading	18	DESIGN ISSUES
Incorrect understanding of aff-feedforward: page turn	12	DESIGN ISSUES
Incorrect understanding of affordance: smiley face	4	DESIGN ISSUES
Partial assessment: correct gesture but incorrect outcome	4	DESIGN ISSUES
Unable to perceive directionality: static affordance gesture	4	DESIGN ISSUES
Unable to perceive feedback: picture selected	3	DESIGN ISSUES
Total	**85**	
Correct understanding of affordance: textual aid	7	DESIGN FEATURE
Correct understanding of affordance: non-aligned dots simulate touch points	3	DESIGN FEATURE
Correct understanding of feedforward: purpose of picture bent top corner	3	DESIGN FEATURE
Total	**13**	
Correct understanding of affordance: general purpose	25	LEARNED NEW VOCABULARY
Criticism: unavailable 1 Tap-to-preview	14	LEARNED NEW VOCABULARY
Correct understanding of affordance: two fingers	12	LEARNED NEW VOCABULARY
Correct understanding of affordance: touch and hold	9	LEARNED NEW VOCABULARY
Criticism: unavailable visual cue for gesture	6	LEARNED NEW VOCABULARY
Total	**66**	
Accidental activation: 1 Tap-to-preview	35	NOVELTY ISSUES
Incorrect gesture: tapped affordance as button	23	NOVELTY ISSUES
Unable to assess: affordance displayed for short time	18	NOVELTY ISSUES
Incorrect gesture: hardship to hit target area	17	NOVELTY ISSUES
Incorrect understanding of 1 tap: mandatory to set mode	8	NOVELTY ISSUES
Unable to assess: affordances general purpose	6	NOVELTY ISSUES
Unexpected: surprise with automatic affordance	5	NOVELTY ISSUES
Unable to assess: did not perceive 1 Tap-to-preview	5	NOVELTY ISSUES
Total	**117**	

Table 64: Code count for Study 2.

APPENDIX V - TRANSCRIPTIONS (STUDY 2)

N	G	A	Int	Des	Vers	Suc	Comments	Code	Theme
1	M	34	2	1	1	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
1	M	34	1	2	4	yes	"I have a MacOSX, laptop, and the finger pad I use two fingers."	Criticism: should be similar to desktop OS	CRITICISM
1	M	34	1	2	5	no	"I don't know what that function means...instinticvely I feel like just pushing that button but nothing happens."	Criticism: system does not respond to basic gestures	CRITICISM
1	M	34	2	1	5	no		Criticism: unavailable 1 Tap-to-preview	CRITICISM
1	M	34	3	2	3	yes		Expectation: drag and drop picture	EXPECTED
1	M	34	1	2	1	no		Expectation: tap button to open	EXPECTED
1	M	34	3	1	4	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
1	M	34	2	1	4	no		Incorrect gesture: 2 fingers to swipe horizontally	INCORRECT GESTURE
1	M	34	2	1	2	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	2	2	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	1	5	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	1	2	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	2	2	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	2	3	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	1	4	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	2	1	5	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
1	M	34	3	1	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
1	M	34	2	1	5	no	"I think I'd press right there but nothing is happening."	Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
1	M	34	2	1	1	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
1	M	34	2	1	1	yes	"My impression is it says to press the circle and hold it down to	Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE

							move it."		
1	M	34	2	2	2	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
1	M	34	2	2	3	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
1	M	34	2	1	4	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
1	M	34	2	1	2	no		Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
1	M	34	1	2	1	no	"Something like a smiley face appeared on the book."	Incorrect understanding of affordance: smiley face	INCORRECT UNDERSTAND ING
1	M	34	2	1	1	yes		Unable to perceive directionality: static affordance gesture	UNABLE TO ACCESS
2	M	30	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
2	M	30	1	1	1	no	"I see the interactive description of how to use..."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
2	M	30	1	1	3	yes	"...but thanks to the interactive descrition otherwise I wouldn't really try to use 2 fingers."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
2	M	30	1	1	3	yes	"...but thanks to the interactive descrition otherwise I wouldn't really try to use 2 fingers."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
3	M	49	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
3	M	49	3	2	4	no	"I saw the triangle..a bookmark maybe?"	Expectation: drag and drop picture	EXPECTED
3	M	49	3	2	3	no	"Ah, it's kinda like it's gonna open big. It's asking mne to wait, I thought was gonna load the image in the main view. This is the starndard wait icon, you see on flash and JS pages...so what am I waiting for now?"	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
3	M	49	3	2	4	no		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
4	F	23	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
4	F	23	3	2	3	yes	"I guess is telling me to wait...I don't know what that big dot means."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
4	F	23	3	1	3	yes	"This time it said	Correct	CORRECT

							'hold', that's easier."	understanding of affordance: textual aid	UNDERSTANDING
4	F	23	1	2	1	no		Expectation: tap button to open	EXPECTED
4	F	23	3	1	4	no	"Something to do with the corner...but I don't know what it means."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTANDING
4	F	23	1	2	1	no	"I can't really remember what happened..."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
5	F	22	3	2	1	yes	"Ah, put the finger for sometime and then recognizes it..."	Correct understanding of affordance: general purpose	CORRECT UNDERSTANDING
5	F	22	3	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
5	F	22	3	1	2	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
5	F	22	1	2	5	yes		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
5	F	22	1	1	3	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
5	F	22	3	2	3	no	"Double click? Drag and drop? It's like loading the images...maybe copying like this?"	Incorrect understanding of affordance: loading	INCORRECT UNDERSTANDING
5	F	22	3	1	2	no	"There was something displaying but I couldn't read it."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
6	M	25	3	2	4	yes	"I'd like to rotate them..." <tried inside the menu>	Acidental activation: rotate to select picture	ACCIDENTAL ACTIVATION
6	M	25	1	2	5	yes	"Ah, these 2 dots..."	Correct understanding of affordance: two fingers	CORRECT UNDERSTANDING
6	M	25	1	2	1	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
6	M	25	1	1	4	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
6	M	25	1	1	1	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
6	M	25	1	2	1	no	"So the previous one was with holding..."	Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
6	M	25	2	1	5	yes	"The menu is something similar to Android.	Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE
7	M	28	3	2	3	yes	"Oh, what's that?"	Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
7	M	28	1	2	5	yes	"The graphic told me how to do it."	Correct understanding of affordance: general	CORRECT UNDERSTANDING

								purpose	
7	M	28	2	1	2	yes	"Now I know what I need to do!"	Correct understanding of affordance: two fingers	CORRECT UNDERSTANDING
7	M	28	1	2	1	no		Expectation: tap button to open	EXPECTED
7	M	28	3	2	3	yes		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
7	M	28	1	2	1	no	"There was a smiley face it just appeared. I guess touching it will make sometihng happen."	Incorrect understanding of affordance: smiley face	INCORRECT UNDERSTANDING
8	M	38	2	1	4	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
8	M	38	3	2	1	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
8	M	38	3	1	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
8	M	38	3	2	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
8	M	38	1	1	1	no	"Basically some teaching, educating the user how to use properly. For me was a bit fast though..."	Correct understanding of affordance: general purpose	CORRECT UNDERSTANDING
8	M	38	3	2	3	no	"It's like a combination: first the circle and then the moving small image...it's timing. Probably some kind of suggestion."	Correct understanding of affordance: touch and hold	CORRECT UNDERSTANDING
8	M	38	3	1	2	no		Expectation: drag and drop picture	EXPECTED
8	M	38	3	2	2	no		Incorrect gesture: 2 fingers to drag picture	INCORRECT GESTURE
8	M	38	3	2	2	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
8	M	38	2	1	4	no		Incorrect gesture: 2 fingers to swipe horizontally	INCORRECT GESTURE
8	M	38	2	1	2	no		Incorrect gesture: 2 fingers to swipe horizontally	INCORRECT GESTURE
8	M	38	1	1	3	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
8	M	38	1	1	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
8	M	38	1	2	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
8	M	38	3	2	2	no		Incorrect understanding of feedforward: picture	INCORRECT UNDERSTANDING

								bent top corner	
8	M	38	3	1	2	no	"I saw some changes on the picture but I wasn't sure if I should touch it, move it or scroll it."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
8	M	38	1	1	1	no		Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
8	M	38	1	2	4	no		Unable to perceive feedback: picture selected	UNABLE TO ACCESS
9	F	39	1	1	2	no	"No, it doesn't work.."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
9	F	39	3	2	1	no	"I wanna see it again…"	Criticism: unavailable 1 Tap-to-preview	CRITICISM
9	F	39	3	2	4	no		Expectation: drag and drop picture	EXPECTED
9	F	39	3	2	4	no		Expectation: tap button to open	EXPECTED
9	F	39	2	1	5	yes		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
9	F	39	3	2	5	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
9	F	39	3	1	4	no	"I have to do something with it?" <referring to top corner>	Incorrect gesture: select picture by top corner	INCORRECT GESTURE
9	F	39	3	1	5	yes	"I understand that first I have to do a small touch for the corner to fade…then I have to hold it and drag it."	Incorrect gesture: select picture by top corner	INCORRECT GESTURE
9	F	39	2	1	5	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
9	F	39	3	1	5	yes	"I understand that first I have to do a small touch for the corner to fade…then I have to hold it and drag it."	Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
9	F	39	3	2	3	no	"It's loading or something?"	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
9	F	39	3	2	4	no	"The corner of the picture faded…"	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
10	M	33	3	1	4	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
10	M	33	3	1	3	yes	"I think that was pretty clear."	Correct understanding of affordance: textual aid	CORRECT UNDERSTAND ING
10	M	33	3	2	3	no		Expectation: drag and drop picture	EXPECTED
10	M	33	1	2	1	no		Expectation: tap button to open	EXPECTED
10	M	33	3	2	3	no		Incorrect gesture: pinch to select	INCORRECT GESTURE

								picture	
10	M	33	1	2	4	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
10	M	33	3	1	4	no	"I wanna cut it…it seems like sometihng that will lead me to cutting it" <referring to the bent corner>	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
11	F	27	1	1	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
11	F	27	3	1	2	yes	"yes, told me to hold the top image…I think the picture will enlarge."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
11	F	27	1	1	1	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
11	F	27	2	2	5	yes	"I think I'll turn the page."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
12	M	20	3	2	4	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
12	M	20	2	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
12	M	20	3	1	4	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
12	M	20	1	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
12	M	20	3	2	5	no	"Do I need to touch the corner?"	Incorrect gesture: select picture by top corner	INCORRECT GESTURE
12	M	20	1	1	2	no	"I've seen the triangle in the corner, I think I did something? Is it a bookmark?"	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
13	F	20	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
13	F	20	1	2	5	yes	"Because of the two dots, I knew i had to pull down."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
13	F	20	1	2	1	no		Expectation: tap button to open	EXPECTED
13	F	20	3	2	3	no	"I tapped it, and it was loading something...so I don't know what is happening."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
13	F	20	3	1	4	no	"I saw the white corner thing...I felt the need to pull that out."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
14	F	19	1	1	1	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
14	F	19	2	2	5	yes	"To drag a finger across the screen...maybe to tun	Incorrect understanding of aff-feedforward: page	INCORRECT UNDERSTAND ING

							the page."	turn	
14	F	19	3	1	2	yes	"I think if I hold on to the picture will make it larger..."	Partial assessment: correct gesture but incorrect outcome	INCORRECT UNDERSTAND ING
14	F	19	1	1	1	no		Unable to perceive directionality: static affordance gesture	UNABLE TO ACCESS
15	F	43	3	2	4	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
15	F	43	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
15	F	43	2	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
15	F	43	3	1	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
15	F	43	3	1	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
15	F	43	3	1	2	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
15	F	43	3	2	3	no		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
15	F	43	3	2	5	yes	"Can't remember if it was 2 fingers or holding longer...I think was holding it."	Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
15	F	43	3	2	4	no		Expectation: drag and drop picture	EXPECTED
15	F	43	1	2	3	yes		Incorrect gesture: 2 fingers to swipe horizontally	INCORRECT GESTURE
15	F	43	1	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
15	F	43	3	2	3	no		Incorrect gesture: pinch to select picture	INCORRECT GESTURE
15	F	43	3	2	3	no	"In the corner, there was something...I was touching everywhere and the corner went white."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
15	F	43	3	2	3	no		Unexpected: expected something different from the menu	UNEXPECTED
16	F	19	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
16	F	19	2	1	5	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
16	F	19	1	2	5	no		Expectation: drag and drop picture	EXPECTED
16	F	19	1	2	1	no		Expectation: tap button to open	EXPECTED
16	F	19	3	1	4	yes		Incorrect gesture: double tap to select picture	INCORRECT GESTURE

16	F	19	1	2	5	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
16	F	19	2	1	2	yes	"You can scroll back that way to turn the page..."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
16	F	19	1	2	4	no	"Hum, it's processing, for the picture to come on."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
16	F	19	1	2	1	no	"I saw something moving there, not sure what."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
17	F	33	1	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
17	F	33	1	1	1	yes		Accidental activation: pinch to select button	ACCIDENTAL ACTIVATION
17	F	33	1	1	1	yes	"It's quite nice icon actually, very indicative just by looking at it."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
17	F	33	3	1	2	no		Expectation: drag and drop picture	EXPECTED
17	F	33	1	1	1	yes		Expectation: tap button to open	EXPECTED
17	F	33	3	2	3	yes		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
17	F	33	3	1	3	yes		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
17	F	33	3	1	1	yes		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
17	F	33	3	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
17	F	33	3	1	3	yes		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
17	F	33	3	1	1	yes		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
17	F	33	3	1	1	yes		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
17	F	33	3	1	1	yes		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
17	F	33	3	1	2	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
17	F	33	1	1	5	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
17	F	33	3	1	3	yes		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
17	F	33	3	1	1	yes		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING

17	F	33	2	2	5	yes	"It showed me to go into that direction, in order to turn the page, maybe?"	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
17	F	33	3	1	1	yes		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
18	F	21	3	2	4	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
18	F	21	3	1	5	yes	"Oh yeah, ok - I have to wait, that's what I forgot to do."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
18	F	21	3	2	4	no		Expectation: drag and drop picture	EXPECTED
18	F	21	3	2	1	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
18	F	21	3	2	3	yes		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
18	F	21	3	1	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
18	F	21	1	2	1	yes	"Like the previous one, place my finger over the button and slide it?"	Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
18	F	21	1	1	2	no	"Gave me the caption to hold it and slide it down."	Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
18	F	21	3	2	5	no		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
18	F	21	3	2	1	no		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
18	F	21	3	2	3	yes		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
18	F	21	3	2	3	yes		Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
18	F	21	1	2	5	yes	"I don't understand what is this trying to say...the two cirlces...smiley face?"	Incorrect understanding of affordance: smiley face	INCORRECT UNDERSTAND ING
18	F	21	2	1	5	yes	"Will give me chapter options, start or end of the book...or going back to the main menu again."	Incorrect understanding of feedforward: book chapters	INCORRECT UNDERSTAND ING
18	F	21	3	2	4	no	"I saw something there..."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
18	F	21	3	2	3	yes	"From my previous knowledge...I've never used an iPad before but I've seen people	Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE

							doing it before..."		
18	F	21	2	1	3	yes	"I didn't know what that meant..."	Unable to assess: affordances general purpose	UNABLE TO ACCESS
19	F	34	2	2	5	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
19	F	34	3	2	2	no		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	1	1	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	3	1	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	3	1	1	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	3	2	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
19	F	34	1	1	3	yes	"I think the symbol looked like two fingers rather than one...and run both over it."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
19	F	34	1	1	3	yes		Correct understanding of feedforward: purpose of picture bent top corner	CORRECT UNDERSTAND ING
19	F	34	3	1	2	no		Expectation: drag and drop picture	EXPECTED
19	F	34	3	1	2	no		Expectation: tap button to open	EXPECTED
19	F	34	3	1	2	no		Incorrect gesture: 2 fingers to drag picture	INCORRECT GESTURE
19	F	34	2	1	2	yes		Incorrect gesture: 2 fingers to swipe horizontally	INCORRECT GESTURE
19	F	34	2	1	5	yes		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
19	F	34	3	2	1	yes		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
19	F	34	2	2	4	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
19	F	34	1	1	3	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
19	F	34	1	1	1	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
19	F	34	3	1	2	no	"Can't remember how to do it..."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
20	M	28	1	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION

20	M	28	1	2	4	yes	"I think is clear because it shows two circles...perhaps if they were side by side I'd be confused but it approximates the direction fingers touch..."	Correct understanding of affordance: non-aligned dots simulate touch points	CORRECT UNDERSTAND ING
20	M	28	1	1	1	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
21	F	31	3	2	4	yes		Accidental activation: correct but unplanned gesture	ACCIDENTAL ACTIVATION
21	F	31	3	2	3	yes		Accidental activation: correct but unplanned gesture	ACCIDENTAL ACTIVATION
21	F	31	3	2	5	yes	"I thought I have to touch for longer..."	Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
21	F	31	1	1	1	yes	"Ah I knew it, two fingers!"	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
21	F	31	3	2	4	yes		Expectation: drag and drop picture	EXPECTED
21	F	31	1	1	2	no		Expectation: tap button to open	EXPECTED
21	F	31	1	1	2	no	"I saw something but..."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
22	M	24	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
22	M	24	1	2	1	no	"Ah the arrow and circles? An instruction telling me to do something? But if there was an instruction I don't think I'd get it."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
22	M	24	2	1	2	yes	"Ok, that one was pretty clear."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
22	M	24	1	2	5	yes	"Ah there was two little circles and perhaps that meant two fingers."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
22	M	24	3	2	3	no		Expectation: drag and drop picture	EXPECTED
22	M	24	1	2	1	no		Expectation: tap button to open	EXPECTED
22	M	24	3	1	4	yes		incorrect gesture: double tap to select picture	INCORRECT GESTURE
22	M	24	3	1	4	yes		incorrect gesture: rotate to select picture	INCORRECT GESTURE
22	M	24	3	1	4	yes		Incorrect gesture: select picture by top corner	INCORRECT GESTURE

22	M	24	3	2	3	no	"Some kind of loading, I don't know."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
22	M	24	3	1	4	yes	"There was little white corner over there."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
23	F	19	3	2	3	yes	"Maybe a double click?"	Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
23	F	19	2	1	5	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
23	F	19	3	2	3	yes		Accidental activation: correct but unplanned gesture	ACCIDENTAL ACTIVATION
23	F	19	1	1	5	yes	"I should use two fingers to open it..."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
23	F	19	1	2	1	no		Expectation: tap button to open	EXPECTED
23	F	19	3	1	4	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
23	F	19	3	2	3	yes		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
23	F	19	1	2	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
23	F	19	1	2	4	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
23	F	19	2	1	2	yes	"I thought was to flip pages..."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
23	F	19	1	2	5	no	"It looked like a smiley face..."	Incorrect understanding of affordance: smiley face	INCORRECT UNDERSTAND ING
23	F	19	3	2	3	yes	"Maybe written instructions would be easier to know what to do next. Some sort of instruction. When I first used my tablet instructions said pull this, hold on to this..."	Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE
23	F	19	1	2	1	no	"Something popped up with the book...but to be honest I didn't concentrate on it, maybe is to click here first, to find out what it is."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
24	F	26	1	1	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
24	F	26	3	1	3	no		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
24	F	26	3	1	1	yes		Accidental	ACCIDENTAL

								activation: 2 fingers to select picture	ACTIVATION
24	F	26	3	2	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
24	F	26	3	1	1	yes		Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
24	F	26	1	1	1	no	"I think I should touch the button I want to open, maybe with two fingers? I'd find it weird if not opening like that."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
24	F	26	3	1	2	no		Expectation: drag and drop picture	EXPECTED
24	F	26	1	1	3	no		Expectation: tap button to open	EXPECTED
24	F	26	3	1	3	no		Incorrect gesture: 2 fingers to drag picture	INCORRECT GESTURE
24	F	26	3	2	2	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
24	F	26	3	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
24	F	26	3	1	2	no	"I guess I could put the photo away by the corner."	Incorrect gesture: select picture by top corner	INCORRECT GESTURE
24	F	26	3	2	3	no	"Maybe I could touch it here first."	Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
24	F	26	2	2	5	yes	"I think if I do like this i'll turn the page."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
24	F	26	1	1	1	no		Unable to perceive directionality: static affordance gesture	UNABLE TO ACCESS
24	F	26	3	1	3	no	"Yeah, I don't know."	Unable to perceive feedback: picture selected	UNABLE TO ACCESS
25	F	27	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
25	F	27	3	2	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
25	F	27	1	1	2	no	"It told me I should open the book."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
25	F	27	1	2	1	no		Criticism: unavailable 1 Tap-to-preview	CRITICISM
25	F	27	3	2	1	no		Criticism: unavailable 1 Tap-to-preview	CRITICISM
25	F	27	3	2	4	no		Expectation: drag and drop picture	EXPECTED
25	F	27	1	1	2	no		Expectation: tap button to open	EXPECTED
25	F	27	2	1	5	no		Incorrect gesture:	INCORRECT

								hardship to hit target area	GESTURE
25	F	27	3	1	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
25	F	27	3	2	5	yes		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
25	F	27	3	2	3	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
25	F	27	3	1	4	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
25	F	27	1	1	4	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
25	F	27	1	2	3	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
25	F	27	3	1	5	yes		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
25	F	27	2	1	5	no	"It's an e-Book, it told me I should turn the pages."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
25	F	27	3	2	5	yes	"What is this? <regarding the top bent corner> it's like an old book with those holders..."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
25	F	27	3	2	4	no		Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
27	F	23	3	2	1	yes	"Oh, what did I do?"	Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
27	F	23	1	1	2	no	"It told me to pull down to open a book app."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
27	F	23	3	1	2	yes	"Oh, I gotta hold it for longer!"	Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
27	F	23	3	2	4	no		Expectation: drag and drop picture	EXPECTED
27	F	23	1	1	2	no		Expectation: tap button to open	EXPECTED
27	F	23	3	2	3	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
27	F	23	1	1	2	no		Incorrect gesture: rotate to select picture	INCORRECT GESTURE
27	F	23	3	2	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
27	F	23	3	2	5	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
27	F	23	3	2	4	no		Incorrect understanding of	INCORRECT UNDERSTAND

								feedforward: picture bent top corner	ING
27	F	23	1	1	2	no		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
28	M	34	3	2	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
28	M	34	3	2	3	yes	"It was fairly intuitive, took a couple of goes and then I notice there was a countdown, it needs to recognise my finger over the image…yeah it seems quite clever."	Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
28	M	34	1	1	5	yes	"Ah, two fingers, I wasn't looking into the details of the atual visual cue."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
28	M	34	1	2	1	no		Expectation: tap button to open	EXPECTED
28	M	34	1	2	5	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
28	M	34	1	2	4	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
28	M	34	2	1	2	yes	"I thought that was quite a subtle indication to swipe across to turn the page."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
28	M	34	1	2	1	no	"I did notice something happening othe book, like to move the pages."	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
29	M	48	2	2	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
29	M	48	3	2	2	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
29	M	48	3	1	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
29	M	48	3	1	1	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
29	M	48	3	2	4	yes		Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
29	M	48	1	1	3	yes	"To activate it I have to do what the hand is doing."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
29	M	48	1	1	1	no	"I'd press the icon like that expecting some text to appear."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
29	M	48	3	1	2	no		Expectation: drag and drop picture	EXPECTED
29	M	48	1	1	1	no		Expectation: tap button to open	EXPECTED

29	M	48	3	1	2	no		Incorrect gesture: double tap to select picture	INCORRECT GESTURE
29	M	48	2	2	5	yes		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
29	M	48	2	2	5	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
29	M	48	3	2	3	yes	"I would guess it's loading or something."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
29	M	48	3	1	2	no	"I saw a finger pointing to a rotating circle and I think it will allow me to pause the image roll."	Partial assessment: correct gesture but incorrect outcome	INCORRECT UNDERSTAND ING
29	M	48	2	2	5	yes	"Well that might allow me to shift the block of text around."	Partial assessment: correct gesture but incorrect outcome	INCORRECT UNDERSTAND ING
30	F	27	2	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
30	F	27	3	2	4	no	"Oh my God, what am I doing?"	Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
30	F	27	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
30	F	27	3	2	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
30	F	27	3	2	3	yes	"What have I done? I would say I selected it but I'm distracted with this thing on the corner."	Correct understanding of feedforward: purpose of picture bent top corner	CORRECT UNDERSTAND ING
30	F	27	3	2	1	no	"Beforehand that circle appeared to say you can move this one but it's not happening now…so it must be a select function of some sort."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
30	F	27	3	2	4	no		Expectation: drag and drop picture	EXPECTED
30	F	27	3	2	1	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
30	F	27	3	2	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
30	F	27	3	2	5	yes	It's loaded I guess.	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
31	M	33	3	1	4	yes	"Eh, what was that?"	Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
31	M	33	1	2	5	yes	"I don't know iPad or Android I'd expect to open it just click on it. Well, I was more focused on the movement down that the two dots."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING

31	M	33	3	2	3	no		Expectation: drag and drop picture	EXPECTED
31	M	33	1	2	1	no		Expectation: tap button to open	EXPECTED
31	M	33	3	2	3	no	"It's not working?"	Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
31	M	33	3	1	4	yes		Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
31	M	33	3	1	3	yes	"Oh both of them?"	Unexpected: possibility to select 1 or more pictures	UNEXPECTED
32	F	27	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
32	F	27	3	2	2	yes	"I think is two fingers and slighly moving…"	Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
32	F	27	3	1	2	yes		Accidental activation: rotate to select picture	ACCIDENTAL ACTIVATION
32	F	27	3	1	3	yes		Accidental activation: rotate to select picture	ACCIDENTAL ACTIVATION
32	F	27	3	1	1	yes		Accidental activation: rotate to select picture	ACCIDENTAL ACTIVATION
32	F	27	3	2	4	yes	"Ah, but it's just one finger."	Accidental activation: rotate to select picture	ACCIDENTAL ACTIVATION
32	F	27	1	2	3	yes	"It's actually easy looking the way you're doing it better than reading the instruction. If you want to show someone things it's better to show someone a picture or video…I know I have to put two fingers and move it down."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
32	F	27	1	1	2	yes	"I think if I put two fingers, not in the same line, one lower than the other I can move down."	Correct understanding of affordance: non-aligned dots simulate touch points	CORRECT UNDERSTAND ING
32	F	27	3	2	4	yes		Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
32	F	27	3	1	2	yes		Expectation: drag and drop picture	EXPECTED
32	F	27	3	2	2	yes		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
32	F	27	3	2	2	yes		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
32	F	27	3	1	2	yes	"I've seen a hand tapping in the image and something like loading and I think some changed on the	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING

							right corner."		
32	F	27	3	1	1	yes		Unexpected: possibility to select 1 or more pictures	UNEXPECTED
33	F	40	3	2	3	no		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
33	F	40	3	2	5	yes	"I don't know how I did it though…"	Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
33	F	40	3	2	1	yes	"I'm still not quite sure how I did it…"	Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
33	F	40	3	1	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
33	F	40	3	1	5	yes	"I'm supposed to hold it then drag."	Correct understanding of affordance: touch and hold	CORRECT UNDERSTAND ING
33	F	40	3	2	4	no		Expectation: drag and drop picture	EXPECTED
33	F	40	3	2	4	no		Incorrect gesture: 2 fingers to drag picture	INCORRECT GESTURE
33	F	40	3	2	4	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
33	F	40	2	1	5	yes	"I expected something to come out but I didn't know it would be the pictures."	Unexpected: expected something different from the menu	UNEXPECTED
34	F	35	2	1	1	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
34	F	35	3	1	3	yes	"Ah, that's better. Much easier when you have a little command as well as the image."	Correct understanding of affordance: textual aid	CORRECT UNDERSTAND ING
34	F	35	1	2	3	no	"I wouldn't know how, would look for the settings somewhere."	Criticism: should be similar to desktop OS	CRITICISM
34	F	35	1	2	3	no	"See, this why I got rid of the smartphone." "I'm looking for an equivalent to a lelt click on a mouse or a right click but I cannot find anything."	Criticism: should be similar to desktop OS	CRITICISM
34	F	35	3	2	3	no	"See, this why I got rid of the smartphone." "I'm looking for an equivalent to a lelt click on a mouse or a right click but I cannot find anything."	Criticism: system does not respond to basic gestures	CRITICISM
34	F	35	1	1	4	no	"Doesn't seem to have much point in that. Doesn't tell you anything."	Criticism: unavailable visual cue for gesture	CRITICISM
34	F	35	3	2	3	no		Expectation: drag and drop picture	EXPECTED
34	F	35	1	2	1	no	"Will these buttons will just sit there until I tried something?"	Incorrect gesture: double tap to activate button	INCORRECT GESTURE

34	F	35	1	2	5	no	"No idea, am I supposed to edit it?"	Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
34	F	35	1	1	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
34	F	35	2	1	1	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
34	F	35	1	1	5	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
34	F	35	3	1	4	no	"Something happened on the top corner."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
34	F	35	1	1	5	no	"Better, but the command should stay for a few more seconds. Looks great but it then just vanishes."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
34	F	35	2	1	2	yes	"Saw the side menu come and slde away…was too short, needs to be there longer."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
34	F	35	2	1	5	yes	"Really easy to use, I could just see it standing there for a couple more seconds so that you see what's there before it vanishes again."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
34	F	35	2	2	2	yes	"That is a developers command and both a customers command."	Unable to assess: affordances general purpose	UNABLE TO ACCESS
35	F	29	2	2	5	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
35	F	29	3	2	2	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
35	F	29	3	1	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
35	F	29	1	2	3	yes	"It tells me uneven fingers in uneven points…"	Correct understanding of affordance: non-aligned dots simulate touch points	CORRECT UNDERSTAND ING
35	F	29	1	1	3	yes	"The picture showed me how to do this."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
35	F	29	3	1	2	no		Expectation: drag and drop picture	EXPECTED
35	F	29	1	1	1	no		Expectation: tap button to open	EXPECTED
35	F	29	3	2	3	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
35	F	29	3	2	1	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE

35	F	29	3	1	2	no	"The circle…it's like you're sownloading something or buffering?"	Incorrect understanding of affordance: loading	INCORRECT UNDERSTANDING
35	F	29	3	2	1	no	"Some kind of corner here…"	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTANDING
35	F	29	1	1	5	yes		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTANDING
35	F	29	1	1	1	no	"Something went on the book, but I didn't see."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
36	F	24	2	1	5	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
36	F	24	2	1	5	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
36	F	24	2	1	3	yes	"Maybe with the symbol that came out before…maybe I released to quickly or maybe I didn'y drag it or I guess I wasn't moving from where was expected on that side…"	Correct understanding of affordance: general purpose	CORRECT UNDERSTANDING
36	F	24	1	1	2	yes	"Need to use to fingers to open the little icon. It said in the little animation the little 'open'"	Correct understanding of affordance: textual aid	CORRECT UNDERSTANDING
36	F	24	3	1	5	yes		Correct understanding of affordance: textual aid	CORRECT UNDERSTANDING
36	F	24	3	2	5	no		Correct understanding of feedforward: purpose of picture bent top corner	CORRECT UNDERSTANDING
36	F	24	3	2	1	no	"Nothing is visually changing when I click on it."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
36	F	24	3	1	4	no	"Got the corner this time but not the circle…"	Criticism: unavailable visual cue for gesture	CRITICISM
36	F	24	3	2	4	no		Expectation: drag and drop picture	EXPECTED
36	F	24	2	1	5	no		Expectation: drag and drop picture	EXPECTED
36	F	24	3	2	5	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
36	F	24	3	1	4	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
36	F	24	3	2	4	no		Incorrect gesture: double tap to activate button	INCORRECT GESTURE
36	F	24	3	2	5	no		Incorrect gesture: double tap to select	INCORRECT GESTURE

								picture	
36	F	24	2	1	5	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
36	F	24	2	1	5	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
36	F	24	3	2	5	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
36	F	24	3	2	5	no		Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
36	F	24	2	1	2	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
36	F	24	3	1	5	yes	"Because it said hold…and before there was a counter, I thought it was loading."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
36	F	24	3	2	4	no	"When I double click it there's a little corner but I don't know hat it means."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
36	F	24	2	1	5	no	"It did that because I tapped or would come anyway?"	Unexpected: surprise with automatic affordance	UNEXPECTED
36	F	24	3	2	5	no	"This came up before I touch it this time." "The corner thing again. Maybe it says it is selected, no?"	Unexpected: surprise with automatic affordance	UNEXPECTED
38	M	43	1	1	3	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
38	M	43	2	1	4	yes	"I remember how to bring the menu because I saw the little cue at the beginning."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
38	M	43	1	1	1	no		Expectation: tap button to open	EXPECTED
38	M	43	3	1	2	yes	"I just saw an icon coming down on top."	Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
38	M	43	3	1	2	yes		Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE
38	M	43	1	1	1	no	"I think I'd have benefitted if I was seeing it for a little longer."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
39	F	56	1	1	1	yes	"It wasn't intuitive, it wasn't clear."	Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
39	F	56	1	1	1	yes		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
39	F	56	3	2	3	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
39	F	56	3	2	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION

39	F	56	3	1	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
39	F	56	1	1	1	yes		Accidental activation: pinch to select button	ACCIDENTAL ACTIVATION
39	F	56	1	1	1	yes		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
39	F	56	1	2	1	yes	"I think this is more intuitive."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
39	F	56	2	2	3	yes	"Generally I don't like the iPad interface."	Criticism: should be similar to desktop OS	CRITICISM
39	F	56	3	2	4	yes		Expectation: drag and drop picture	EXPECTED
39	F	56	1	1	2	no		Expectation: tap button to open	EXPECTED
39	F	56	3	1	2	yes		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
39	F	56	2	1	2	yes		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
39	F	56	1	1	2	no		Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
39	F	56	2	2	2	yes	"I think is telling me there's a menu over there but disappeared very quickly."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
39	F	56	1	2	5	yes	"The book one would be better if the icon could come towards me." <Did a zoom in movement with her hand> "Even thought the icon appeared I wasn't sure if should push it or whatever."	Unable to assess: affordances general purpose	UNABLE TO ACCESS
39	F	56	1	1	2	no	"How do I present what I saw before?"	Unable to assess: did not perceive 1 Tap-to-preview	UNABLE TO ACCESS
39	F	56	3	1	2	yes	"I didn't touch that."	Unexpected: surprise with automatic affordance	UNEXPECTED
40	M	42	2	1	5	yes	"This time I moved further to the left, to the border and then worked."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
40	M	42	3	1	3	yes	"But wasn't written 'hold' beforehand.."	Correct understanding of affordance: textual aid	CORRECT UNDERSTAND ING
40	M	42	3	2	1	yes	"I'd like to see that again, if possible."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
40	M	42	1	2	4	no	"Similar to the one before but with no dots…still unclear."	Criticism: unavailable visual cue for gesture	CRITICISM
40	M	42	3	2	3	no		Expectation: drag and drop picture	EXPECTED
40	M	42	1	2	1	no		Expectation: tap button to open	EXPECTED

40	M	42	1	2	2	no	"It's unclear to me."	Incorrect gesture: double tap to activate button	INCORRECT GESTURE
40	M	42	2	1	2	no		Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
40	M	42	3	1	4	no		Incorrect gesture: select picture by top corner	INCORRECT GESTURE
40	M	42	1	2	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
40	M	42	1	2	1	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
40	M	42	1	1	5	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
40	M	42	1	2	1	no	"An image of an icon appeared there…would be useful if you wanted to go back to the same menu again."	Incorrect understanding of feedforward: back to home screen	INCORRECT UNDERSTAND ING
40	F	56	3	2	4	yes		Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE
40	M	42	1	2	1	no	"the image has sharpened, slightly…perhaps just to draw your attention to the book icon"	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
40	M	42	2	2	2	yes	"It's obviously providing some help but it's not clear what that help is."	Unable to assess: affordances general purpose	UNABLE TO ACCESS
41	F	55	3	2	1	yes	"But wasn't written 'hold' beforehand.."	Correct understanding of affordance: textual aid	CORRECT UNDERSTAND ING
41	F	55	3	2	1	yes		Criticism: unavailable 1 Tap-to-preview	CRITICISM
41	F	55	1	1	3	yes	"The command didn't show."	Criticism: unavailable visual cue for gesture	CRITICISM
41	F	55	3	1	2	yes		Expectation: drag and drop picture	EXPECTED
41	F	55	3	1	2	yes	"It appears to be loading." "You hold on to the picture and drag it. I thought it would maximise the picture."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
41	F	55	3	2	3	yes	"It's loading."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
41	F	55	3	1	2	yes	"It appears to be loading." "You hold on to the picture and drag it. I thought it would maximise the picture."	Partial assessment: correct gesture but incorrect outcome	INCORRECT UNDERSTAND ING
41	F	55	3	1	2	yes		Previous experience helped executing: smartphones &	PREVIOUS EXPERIENCE

								tablets	
41	F	56	3	2	4	yes		Unable to assess: did not perceive 1 Tap-to-preview	UNABLE TO ACCESS
42	F	56	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
42	F	56	3	2	5	yes		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
42	F	56	3	1	4	yes		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
42	F	56	3	1	5	yes		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
42	F	56	1	1	2	no	"It's telling me to open the book!"	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
42	F	56	3	1	2	yes	"How about now that nothing shows up?	Criticism: unavailable 1 Tap-to-preview	CRITICISM
42	F	56	3	2	4	no	"Well, it doesn't come."	Expectation: drag and drop picture	EXPECTED
42	F	56	1	1	1	no		Expectation: tap button to open	EXPECTED
42	F	56	2	1	5	yes	"Ah, this will give me the menu.'"	Incorrect gesture: hardship to hit target area	INCORRECT GESTURE
42	F	56	3	1	2	yes		Incorrect understanding of 1 tap: mandatory to set mode	INCORRECT UNDERSTAND ING
42	F	56	3	2	3	no	"It's a little sun. It's working."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
42	F	56	3	1	4	yes	"No, let it load first."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING
42	F	56	3	1	5	yes		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
43	F	35	2	1	5	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
43	F	35	1	2	1	yes		Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
43	F	35	1	2	5	yes		Criticism: unavailable 1 Tap-to-preview	CRITICISM
43	F	35	1	2	1	yes	"Something showed and disappeared..two circles...maybe zoom perhaps? Ah, the was two dots, guess had to bring down."	Expectation: tap button to open	EXPECTED
43	F	35	3	1	4	no	"It's not coming!"	Incorrect gesture: select picture by top corner	INCORRECT GESTURE
43	F	35	3	2	3	yes	"Guess I have to wait?"	Incorrect understanding of	INCORRECT UNDERSTAND

								affordance: loading	ING
43	F	35	1	2	5	yes	"Ah, how do I bring this back?" <regarding the auto affordance>	Unable to assess: did not perceive 1 Tap-to-preview	UNABLE TO ACCESS
43	F	35	1	2	4	yes	"Now I saw it. Now I saw it coming down. The previous should have moved as well, better when it moves down."	Unable to perceive directionality: static affordance gesture	UNABLE TO ACCESS
43	F	35	3	2	1	yes	"But I haven't done anything! Feels like it was doing something I didn't ask for..."	Unexpected: surprise with automatic affordance	UNEXPECTED
43	F	35	2	1	2	yes	"Will this always appear in the program?" <regarding the automatic affordances>	Unexpected: surprise with automatic affordance	UNEXPECTED
44	M	53	3	2	2	no		Criticism: unavailable 1 Tap-to-preview	CRITICISM
44	M	53	3	1	2	no		Expectation: drag and drop picture	EXPECTED
44	M	53	3	2	3	no		Expectation: drag and drop picture	EXPECTED
44	M	53	1	1	1	no		Expectation: tap button to open	EXPECTED
44	M	53	3	2	2	no		Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
44	M	53	3	2	2	no	"Well if it was two before..."	Incorrect gesture: 2 fingers to select picture	INCORRECT GESTURE
44	M	53	2	2	5	yes	"Sometimes with iPads you have gestures where you can bring things down...it's a normal thing to do on a tablet I think."	Previous experience helped executing: smartphones & tablets	PREVIOUS EXPERIENCE
44	M	53	1	1	1	no	"There was something in here but I missed..."	Unable to assess: affordance displayed for short time	UNABLE TO ACCESS
45	M	24	3	2	3	no		Accidental activation: 1 Tap-to-preview	ACCIDENTAL ACTIVATION
45	M	24	3	1	4	yes		Accidental activation: 2 fingers to select picture	ACCIDENTAL ACTIVATION
45	M	24	3	2	4	no		Accidental activation: pinch to select picture	ACCIDENTAL ACTIVATION
45	M	24	1	1	2	no	"I've seen animations to show me how to click it, how to do it...it's like moving from top to down and up again."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
45	M	24	3	2	4	no		Expectation: drag and drop picture	EXPECTED
45	M	24	1	1	2	no		Expectation: tap button to open	EXPECTED
45	M	24	3	2	4	no		Incorrect gesture: pinch to select picture	INCORRECT GESTURE

45	M	24	3	2	1	no		Incorrect gesture: pinch to select picture	INCORRECT GESTURE
45	M	24	3	2	4	no		Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
45	M	24	3	2	4	no	"When I tap the pictures I notice the presence of this cue here but I don't know what it the function of this cue."	Unable to assess: affordances general purpose	UNABLE TO ACCESS
45	M	24	3	2	4	no		Unable to perceive feedback: picture selected	UNABLE TO ACCESS
46	M	54	1	2	1	no	"I thought there was an indication for me to press that."	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
46	M	54	1	2	4	no	The circles, it suggests to me that if I tap them I'll get some sort of response from the tablet.	Correct understanding of affordance: general purpose	CORRECT UNDERSTAND ING
46	M	54	1	1	5	yes	"So the symbol is telling me to drag with 2 fingers....pretty obscure I think."	Correct understanding of affordance: two fingers	CORRECT UNDERSTAND ING
46	M	54	1	1	5	yes		Criticism: system does not respond to basic gestures	CRITICISM
46	M	54	1	2	3	yes	"I find a bit irritating, don't see the purpose of using 2 fingers to drag it down."	Criticism: system does not respond to basic gestures	CRITICISM
46	M	54	3	1	1	yes	"Not getting anything..."	Criticism: unavailable 1 Tap-to-preview	CRITICISM
46	M	54	2	1	2	yes	"I'd try to see if the sign comes back."	Criticism: unavailable visual cue for gesture	CRITICISM
46	M	54	1	2	4	no	"This time I got the same symbol but without the fingers circles..."	Criticism: unavailable visual cue for gesture	CRITICISM
46	M	54	1	2	1	no		Expectation: tap button to open	EXPECTED
46	M	54	3	1	3	yes	"Still tempted to drag these pictures across, simply because there is a gap in there."	Incorrect gesture: tap target area and then picture	INCORRECT GESTURE
46	M	54	1	2	5	no		Incorrect gesture: tapped affordance as button	INCORRECT GESTURE
46	M	54	3	1	4	no	"There's something on top right corner but I'm not familiar with what would that be."	Incorrect understanding of feedforward: picture bent top corner	INCORRECT UNDERSTAND ING
46	M	54	1	2	4	no		Incorrect understanding of gesture: sequential tapping	INCORRECT UNDERSTAND ING
46	M	54	3	2	3	no	"When I tap the image I got a circle and some	Unable to assess: affordances general	UNABLE TO ACCESS

							indication that something is happening, but I don't know what I should do."	purpose	
47	F	26	1	1	1	no		Expectation: tap button to open	EXPECTED
47	F	26	1	1	1	no	"Just to tap on it and open it?"	Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
47	F	26	1	1	3	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
47	F	26	1	1	5	no		Incorrect gesture: touch and hold to activate button	INCORRECT GESTURE
47	F	26	2	2	5	yes	"Is it to turn the page back?"	Incorrect understanding of aff-feedforward: page turn	INCORRECT UNDERSTAND ING
47	F	26	1	1	1	no	"I don't know how to make the instruction appear again..."	Unable to assess: did not perceive 1 Tap-to-preview	UNABLE TO ACCESS
47	F	26	1	1	1	no	"Did I already did that before? Brought back the cue?"	Unable to assess: did not perceive 1 Tap-to-preview	UNABLE TO ACCESS
47	F	26	1	1	1	no	"It's kind of loading something...I assume it tells me to wait. I'm quite confused about this one."	Incorrect understanding of affordance: loading	INCORRECT UNDERSTAND ING

Table 65: Transcriptions from all test sessions (Study 2).