Enhancing Interaction with Dual-Screen Television Through Display Commonalities

Timothy Neate[1], Michael Evans[2], Matt Jones[1]

[1]FIT Lab, Department of Computer Science, Swansea University, Swansea, UK
[2]BBC Research and Development, Salford, Greater Manchester, UK
[1]firstname.lastname@swansea.ac.uk, [2]firstname.lastname@rd.bbc.co.uk

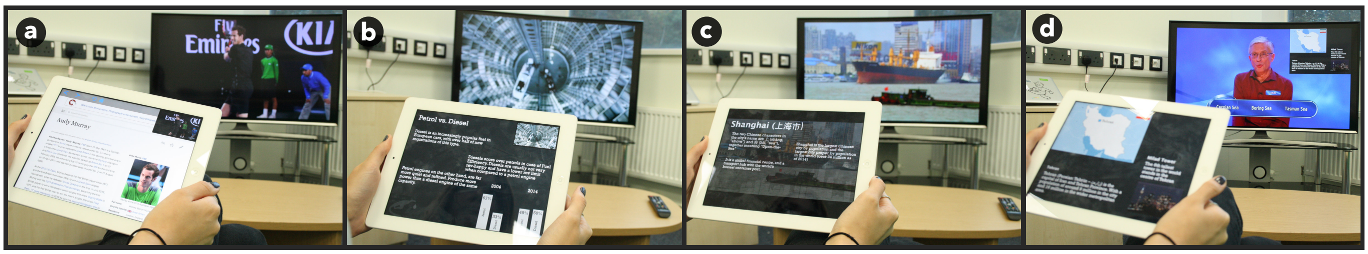

Figure 1: A user utilising display commonalities. In a) we can see the feed from the TV duplicated in the corner of the tablet as the user browses related information on the web; then in b) the same concept is implemented for a companion application; in c) the TV material is mirrored behind a companion application; and, in d), the user is casting her companion application into the corner of the TV.

ABSTRACT

Second screening – engaging with a mobile device while watching TV – is ubiquitous. Previous research demonstrates that this is hampered by cognitive and physical disjuncts between the simultaneous content streams. To engage effectively with more than one screen, users must manage their attention, for example, by frequently adjusting their gaze or posture. This can lead to cognitive effort, which leads to disengagement, content sacrifice, and ultimately, affects user experience (UX) negatively. In this paper, we look to improve the design of the dual-screen scenario through *display commonalities*; the mirroring of one content stream (e.g., TV material or second screen content) within the other. We evaluate this design space with professional broadcast practitioners, and then conduct an empirical investigation to determine the impact of the most successful methods towards understanding their impact, and designing towards positive UX with multi-device scenarios.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation: Misc.

Author Keywords

Second screening; screen mirroring; attention; TV; companion content; display commonalities; multi-device

INTRODUCTION

This decade has seen mobile devices spread into and disrupt almost every commonplace routine. Second screening – the act of engaging with one's mobile device while watching TV – is a salient example of this. Whether users are engaging with social media, searching an actor they recognise, or playing-along with a gameshow, the opportunities for designing cross-device media are evident and numerous. As many of us as 87% are second screening [27], with an even higher proportion of younger audiences having this kind of experience [18], suggesting a strong upwards trend; media entertainment veering strongly towards non-linear, time shifted, and ultimately, multi-device experiences.

Our living rooms are becoming increasingly connected and many of us now have internet-enabled TVs and regularly connect devices to them. Broadcasters, developers and interaction designers now wish to design for this use case by providing multi-device experiences. These are often termed as *companion experiences*. Such content supports a TV programme by providing additional material on a secondary device. This material can vary from interesting related facts and social media, to a full interactive play-along game.

Whether driven by companion applications or by users freely second screening, researchers working in the domain of second screens have surfaced some cognitive and physical constraints of the scenario, which generally reduce the quality of the experience. Second screening typically involves a user gazing down towards their mobile device and, therefore, away from the TV. This means users must monitor the TV for events by listening and catching information in the peripheral of their vision. Then, to engage with the TV and the second screen visually, the user must adjust their gaze, and often their physical posture. The use case implies significant cognitive and physical switching cost, which is not ideal for such leisure scenarios. Moreover, such effects are exacerbated for those who are engaging with complex material, using subtitles, or have some degree of auditory or visual disability.

In this paper, we investigate the potential of duplicating elements of a user experience over multiple devices, so that a user may monitor the visual events of an unattended display on the screen they are focusing on. We term this concept *display commonalities*, illustrated in Figure 1. We investigate this concept by first conducting a focus group with professional content designers at a major broadcaster. By creating prototype dual-screen applications and their respective design space with the practitioners, we establish the most promising designs to focus on. We then use our findings to conduct an empirical investigation of display commonalities with 40 participants in the two most common second screen use cases, with an aim to evaluate their effect and consider how they may be utilised as a design lever for supporting inter-device experiences.

BACKGROUND

The focus of this paper is the duplication of elements across dual-screen UIs to improve UX. Much of the work in the second screen scenario explores how we may measure [7, 22], and intervene in [33, 34] users' attention. However, this work does not consider the full capabilities of the connected living room for the second screen use case. The research around screen mirroring, though fruitful for shared experiences in the living room, generally focuses on how we may design to enhance shared viewing experiences (c.f., the work of McGill et al. [29]). We, in this paper, seek to combine the research around screen mirroring to extend and embellish the UX of multi-device media.

Screen Mirroring

Statistics from a 2013 study with 2600 users suggests that screen mirroring awareness was at around 40% [20]. As of 2016, little recent data exists on screen mirroring penetration, however, given the increasing proliferation of casting services such as Google's Chromecast [19] and Apple's AirPlay [5], it is likely to be an increasing trajectory. The interactions afforded by casting services allow us to utilise the superior interaction capabilities of our touchscreen handheld devices, in tandem with the superior visual capabilities of a large display, such as a TV.

Empirical investigations have looked at how to best cast a device's whole screen to a TV. For example, Fleury et al. [14] investigated user preferences for screen mirroring with a mobile and a TV. Screen mirroring has been further explored with an aim to promote mutual sharing of content between users from their personal mobile devices. For instance, McGill et al. [29] look at how, in a shared viewing experience, we may use the affordances of screen mirroring to foster enhanced collaboration between users of a TV towards equal participation in mirroring.

Second Screening and Cross-Device Experiences

Over the past few years, for users in relatively affluent economies, it has become hard to imagine the living-room media landscape without interactions on a second screen personal device. A nuanced and vast set of second screen behaviours has been noted by the HCI community [10, 23, 38]. These focus around unrelated interactions, such as social media and, more pertinently, related interactions such as searching for information related to a programme, or engaging with points in a debate on social media. It is these related interactions that have fuelled major broadcasters and developers to aspire to create engaging, meaningful cross-device experiences.

Many companion applications address user inclination to discover more about things they have seen in a programme, and much empirical work has explored the provision of programme-specific second screen companion content: typically complementary information [11, 12, 32], related social media [21, 26], and play-along games [8]. Many broadcasters and developers have created companion apps for public distribution (e.g., [1, 30, 31]). These apps aim to support preexisting behaviours and allow users to better tie together the television programme and the second screen material, creating a more unified cross-device experience.

The HCI community has considered how to improve companion UX using supporting, tangential information: Geerts et al. [17] use a companion application live-synced to a programme to examine the perspectives of users and producers, yielding qualitative and analytics-based insights; Fallahkhair et al. [13] described the potential for supporting language learning through combining a foreign television programme with a companion application; and, much work has looked at how we can provide second screen applications to simplify complex plot lines and concepts [11, 32, 40]. Another avenue of exploration has looked at support for social second screeners through dedicated apps. For example, early work by Regan and Todd [37] on instant messaging in a media centre, has more recently been extended by systems which allow people to share and communicate while watching TV; to become further engaged with their programmes, both when co-located [3, 29] and distributed [6].

In terms of large-scale adoption, many online streaming services now offer interactions on a second screen to support their viewing, for example Amazon Prime Video allows for the casting of video to another display (typically a TV) while engaging with second screen content: the *X-Ray* [2] service provides encyclopaedic, time-synchronised, content and information about people featured in a film when a user interacts.

Dual-Screen Attention: Hinderances and Enhancements

Although, in general, companion experiences are positively received by audiences, there are some clear constraints around the amount of audio-visual information we can attend to. For instance, we are poorly cognitively equipped to deal with simultaneous reading and listening [39]. Deployments and empirical investigations of dual-screen scenarios have suggested that additional cognitive load is introduced when compared to traditional TV use: Basapur et al. [6] note in their deployment of a companion system that users considered this 'active' TV, and not necessarily something one would unwind to. Such findings were also observed by Geerts et al. [17], who noted that viewers had to manage a good balance between engagement and distraction with the second screen application, and return to some details in the application later (i.e., when the TV material was no longer relevant). Moreover, such scenarios are driven by the effect of visual separation (both angular and depth of field) between the TV and the mobile device, which introduces a switching cost [36] and have shown to inhibit presentation of content across screens [42].

In terms of overcoming such issues, viewers regularly pause or rewind to catch up with material they miss during a programme [35]. However, these behaviours mean users are required to to re-watch scenes, or may miss key points in live programming – likely hampering UX. Therefore, towards understanding dual-screen visual attention more completely, work by Holmes et al. [22] and Brown et al. [7] has sought to better comprehend the nuances of this use case through eye-tracking users when engaging with TV and a companion application.

In extension to this work, proactive solutions have been investigated. Geerts et al. [17], for example, suggest that by informing the user when a piece of content will become available, using a timer, that they may then adjust attention in a timely manner. Further, Neate et al. [34] have looked at how to effectively shift a user's attention between screens in a cross-device experience, and how one may vary visual complexity on a handheld device to compensate for the perceived complexity on the TV material [33]. Finally, Valuch et al. [43], when considering the effect of cinematic cuts on a single screen, noted that viewers were able to better re-orient their attention more quickly if visual content is repeated from a pre-cut scene, suggesting that a similar approach may aid reorientation of visual attention in a cross-device experience.

DISPLAY COMMONALITIES DESIGN SPACE

When considering the design space for integrating video feeds into a second screen we sought inspiration from the early interactive TV literature, which often focused on the design of EPGs (Electronic Programme Guides). Although historically remote controlled EPGs often consisted of a video embedded into the top right-hand corner of the TV (screen-in-screen), so that a user may attend to a programme and channel surf, handheld EPGs (c.f, [9, 41]) have not incorporated this. More recently, however, browser-based video experiences have used similar design ideas (e.g., the Floating Youtube Chrome extension [15]). As the user scrolls down the page using this extension (to read an article, for example) the video embeds into the corner and follows as they scroll. Further, to allow for multitasking, recent iPad devices also implement a screen-in-screen feature to allow users to attend to video [4]. Such designs, however, only allow for the direct mirroring of the mobile device's screen, and do not afford users the opportunity to integrate individual elements of the TV display into a mobile user interface.

In considering alternative approaches for embedding a video stream into the periphery of a handheld display, there is a clear tradeoff between video detail and screen space: as the video feed becomes bigger more of the content that is native to the device is occluded. Knoche et al. [25] investigated users' optimum viewing ergonomics for video on mobile devices and found that given the relative smaller distance between the user and the device (compared to the user and the TV), many mobile devices afford an acceptable viewing angle. However, shrinking this video to show other content on the mobile device is likely to impact the ideal video angle; an effect which is likely to get worse for smaller devices. The optimum design, then, would allow sufficient screen real estate for the content mirrored from the 'other' device, without obfuscating the material on the display the user wishes to attend.

In addition to the loss of video detail in such screen-in-screen designs, such approaches generally cause obstruction to viewing content in the corner of the screen. To alleviate this issue, we considered the option of non-opaque displays. Kamba et al. [24] considered, in their early work on mobiles, how the transparency control widgets in a display can act as a method to extend smaller screens and to allow for all interface elements to be visible. Such methods, in our case, would allow for the whole screen to be occupied by the companion content while still allowing a user maximised resolution of the video. However, this use of transparent overlay is bound to introduce additional issues in terms of visual ergonomics.

FOCUS GROUP WITH CONTENT DESIGNERS

From the methods discussed in the literature, we mapped out the design space depicted in Figure 2. To progress our investigation, we were inspired by work which uses experts to whittle down a large set of designs before exposing them to users (c.f. Marsden et al. [28]). In particular, we considered work such as that by Geerts et al. [17], where the opinions of experts are garnered towards designing better second screen applications. To further consider methods which would be viewed feasible in terms of an editorial perspective we engaged with content designers and creators at a major broadcasting corporation through a focus group. The benefits of doing so are practical and ecological; it allowed the expert consideration of the fully-populated design space with a manageable set of options for audience user research determined by considered, reproducible practice. We recruited four professional designers at the broadcaster, along with a creative director. Designer participants are referred to as D1 through D5. The participants' professional practice included a focus on designing the 'live experience', to accompanying produced content, for example, real-time sports statistics and social media integration. Their core skill-sets and backgrounds were broad and ranged from graphic design to programming.

Procedure

In order to identify which were the most viable design approaches warranting further exploration we first showed the expert professional participants our designs mocked up in a graphic design package (as in Figure 2), without explaining what they may be used for to reduce the priming of genre effects. We then showed them the same designs, except as nine working prototype companion applications, each with example pieces of companion content for the BBC programme "Wild China", while casting the video to a television.

Participants freely discussed the prototypes using critical skills from their professional practice then, at the end of interacting with each UI, we asked them to reflect on their experience,

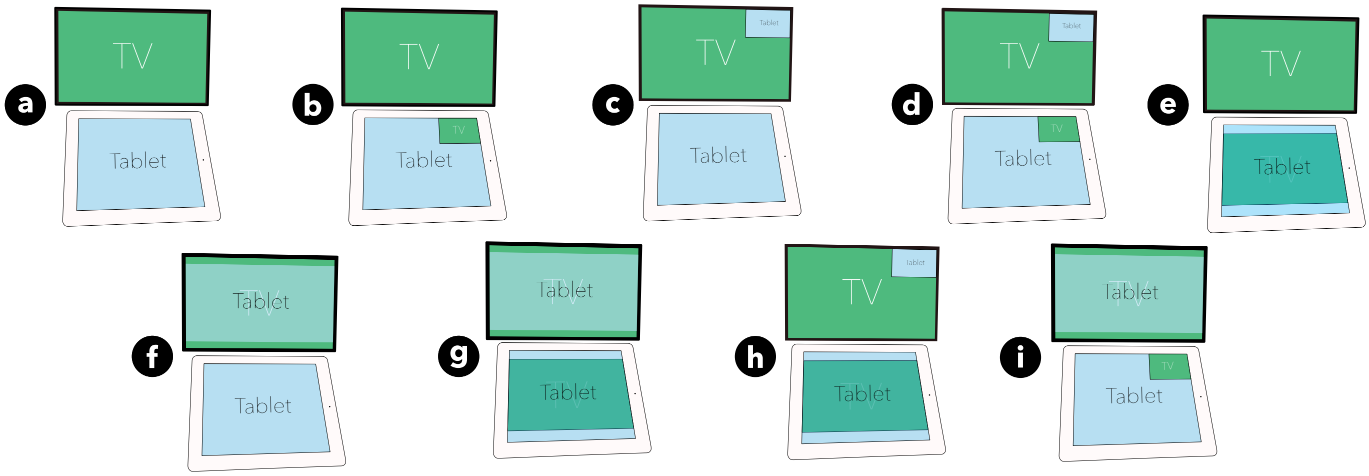

Figure 2: Initial design space: we considered the permutations of previously mentioned techniques to stimulate discussion in our focus group. a) depicts the 'default' no commonalities case, b) the TV material being mirrored from the TV to the corner of the tablet, c) the tablet being mirrored to the TV, and d) a combination of b) and c). In e) we depict mirroring the TV behind the content on the tablet, with the opacity of the content lowered to allow for the user to see through it, and method f) then reverses this concept and projects from the tablet to the TV. Technique g) is a combination of e) and f), and h) considers a hybrid of projecting from the tablet to the corner of the TV while simultaneously placing the TV content behind the tablet screen. Finally, i) shows the inverse of h) – placing the tablet content over the programme on the TV, and the TV programme in the corner of the mobile device.

noting the positives and/or negatives, along with any potential envisioned usage. Finally, after interacting with each interface arrangement, we asked them to state their informed expert preference in terms how they may utilise each UI in their content creation. All comments were recorded for later transcription and exploration through thematic analysis.

Results

In general, practitioners strongly preferred UIs that mirrored the TV on the tablet. Three preferred UI b) and two preferred UI e). A recurring theme in our discussions was that any overlay on the TV puts the designer at risk of encroaching on the TV programme, occluding important elements. The designers referred to the TV as 'sacred space': "*I just feel like that space there [the TV]. That's the primary – that's sacred. And I don't feel like you should really encroach on that*" (D1). Generally, they favoured methods that either did not cast to the TV or methods that did so discreetly (for example, h) and c)). Persistent material was viewed negatively. Participants believed that it encroached on TV's territory and that it should only be placed at very specific points as a call to action – "*kind of at trigger points letting you know that there is something on your companion screen, so that you can be involved with it.*"(D2).

Designers responded positively to on-tablet mirroring of video content, both in the corner of the handheld screen (b)), and presented behind the handheld device's native content – e). Screen-in-screen on tablet, b), was the most preferred because it was seen to work for basically all types of envisioned usage (e.g., companion content and browsing of the web). Some preferred it to the overlaid content, e), because it allowed them, as designers and viewers, to compartmentalise the mirrored TV and the supporting content.

The positive comments around mirroring from the TV to the mobile device, however, were also mixed with concerns about users focusing wholly on their mobile device, negating the reason to have the TV in the background (despite its superior viewing quality) – "*I kind of feel like you don't have to look at the TV. But I like how you can look at the view and then back at the TV so you don't have to deal with 'both'*" (D2).

The opacity overlay was a divisive UI, with some (2/5) preferring it to the screen-in-screen. The positives for this UI mostly edged around the fact that it was aesthetically pleasing (that it worked like a wallpaper), that it afforded a larger screen, and that it allowed the users to absorb both streams of information simultaneously: "*I do actually prefer it when it's the whole video behind the screen, rather than when it's in the corner. Like I said before – you're watching the TV or reading the text. Whereas with this it feels like you're absorbing both bits of information*" (D3). Criticisms focused around the fact that opacity-overlay UIs may not work for non-designed experiences such as free browsing, as the opacity of the overlay may occlude some parts of the video display. Overlay on tablet, for example e), was generally seen to afford 'designed experiences' more – "*...information overlaid on top of video; it looks somehow compelling and seamless. But you know, if it was anything other than these pleasant meditative screens it would be a lot more competing*" (D2).

Dual-mirroring (mirrored elements on both UI) was generally seen as excessive and was seen to introduce redundancies. The designers tended to prefer more universal UI. Essentially, they preferred UIs which could be applied to the most scenarios, over powerful ones which could be used in few. UIs which were thought to afford only one type of viewing, for example the overlay on the TV, which they only saw useful for brief sharing, were generally not praised. All cases where content was mirrored onto the TV with an opaque overlay were generally noted to be good for only one use case – sharing content with others. The favoured method of mirroring to the TV was to keep the mirrored content discreet by placing it in the corner of the display c). Finally, weighing up the benefits of each, they reached a consensus that the most viable methods for future exploration were: b), the video feed from the television in the corner of the handheld device; c), the mirroring of the mobile device to the corner of the TV; and e), the TV video feed behind the material on the mobile device.

Reflections

The professional focus group allowed us to refine our design space, informed by the insight of the expert content designers who would be tasked with delivering audience value my media products using these concepts. With the experts we made the following conclusions:

- Mirroring back from the TV (e.g., b), d), e), g), h) and i)) to the device was considered viable as a commonality method;
- Screen-in-screen mirroring on the tablet and TV (b) and c) respectively) could be applied to the most scenarios they envisioned;
- The TV is sacred: the use of mirroring fully over TV content (e.g., f), g), and i)) is generally advised against for most scenarios;
- Dual-mirroring (e.g., d), g), h) and i)) was generally viewed as cluttered and redundant.

EMPIRICAL INVESTIGATION OF COMMONALITIES

The initial exhaustive design space had now been constrained to three commonality conditions selected by the professional assessment undertaken by the experts. These were then used in a large-scale empirical user study. We investigated the subjective and objective effects of display commonalities from the perspective of end users (i.e., viewers). These three, and a no-commonalities baseline, are as follows:

- C1 – the baseline condition with no commonalities, depicted as a) in Figure 2. This is the typical experience of a second screener as it stands;
- C2 – mirroring from the TV into the right hand corner of the tablet computer, represented by b) in Figure 2;
- C3 – mirroring from the TV behind the content on the tablet computer screen, as depicted in e) with the opacity of the overlaid content's alpha set to 0.7;
- C4 – mirroring from the tablet to the top right hand corner of the TV, as depicted in c).

Participants and Study Environment

We recruited 40 second screeners (P1 – P40) from a university population, both students and staff. Participation was rewarded with £5. The average age of our participants was 32.5 years old (SD = 8.6), of which 26 of identified as female and 14 male. On average, our participants watched 2.34 (SD = 1.65) hours of TV per day, and either strongly agreed (31) or agreed (9) that they regularly engage with touch screen devices, and all were second screeners to some degree. Five had noted using a companion application to support a TV programme before. All studies were conducted in HCI research lab configured as a living room (pictured in Figure 1). We used an LG 49UH620V 49 inch TV, connected to a laptop. From this, video was cast from an iPad 2 over a personal Wi-Fi hotspot enabling negligible latency between the video streams.

Study Procedure

Each study participant first read and completed a consent form, then filled out a demographics form to allow us to better understand our sample. The participants were then given their individual brief, dependent on the experimental group they were in (COMPANION or FREE-BROWSE, discussed in the next subsections). Following this, they watched a diverse set of four clips (to mitigate genre effects, which are shown to have a major effect on the viewing experience [16, 35]) from popular programmes (see Table 1), each followed by a questionnaire to evaluate their experience. Condition-wise ordering effects were mitigated against with a Latin Square design (5 rotations of 4, over each 20 participant set).

Then after watching all four clips, the participants filled out a post-study questionnaire to allow them to reflect on their whole experience, and an investigator then conducted a short semi-structured interview to capture qualitative insight. The interview questions focused on understanding if the participants noticed any of the conditions affect their attention management during the study by explicitly asking them to state a preference and to explain their perception of each method.

Clip No.	TV Programme	Summary
1	Wild China	Documentary about China
2	Australian Open Final	Tennis game
3	VW Scandal	Emissions scandal documentary
4	Eggheads	Quiz programme

Table 1: Clips used in the display commonalities complexity experiment. Each programme was edited to run for approximately 5 minutes.

The experiment followed one of two formats: the COMPANION condition, in which the TV viewing experience was accompanied by a dedicated companion app (P1 – P20), and the FREE-BROWSE condition, where the participants were free to browse the web (P21 – P40). The participants for this were assigned chronologically; after 20 participants, we began running the study with the FREE-BROWSE condition. We used both scenarios so that our findings are generic to the two common second screen cases, with varying user autonomy. To ensure the validity of our between-participants results, we conducted statistical analysis of the participants' demographics using paired t-tests and found no significant differences between the populations.

Companion and Free-Browse Conditions

To explore the effect of commonalities on a *designed* experience we built four companion applications; one for each programme, which were representative of typical applications. Each app contained four main screens of programme-relevant material, which became available at key points in the experience, at which point the participant was notified of the new content with a notification sound and a visual cue. Figure 3 illustrates the companion application layout for one of the programmes the participants watched in the experiment. The four screens are indicative of the applications we used in the experiment. In addition, to explore the effects of the commonalities on the participants when actively engaged in knowledge query we created a simplistic web browser, with 'back','forward', 'home', and 'refresh'

Figure 3: The Wild China Companion Application (depicted here with no commonality methods), in order of appearance to the user: a) shows a simple non-interactive plain text screen b) shows the interactive text screen of the application, here participants could swipe up and explore more text; c), the animation scree. In this case the participants explored an interactive time-lapse of desertification; d) shows the quiz; here, as influenced by [33], participants were given true/false questions related to programme and the tablet material to motivate engagement with the materials on both screens. They were free to repeat the quiz as many times as possible, while also visiting other screens to fill in gaps in their knowledge. For each clip, the applications followed this same format but with programme-related information.

buttons, with the relevant commonality methods included. We motivated the participants to engage with the TV material and the browser as they would in their regular browsing habits.

Measures and Motivations

Subjective metrics were gathered by asking participants several questions after each clip through the form of a questionnaire. We asked these questions with a motivation to understand the benefits of each commonality method in terms of how the participants take in information on the screens at the same time, how they perceive the cost of switching between them, the visual appeal of each technique, how aware of the 'other' device the participants were, and how each technique occluded the materials across the two screens (exact questions shown in Table 2). We also used a post-study questionnaire to allow the participants to compare and contrast the techniques, and reflect on the experience as a whole. In this, we asked them how they felt about each individual technique as a whole (exact questions shown in Table 3). Our hypotheses around the qualitative data were that the commonalities would allow the users to more positively manage their attention, and therefore we would expect to see this reflected in our Likert scores.

In terms of objective metrics, we measured the participants' interactions with the mobile device to determine how the conditions affected their experience. We logged time-stamped events on the device and stored them for later analysis. For the COMPANION condition, interactions were logged within the app as a proxy for participant involvement with the second screen material (as in [33]). We logged when the participants moved to a new screen on the application, when they completed a quiz, and when they interacted with an animated widget. For the FREE-BROWSE condition we logged the browser button actions, such as 'back' and 'home', along with each individual webpage they visited. In both the COMPANION and FREE-BROWSE conditions we expected to see greater interactions with mirroring methods that allowed participants to better manage their attention. We then used the interview data to frame the quantitive data and explain any anomalies.

Results: Post-clip Questionnaires

We considered a range of objective and subjective metrics to evaluate the participants' experience of the commonality methods. For the Likert scale questionnaires, we conducted Friedman tests to determine if there was a general overall effect, running post hoc Wilcoxon tests between the conditions to determine any inter-condition effects. We set $\alpha = 0.05$ for significance testing throughout our analysis. The results for the post-clip questionnaires are shown in Table 2. These are divided into those participants who got the FREE-BROWSE condition, and those who got the COMPANION condition.

Taking in Information on Screens Simultaneously

For the COMPANION condition there was a significant effect for the participants' ability to take in the content over two screens (statement a)), with pairwise differences; the participants found it significantly easier for the C2 condition (Z = 3.24, $p < 0.001$) and the C4 condition (Z = 1.95, p = 0.003), compared to the C1 condition. These results were similar to those participants who had the FREE-BROWSE condition – there was a significant overall effect, and C2 was the most preferred method. From conducting pairwise post hoc tests we were able to determine that C2 was significantly preferred to C1(Z = 3.00, $p < 0.001$) and C3 (Z = 1.789, p = 0.037). In addition, the participants felt that they were able to manage their attention across the two screens significantly better for C2 than C3 (Z = 2.079, p = 0.019).

Perceived Switching Cost

For the COMPANION scenario, there was a significant overall effect for switching cost across conditions (statement b)). Compared to the baseline (C1), all conditions were significantly better at reducing switching cost: C2 (Z = 2.70, p = 0.004); C3 (Z = 1.94, p = 0.027); C4 (Z = 1.65, p = 0.026). In general, C2 was ranked consistently the highest and ranked significantly higher than the screen-in-screen on the TV case: C4 (Z = 1.949, p = 0.026). This effect was also observed in the FREE-BROWSE condition, with a much larger effect than the companion case (COMPANION χ^2 = 11.86; FREE-BROWSE χ^2 = 27.16). For the case where content was mirrored from the tablet to the corner of the TV, in the FREE-BROWSE case, there was a significant difference between both the screen-in-screen on tablet C2 (Z = 3.22, p = 0.005) and the condition in which we mirrored the TV content behind the tablet's browser (C3) (Z = 3.131, $p < 0.001$).

Visual Appeal

For the COMPANION condition there was no significant difference in terms of visual appeal for the conditions (statement

	Statement	Mean Rank C1	C2	C3	C4	χ^2	p
COMPANION	**a)** *I found that I could take in the content over the two screens at the same time effectively*	2.00	3.10	2.58	2.23	9.45	0.024
	b) *I had to shift my viewing between the screens a lot to take in the TV and tablet content*	3.08	1.93	2.35	2.65	11.86	0.003
	c) *I found this commonality presentation method visually appealing*	2.63	2.95	2.33	2.10	7.10	0.069
	d) *I found the commonality method used got in the way of my content viewing on the tablet*	2.85	2.35	2.40	2.40	2.76	0.490
	e) *I found that the commonality method got in the way of viewing the TV material*	2.35	2.08	2.70	2.88	5.48	0.140
	f) *I felt I had good awareness of what was happening on the TV while looking at the tablet*	2.33	2.58	2.88	2.23	4.01	0.260
	g) *I felt I had good awareness of what was happening on the tablet while looking at the TV*	2.50	2.43	2.88	2.80	2.66	0.447
FREE-BROWSE	**a)** *I found that I could take in the content over the two screens at the same time effectively*	2.15	3.43	2.63	1.80	23.90	0.000
	b) *I had to shift my viewing between the screens a lot to take in the TV and tablet content*	3.20	1.73	2.03	3.05	27.17	0.000
	c) *I found this commonality presentation method visually appealing*	2.63	3.28	2.48	1.63	18.43	0.000
	d) *I found the commonality method used got in the way of my content viewing on the tablet*	2.43	2.53	3.03	2.00	9.26	0.026
	e) *I found that the commonality method got in the way of viewing the TV material*	2.55	1.65	2.48	3.33	23.44	0.000
	f) *I felt I had good awareness of what was happening on the TV while looking at the tablet*	2.15	3.28	2.70	1.88	19.36	0.000
	g) *I felt I had good awareness of what was happening on the tablet while looking at the TV*	2.60	2.75	2.25	2.40	2.52	0.410

Table 2: This table denotes the extent to which the participants agreed with the noted statement from: Strongly Agree (5); to Strongly Disagree (1). Larger numbers are indicated with darker colours for the mean ranks and the χ^2 value, and statistically significant ($p < 0.05$) are denoted in red – with increasing darkness at higher significance levels. It is clear from observation of the number of statistically significant results that the FREE-BROWSE condition results in a larger effect for many conditions.

c)). However, for the FREE-BROWSE condition, there was an overall significant effect for the conditions. In general, C2 was preferred significantly more than C1 (Z = 1.724, p = 0.034) and C4 (Z = 2.411, p = 0.008).

Occlusion of Tablet Content

There was no significant effect in the COMPANION condition for the commonality methods occluding the tablet content (statement d)). However, for the FREE-BROWSE condition it was evident that C3 – the condition where the video was placed behind the tablet content caused more interference with the web browser C4 (Z = 2.153, p = 0.016).

Occlusion of TV Material

For the COMPANION study there were no significant effects for perceived occlusion of the TV material (statement e)). However, it was evident that for the FREE-BROWSE study, the participants found that the placement of the tablet on the TV affected their perceived occlusion of the TV.

Tablet Awareness

In terms of the participants' awareness of the tablet content there was no significant effect observed for the COMPANION condition (statement f)). However for the FREE-BROWSE case there was a significant effect. Significant pairwise differences were observed between the baseline (C1), which was perceived as worse than C2 (Z = 3.363, $p < 0.001$) and C3 (Z = 1.65, p = 0.049). In addition it is possible to see that C3 was rated significantly worse than C2 (Z = 1.854, p = 0.032) and C4 (Z = 2.052, p = 0.020).

TV Awareness

As with tablet awareness there was no major effects for the amount to which the users were aware of the TV (statement g)).And, in contrast to the participant's reported tablet awareness, we did not see any significant effects for the FREE-BROWSE case.

Results: Post-study Questionnaires

We conducted analysis of the post-study questionnaires presented to the participants, the results of which are shown in Table 3. With regards to perceived mental effort (statement a)), as described in Table 3, a significant overall effect for the COMPANION content condition was observed. Upon conducting post hoc analysis of the data, it was evident that the video content in the corner of the tablet (C2) resulted in the participants experiencing less mental effort than the baseline case (C1) (Z = 3.096, p = 0.001). In addition, there was a similar, but not as pronounced effect, for when casting the tablet content on the TV C4 (Z = 2.397, p = 0.009), and when placing the video content behind the tablet material (C3) (Z = 1.911, p = 0.028).

There was a similar, but more pronounced difference for the FREE-BROWSE case, where all conditions were ranked significantly lower for perceived mental effort than the baseline: C2 (Z = 3.223, $p < 0.001$); C3 (Z = 2.303, p = 0.010); C4 (Z = 2.236, p = 0.013). In addition the TV mirrored in the top of the tablet, C2, was also ranked significantly better than when the video was mirrored behind the web browser, C3, (Z = 2.797, p = 0.025) and when compared to when mirroring the tablet content to the TV (C4): Z = 2.753, p = 0.003. Finally, with regards to the clip preference it was clear that the participants' least favourite clip was Clip 2 (statement b)). Interestingly, there was a significant effect for how much the participants enjoyed each clip for the FREE-BROWSE, but not for the COMPANION clips.

Results: Device Log Data

As shown in the bar chart in Figure 4, C2 generally elicited more interaction than any other condition. There was a significant overall effect between the four conditions: (F(3, 17) = 3.314, p = 0.045). Post hoc tests indicated that the case in which the participants had the TV screen mirrored into the corner of their device, C2, elicited significantly more interaction than the baseline case, C1 (Z = 3.104, p = 0.002) and when mirroring behind the tablet content (C3) (Z = 2.296, p = 0.022). In addition, as shown in

	Statement	Mean Rank				χ^2	p
		1	2	3	4		
COMPANION	**a)** I found that the UI for condition *N* required mental effort to view both screens	3.15	1.93	2.53	2.40	11.18	0.011
	b) I liked clip *N*	2.48	2.23	2.60	2.70	2.06	0.56
FREE-BROWSE	**a)** I found that the UI for condition *N* required mental effort to view both screens	3.23	1.63	2.50	2.65	19.34	0.000
	b) I liked clip *N*	3.10	1.75	2.50	2.65	14.17	0.003

Table 3: Post-study questionnaire: the extent to which participants agreed with a given statement. *N* refers to the particular number of the clip, or condition. It is clear that, when reflecting on their experiences, the participants saw major differences between the conditions in terms of their attention.

Figure 4, we conducted an analysis of the number of times that the participants interacted with the animation and found this was consistent across all conditions, with no significant effect.

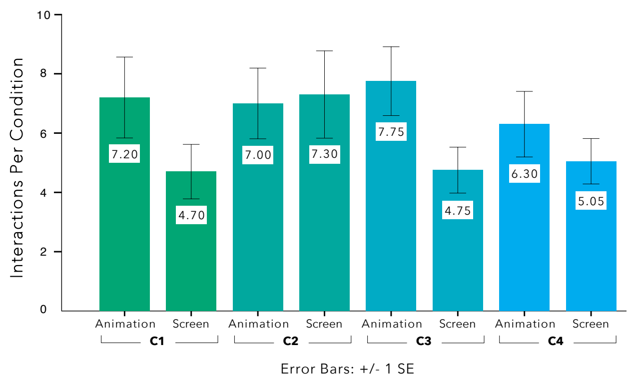

Figure 4: Mean interactions per condition, per participant: this graph describes the average number of each type of interaction per condition. Note that users were much more likely to move *screen* when in the TV was mirrored into the corner of the tablet screen – C2.

Now, turning to the FREE-BROWSE condition – it was clear that different commonality methods appeared to have an effect on the participants' browsing of the internet (F(3, 17) = 3.871, p = 0.028). As shown in Figure 5, it is clear that when the participants had the TV in the corner of the tablet screen (C2). From conducting post hoc analysis we were able to determine that the users were significantly more active browsers when searching the internet with the TV mirrored in the corner of the tablet (C2) compared to the baseline (p = 0.039) and when compared to the video underlay condition (C3) (p = 0.022).

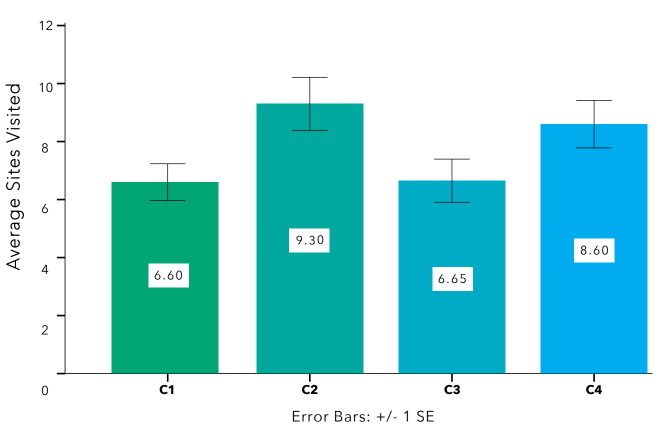

Figure 5: Mean number of sites visited per session, per participant.

Results: Post-Study Interviews

In general, the participants enjoyed the methods in which the tablet mirrored the content from the TV to the tablet. For example, to the initial question, which asked if the participants found that any of the methods were useful for taking in the content across the two screens C2, was noted as the preferred method over half of the time, with 23/40 stating that this method helped them take in the content over two screens: 10/20 for the COMPANION content study and 13/20 for the FREE-BROWSE. The case in which the TV content was mirrored under the mobile device content, C3, came second in terms of preferences: 12/40 participants favouring this option. Mirroring to the TV was not regarded as popular, as indicated by the fact that only four of our of 40 participants preferred this condition. Only one participant out of 40 said that the commonalities did not help them.

Regarding the participants' reasoning for their preferences, many of those who enjoyed the content mirrored from the TV to the tablet appeared to do so because it allowed them to get a gist of what was happening on the TV, meaning that they could better choose when to look up to view the TV content, for example, participant 34 who stated "*I could see this thing [the mirrored TV content] in the corner of the screen and if there was something I thought was really interesting and I wanted to see in full view, I could just look up at the TV. I felt like I was in control*" and participant 39 who said "*My preference is having the small screen in the corner of the device – you sort of then look at the TV if you see that something interesting is going to happen on it in more detail"*.

When comparing C2 and C3 (the techniques which mirrored the TV on the tablet) the participants tended to prefer C2 because of the *way it occluded the tablet content*. For example, C2 fully occluded a small part of it, instead of partially occluding all content, as C3 does. This trade-off between size and opacity was something that the participants discussed extensively, for instance, P26 preferred C3 as it allowed for better resolution for the video content: "*I think it was easier to both watch the show and google at the same time, because of the overlay you weren't losing any size of screen.*" (P35). Many participants who preferred C2 noted that, even though the mirrored video was small, because they were using it as a cue when to look up at the full-size picture on the TV, this wasn't a major concern, as indicated by P22: "*It was handy – didn't feel it got in the way of anything. And sometimes, as it was a little small, for the more visual aspects I would look up to see what was going on"*.

Participants also noted differences in the way that they experienced their eyes shifting around the tablet screen between the mobile device intra-screen conditions – C2 and C3. Some users' comments tended to indicate that they preferred C3 because it allowed them to monitor the events better on the TV as they did not need to consciously switch their gaze to the tablet computer's corner in their peripheral, but simply change their focus slightly and look 'through' the overlaid content: "*...the one that was [mirrored] behind gave me the opportunity to read what was on the screen without having to move my eyes to see what was happening*" (P8). However, on the other hand, they found that the intermixing of the video and the material on the tablet often became confusing, especially for those doing the FREE-BROWSE condition: "*I couldn't see when I wanted to look at the internet properly – it put me off what was going on behind it*" (P38). One participant even found the underlaid video content disorienting to the point where it made them feel slightly nauseous – "*yeah there was a big swooping shot and I was like *blergh**" (P21). One participant noted a limitation of C2 may be the fact that as well as fully occluding an area, it may totally block off interface elements with some applications if not thought out properly – *I thought that it was quite useful, but if you need to interact with anything in the top corner, like to close an app or something, you can't.*" (P30).

Participants generally did not respond as positively when the content from the tablet was mirrored onto the TV (C4). Generally, this was because they believed it to be occluding the larger screen, for instance, P1 noted "*it got in the way when I was watching the TV*". Also, participants often noted that, as it was on the TV, it did not afford reading text – *"I didn't like that so much because the writing was smaller and I found it easier to read when it was right in front of me"* (P2). Another concern from the participants was typing. As they were using a non-tactile (tablet) keyboard, this meant that they had to regularly look down at the tablet to type regardless, for example, P29, who had issues typing in queries on the second screen and looking at the TV, just resorted to switching back to the tablet regardless: "*I couldn't type on the tablet and look up. I couldn't move back and forth between the screens"*.

The 'default' condition without any commonalities, which all second screeners currently experience in their day to day viewing – was the least preferred according to our data. Our interviews suggest that this is due to perceived switching cost and the mental load of the simultaneous information streams – for example P14's comment – *"...and the most difficult was the last one"* (C1) *because I had to check the TV and the tablet*". In fact, only one participant, P18, noted disliking the commonality methods as they were not familiar with their regular second screen routine: *"In the beginning, it's a little overwhelming because you're not used to watching this way. But actually, you're used to doing the 4th method"* (C1).

Discussion

It was clear from the post-clip questionnaire that the commonality methods appeared to help the participants take in the information across the two screens, to varying degrees. Mirroring from the TV into the corner of the tablet (C2) appeared to be the most effective method for the COMPANION and the FREE-BROWSE case. And, generally, the methods in which the TV was mirrored to the tablet were considered the most effective. The interview data suggests that C3 did not perform as well as C2 because of the way that it visually clashed with the video content. Evidently, this was more predominant in the FREE-BROWSE case, where the visual content was dictated by the user freely browsing the web. As one would expect, however, there were some strong inter-participant and inter-content variances due to differences in personal preferences.

The commonality methods also appeared to reduce the perceived cost of the participants moving their focus from one display to another in both the COMPANION and the FREE-BROWSE condition. The qualitative interview data suggests that the participants were switching their focus intra-device, and then making an active decision to switch their focus when they wanted; empowering them to be more in control of their own attention. Here, the screen-in-screen method on the tablet (C2) resulted in significantly lower switching cost than when replicated on the TV (C4). This finding is likely because the TV updates faster than the tablet, and therefore the method enabled the participants to monitor the events on the TV, and to look up when their attention was caught by the visuals of the TV in the corner, or when something in the audio could not be clearly inferred from the small screen in the corner of the tablet.

When checking to determine how aware the participants were of the tablet material, we expected that the method in which we mirrored the tablet content to the TV would improve this significantly compared to the baseline (no commonalities), which it did. However, what we did not expect was that, when browsing the web, the participants appeared more aware of the tablet content for the two methods which mirrored content from the TV to the tablet. This, as indicated by the interview data, is likely because they did not have to look up at the TV as much to fill in the gaps in their (visual) perception, essentially meaning they were, as a result of this, more focused on their web browsing experience. These tablet awareness effects, however, were only seen in the FREE-BROWSE, and not the COMPANION condition. A potential explanation, here, is that it is simply the amount of information on the web browser, and the cognitive effort associated with knowledge query which exacerbated this effect. Work by Neate et al. [33] shows that the textual and graphical complexity of second screen content has a large effect on the mental effort required to engage with second screens.

Evidently, the log data shows that the participants navigated around the application much more when in the condition in which we mirrored the TV in the corner of the mobile device. In light of the subjective quantitative and qualitative data, this is likely because they experienced the least mental demand in this scenario and therefore were able to engage more with the application. The animation, however, did not show this pattern. The log data suggests that this is because most participants went through the transitions in the animation, and just stopped at the final one for each, resulting in quite uniform inter-condition data.

This propensity to search for more information when the TV was mirrored onto the tablet was also reflected in the amount of web browsing the participants did. This is likely the same effect being exhibited – as the participants can easily monitor the TV in the app, they were able to engage with it more. This effect, interestingly, was not seen when the browser was placed over the full mirrored TV screen on the tablet. The interview data indicates that this may be to do with the perceived issues some of the participants faced in this condition due to the two streams of content clashing.

IMPLICATIONS, FEASIBILITY AND THE FUTURE

Our investigations with both expert practitioners and second screeners strongly suggest that methods in which material is mirrored from the TV to a mobile device can be of significant benefit to users in mitigating the attention constraints of multi-device media. This was particularly evident when mirroring from the TV to a tablet in a screen-in-screen method. In addition, it is clear that other methods, such as placing a video stream behind content on a mobile device, are also useful techniques, but are perhaps most beneficial to scenarios in which the content on the mobile device can be designed around this (e.g., companion content scenarios). We, therefore, suggest that, in general, to improve the experience of such applications, designers should consider using techniques that use such duplication of common elements, in order to reduce the effort required in viewing companion applications or similar material.

Though we envision a future in which both persistent and non-persistent duplicate mirroring can be easily integrated into cross-device media scenarios, further research is still required. Our studies, for example, have not explored the effect of persistence: all of our commonality methods were constant, and the participants were not able to dismiss the duplicated video from their attended device. Future prototypes will transcend this experimental constraint, and allow users to control which mirroring method they employ in their browsing. Future work could then observe the appropriation of mirroring methods by users in their everyday viewing. This may uncover further concerns, for example, the issues of privacy when sharing one's screen to the television.

Longitudinal deployments, however, would open up new problems, questions and areas for design. The further investigation of such methods on a variety of devices, for example, would be of considerable interest as a next step. By exploring diverse form factors, and screen sizes of everyday mobile devices we can explore the transferability of commonality methods across device types. With smaller devices, such as smartphones and phablets, there are likely to be bottlenecks in the effectiveness of the techniques, leading to new design requirements. For example, the screen-in-screen condition in our experiments (C2), is likely to require adaption to mitigate against occlusion of the materials under the video content. In such cases, methods such as C3, C4 (and indeed methods not discussed in this paper) may begin to become more beneficial to users.

Thinking beyond the second screening scenario, the ideas and findings in this paper have implications for other use cases: for example, we could extend current mobile device EPGs by integrating the feed from the TV into the corner of the screen, allowing a user to choose a new programme while still retaining awareness of the content running on the television screen. Designs, such as those proposed in this paper, may assist designers in overcoming the issues with eyes-off interactions with non-tactile surfaces (e.g., tablets) when engaging with EPGs.

Methodologically, making use of the expertise of professional UX practitioners in this domain mitigated against subjectivity in selecting particular stimuli for the large-scale user study. Using a repeatable expert process of analysis against the full design space to derive the most valuable individual designs was a successful approach, allowing us to be confident that our user study assessed the right subset of designs. It must be noted, however, that our design space in this paper was not exhaustive and only aimed at targeting the two most frequent use cases and encourage further work refining this design space. We, therefore, encourage further mapping of the design space in future research. Finally, in terms of the infrastructure to enable such experiences, it is assumed that our users have a Smart TV, devices connected to it, and a seamless and uninterrupted internet connection. Though an increasing trend, the standards around the device-agnostic connected living room are not wholly realised for broadcast content. With recent developments in the protocols of cross-device interaction, e.g., work on frame-accurate multi-device content [44], and the increasing demand to provide users with engaging multi-device experiences, there is great potential for interaction designers and researchers to enhance the understanding and impact of this design space.

CONCLUSION

This paper has explored *display commonalities* – the concept of duplicating elements of a user experience over multiple screens, in order to lower the cognitive effort required to use the dual-screen material. Through discussions with professional content designers, we refined our initial design space and conducted an empirical investigation of the proposed techniques under the two prominent scenarios in this use case (web browsing and companion content). By analysing the objective and subjective data we have been able to determine the efficacy of the proposed techniques. In general, we found that, by duplicating the video of the television on a handheld device, we can significantly reduce the required level of cognitive effort require to engage with dual-screens. The findings and design concepts proposed in this paper which were explored, from a designer and a user perspective, can better equip content creators and developers to overcome the disjuncts in visual attention that exist in multiple screen scenarios and, therefore, improve the UX of cross-device media.

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