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Traditions of research into interruptions in healthcare:

A conceptual review

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Abstract

Background. Researchers from diverse theoretical backgrounds have studied workplace interruptions in healthcare, leading to a complex and conflicting body of literature. Understanding pre-existing viewpoints may advance the field more effectively than attempts to remove bias from investigations.

Objective. To identify research traditions that have motivated and guided interruptions research, and to note research questions posed, gaps in approach, and possible avenues for future research.

Methods. A critical review was conducted of research on interruptions in healthcare. Two researchers identified core research communities based on the community's motivations, philosophical outlook, and methods. Among the characteristics used to categorise papers into research communities were the predominant motivation for studying interruptions, the research questions posed, and key contributions to the body of knowledge on interruptions in healthcare. In cases where a paper approached an equal number of characteristics from two traditions, it was placed in a blended research community.

Results. A total of 141 papers were identified and categorised; all papers identified were published from 1994 onwards. Four principal research communities emerged: epidemiology, quality improvement, cognitive systems engineering (CSE), and applied cognitive psychology. Blends and areas of mutual influence between the research communities were identified that combine the benefits of individual traditions, but there was a notable lack of blends incorporating quality improvement initiatives. The question most commonly posed by researchers across multiple communities was: what is the impact of interruptions? Impact was measured as a function of task time or risk in the epidemiology tradition, situation awareness in the CSE tradition, or resumption lag (time to resume an interrupted task) in the applied cognitive psychology tradition. No single question about interruptions in healthcare was shared by all four of the core communities.

Conclusions. Much research on workplace interruptions in healthcare can be described in terms of fundamental values of four distinct research traditions and the communities that bring the values and methods of those research traditions to their investigations. Blends between communities indicate

that mutual influence has occurred as interruptions research has progressed. It is clear from this review that there is no single or privileged perspective to study interruptions. Instead, these findings suggest that researchers investigating interruptions in healthcare would benefit from being more aware of different perspectives from their own, especially when they consider workplace interventions to reduce interruptions.

1   Introduction

Research into the impact of interruptions on the quality and safety of healthcare work has burgeoned over the last fifteen years. Early studies noted that interruptions seemed to be associated with medication errors [1–3]. Subsequently, interruptions have been associated with lost time [4], cognitive failures [5,6], and staff and patient frustration [7]. Interruptions have also been associated with positive outcomes, such as conveying critical information by way of alarms [8], clinical decision support systems [9], and person-to-person communication [10]. Some researchers have recommended that the number of interruptions be reduced, whereas others have encouraged practitioners to use them to increase efficiency [9]. Commentaries and reviews of interruptions in healthcare also reflect conflicting views and differing conclusions [5,8,11–18]. It is therefore not surprising that despite extensive efforts to guide mitigation strategies, the effectiveness of interventions remains mixed [19].

In their useful review of interruptions in healthcare, Hopkinson and Jennings [14] suggest an explanation for conflicting outcomes: "Our assumptions about interruptions likely guide the development of data collection instruments that, in turn, may interfere with a grasp of interruptions that is free from the constraints of pre-existing beliefs and biases" (p. 12). Hopkinson and Jennings note that if researchers assume that interruptions have only negative effects then they may overlook the potential positive effects of interruptions. At some level, researchers' grasp of interruptions may never be free of pre-existing beliefs and biases, given that biases are deeply held, unquestioned assumptions held to be self-evident. However, if researchers were more thoroughly aware of the beliefs and biases of the varying communities studying interruptions in healthcare, including their own, they could potentially interpret findings more accurately, identify differing conclusions and gaps in evidence more clearly, and make more considered designs about what, if anything, to do about workplace interruptions in healthcare.

When faced with an equally complex, heterogeneous, and conflicting body of literature Greenhalgh and colleagues developed a *meta-narrative method* [20,21] as a way of making sense of tensions and paradoxes across research traditions. Citing the role of Kuhn's scientific paradigms [22], Greenhalgh [20] notes, "Any group of researchers views the world through a particular 'lens' or

paradigm that has four dimensions: conceptual (what are considered the important objects of study and, hence, what counts as a legitimate problem to be solved by science), theoretical (how the objects of study are considered to relate to one another and to the world), methodological (the accepted ways in which problems might be investigated) and instrumental (the accepted tools and techniques to be used by scientists)". Greenhalgh and colleagues posed five questions about a tradition: (1) its parameters and theoretical basis, (2) the questions it asks, (3), its main findings, (4) how it has unfolded over time, and (5) its strengths and limitations. We used this framework to better illustrate pre-existing viewpoints in the conflicting body of interruptions literature.

Our goal in this paper was to conduct a broad analysis of the research on interruptions in healthcare, referring to aspects of the above view. Specifically, we explored the following: (i) different research traditions and disciplines that are currently contributing to interruptions research, (ii) how communities studying interruptions in healthcare bring the values and methods of one or more research traditions to their investigations, (iii) how those traditions, or worldviews, shape the questions that are asked about interruptions.

2   Method

To guide our critical review, we adopted some elements of the meta-narrative approach to systematic review outlined by Greenhalgh and colleagues [20] (see Figure 1). We undertook a broad initial review of papers published on interruptions research in the healthcare domain. The broad review led to a preliminary conceptualization of the perspectives and approaches employed by the various research communities. Then we performed a more systematic search of the literature as the emerging communities and their values evolved.

The criteria for including papers in the review were: (i) either the context was healthcare or the authors stated that the results were relevant to healthcare (ii) the primary focus was workplace interruptions (or disruptions or distractions) and (iii) the paper was written in English. All types of full-length papers were eligible for inclusion, including empirical papers, conference papers, theoretical papers, and commentaries, and therefore excluding abstracts. We did not specify a particular date range in our search for literature, but instead chose to include all papers that matched the inclusion

criteria stated above. Papers from any healthcare setting were included. The inclusion criteria were set broadly so that a wide variety of papers, and therefore perspectives, could be considered.
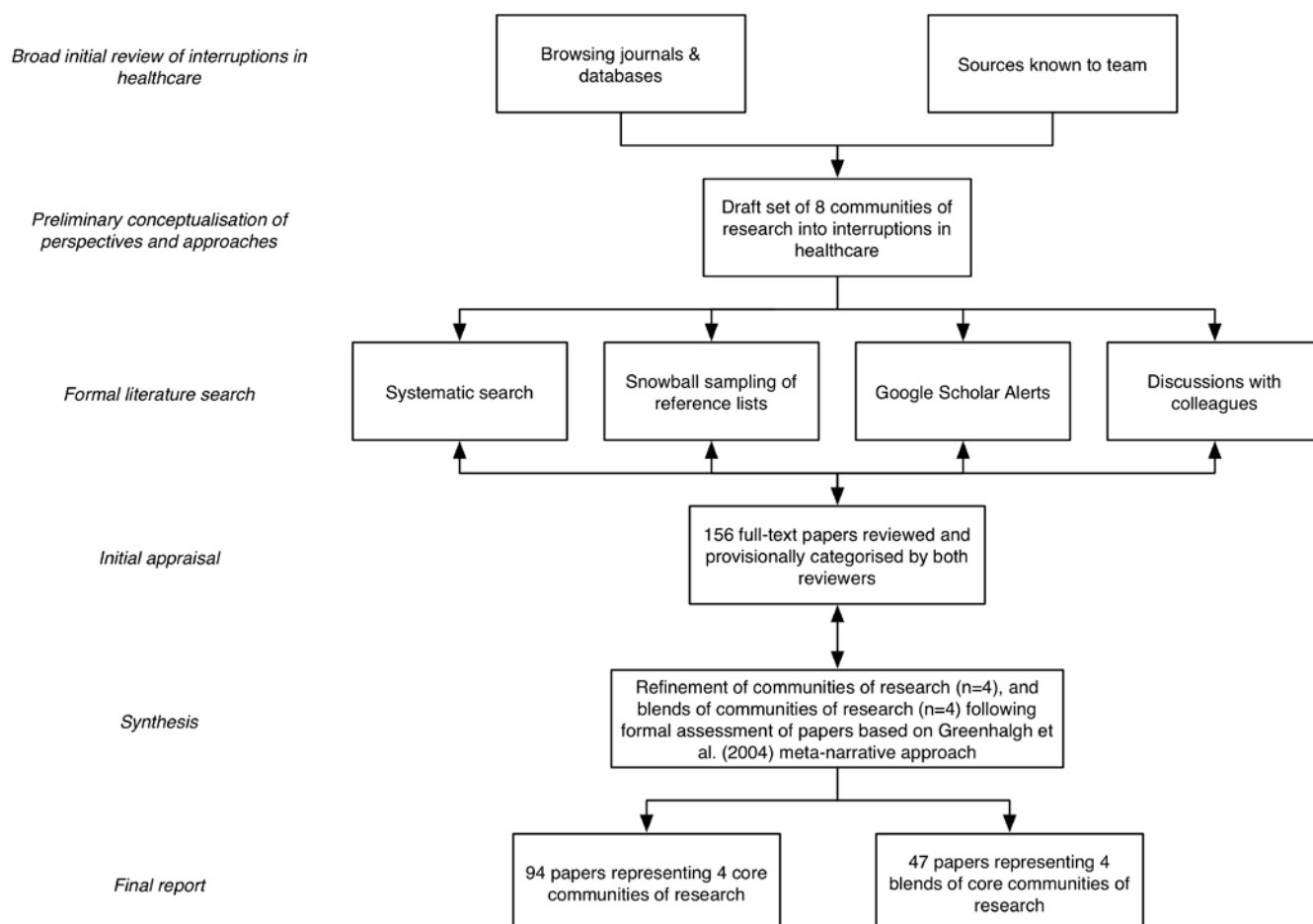
Figure 1: Illustration of the critical review process (adapted from [21])

Our search was conducted with the online database Web of Science using the following search phrases: (i) healthcare AND interrupt* (ii) health care AND interrupt* (iii) interrupt* AND nurs* (iv) healthcare AND distract* (v) health care AND distract*. Google Scholar and Google Scholar Alerts using similar free text search terms further supplemented the list of reviewed papers. It has been noted that there is variation in how interruptions are defined [17,23], and also whether interruptions or distractions differ or are terms that can be used interchangeably. Given this recognition and our desire to be as inclusive as possible, we have not attempted to use a single definition of interruptions, but have accepted any definition used by authors. Collaborators also

provided relevant papers they thought might meet the inclusion criteria. A further search through reference lists yielded additional papers meeting the inclusion criteria. References were also analysed for books and papers that appeared to be seminal authorities for the research.

The full-text papers were independently reviewed and categorised by two reviewers [TMcC and PS]. We used some provisional characteristics to perform an initial categorisation of the papers, such as the purpose of the investigation, investigative design, the situations or contexts in which interruptions were examined, whether interruptions were considered positive or negative, and the locus of actual or potential solutions. Then, through an ongoing process of clustering and discrimination, we refined the initial categorisation and allocations of papers to research communities. In cases where a paper approached an equal number of characteristics from two traditions, it was placed in a blended research community. Where there were points of uncertainty, or new information arose based on the refinement of categories, we completed additional independent reviews and reconvened to discuss our findings. An inter-rater reliability analysis using the final categorisation scheme was performed on a previously uncategorised subset of the papers, resulting in a level of 'almost perfect agreement' using Cohen's Kappa ($\kappa = 0.814$).

Once the mapping of the papers to communities was stable—in other words, the papers could be placed into one of the research communities (or blend of research communities) without disagreement—we performed a final assessment using Greenhalgh's questions 1, 2, and 5. Specifically, we assessed (a) the defining characteristics of the tradition, including the predominant motivation for studying interruptions and the predominant philosophical position of that tradition with respect to interruptions, (b) the research questions posed by each of the communities, including the methods they have used to answer those questions, and (c) the key similarities with other communities and the key areas of difference from other communities, including their overall contribution to the body of knowledge on healthcare interruptions.

We did not investigate Greenhalgh's questions 3 and 4—how the traditions have unfolded over time or the main empirical findings from each tradition for the following reasons. First, research on interruptions in healthcare is still sufficiently new that temporal patterns are hard to discern reliably. Second, our focus is the way the theoretical background of each tradition molds the

questions its practitioners ask and the kind of answers that are possible, rather than the specific empirical findings.

If more than 80% of papers allocated to a research tradition shared a specific characteristic, then that characteristic was included in our synopsis of that tradition. Not all papers showed evidence of all the characteristics of the tradition into which they were categorised, but they showed evidence of more characteristics in that tradition than in any other tradition. The report of findings is followed by a discussion of gaps, opportunities and recommendations for future research.

3 Results

A total of 141 papers, encompassing research from 1994 to the present, were included in this review. A further 19 papers failed to meet the inclusion criteria because they duplicated later more authoritative reports of the same research, they did not focus on healthcare interruptions, or they did not have a full-text version.

3.1 Research Traditions

The most stable categorisation of the literature comprised four research communities representing 94 (67%) of the papers reviewed—communities representing epidemiology, quality improvement, cognitive systems engineering (CSE), and applied cognitive psychology are shown in Table 1. Blends of the four research communities accounted for the remaining 33% of papers reviewed. In Table 2 we summarize some defining characteristics of the four research communities and the traditions evident in the work of each community. Specifically, we summarize each community's predominant philosophical position and the methods its practitioners use to study interruptions in healthcare.

As will be seen, it is not the case that each paper embodies all aspects of the research tradition into which we categorised it, or even that the tradition can be described in unambiguous terms with which all would agree. Nor is it necessarily the case that authors whose work is cited would subscribe to all aspects of the research tradition under which their work has been categorised, or that the authors necessarily view themselves as part of a research community working within a specific research tradition. Perspectives or methods of research in one research tradition will

influence the perspectives or methods of research in another tradition, so that some papers show strong features of more than one research tradition.

Table 1. Categorisation of papers included in review

Categorisation	Number of Papers
Research Tradition	
Epidemiology (EPI)	35
Quality Improvement (QI)	27
Cognitive Systems Engineering (CSE)	21
Applied Cognitive Psychology (COG)	11
Blends of Research Traditions	
EPI+CSE	21
EPI+COG	14
CSE+COG	10
CSE+QI	2
Total	**141**

Table 2. Contrasts of characteristics and typical investigative motivations across research traditions

	Attitude Toward Interruptions	Purpose of Investigation	Context of Investigation	Primary Locus of Solutions
Epidemiology	Mostly negative	Determine burden of the problem and eradicate the problem	Observational fieldwork and quantitative analysis	Elimination of interruptions during safety critical tasks
Quality Improvement	Mostly negative	Pursue rapid change in order to improve safety	Observational fieldwork, evaluation of intervention	Elimination of interruptions during safety critical tasks using person-centred interventions
Cognitive Systems Engineering	Mixture of positive and negative	Understand the purpose of interruptions with a goal of improving work through system-based redesign	Varies widely; naturalistic studies of work and high-fidelity simulation	Interventions that redesign "joint cognitive system" between human and technological components
Applied Cognitive Psychology	Mostly negative	Understand how interruptions disrupt cognitive processes in order to protect those processes	Controlled laboratory studies	Solutions that protect cognitive processes of an individual clinician

3.1.1 Epidemiology

In the study of interruptions in healthcare within the epidemiology tradition, clinical errors are handled as if they are a 'symptom' of a process that is 'diseased'. When considering a clinician preparing and administering medication, an interruption is a potential pathogen that could compromise the viability of the work process. For this reason, in the epidemiology tradition interruptions are mostly perceived as actually or potentially negative [4,19,24–50]. Given that a hallmark of epidemiology is the use of quantitative methods involving statistical estimation or testing [51], researchers focus on finding statistical evidence for the effects of interruptions that might guide policy or justify intervention, rather than understanding the role that interruptions might play in the clinical context.

Fieldwork is universally used in epidemiology to determine the burden of interruptions, often with very large samples [4,25–27,31–33,35,36,39–41,43,45,48–50,52–55]. Epidemiology researchers identify and classify the interruptions that occur, using strict operational criteria. The researchers seek to determine: (i) the frequency of interruptions, (ii) the initiators and receivers of interruptions, (iii) the content of interruptions, and (iv) locations where the interruptions occur. Using this information, rates of interruptions per hour, per task, or per shift are calculated [4,19,24–36,38–41,43–50,52–57] and used to indicate where interruptions might pose an unacceptable risk to patients and others. Fieldwork provides an opportunity to explore the properties or contexts of interruptions that make people more prone to error [27,39,50].

Interruptions research from the epidemiology tradition is predominantly nursing- or physician-focused. The nursing-focused epidemiology research is hospital based, and examines the distribution, determinants and frequency of interruptions either to nursing tasks in general [31–33,37,40,43,52,54], or to medication related activities exclusively [4,27,28,34,36,39,46,48,49]. Exceptions to this include an examination of interruptions and distractions to Certified Registered Nurse Anesthetists during anesthesia induction [38] and self-reported tallies of the causes and occurrences of interruptions to ED triage nurses [44]. Physician-centric research in the epidemiology tradition investigates interruptions experienced by Emergency Department physicians [24,26,50], paediatric residents [29], urologists and urology residents [25], general practitioners [53],

anaesthetists [45,57], radiologists [55], or hospital physicians in general [47,56]. In a small number of studies, both nurses and physicians from a single clinical group form the sample population [30,35,42]. In summary, epidemiology brings a disease model, rigorous field methods, and quantitative techniques to interruptions research that provides a well-grounded quantitative understanding of the effects of interruptions.

3.1.2 Quality Improvement

In general terms, researchers in the quality improvement tradition are typically clinicians who are focused on changing clinical practices to improve the safety and quality of care provided to patients. For the most part, the quality improvement papers in our review report naturalistic studies conducted in the clinical environment. The nursing population was the focus of 81% of the papers in this tradition (22/27). As with the epidemiology tradition, interruptions were portrayed negatively due to their potential impact on safety. A commonly reported quality improvement initiative was the systematic elimination of interruptions during critical tasks, such as during medication administration. This initiative, borrowed from the "sterile cockpit" principle in aviation [58], prohibits staff from engaging in activity or conversation that is unrelated to the safety critical task at hand. As with many quality improvement initiatives, the focus is on the human side of change, emphasizing that staff should organise themselves individually, and as members of teams, to intercept and defer interruptions until safety critical tasks are complete [59–65].

Despite its helpful outcomes for aviation, the implementation and success of the sterile cockpit principle in the healthcare environment has led to mixed results. Quality improvement researchers reporting the successful implementation of the sterile cockpit point to improvements such as lower rates of interruptions, fewer medication errors, greater efficiency and subjective reports of greater satisfaction [64–78]. Verweij and colleagues found significant reductions in interruptions and medication administration errors after implementation of a drug round tabard; however, they note that factors other than the vests probably influenced the results, such as increased involvement from the ward managers during drug rounds who were "eager to reduce MAEs (medication administration errors) and wanted to contribute to the study" [79]. Quality improvement researchers who did not report success after implementation of the sterile cockpit

principle cited paradoxical effects (patient interruptions decreased whereas interruptions from colleagues increased) [80], resistance due to cultural acceptance of 'interruptions as part of the job' [81,82], lack of improvement versus control group [83], and the perception that the sterile cockpit principle may be incompatible with total patient-centred care [84]. An unusual paper in the quality improvement tradition is that by Stamp and Willis [85] who report using changes in interruption rates as a measure of the effectiveness of a point-of-care medication administration intervention.

Quality improvement research sometimes lacks sophisticated statistical approaches that are more typical of the epidemiology tradition. However, within the quality improvement tradition, measurement does not require precisely designed trials and large samples. Rather, the focus is on actions that are systematic and well-sustained, and that cumulatively lead to large-scale improvements [86]. As a result, change is implemented and evaluated quickly [87] often using mixed methods or with ongoing monitoring. In summary, quality improvement brings to interruptions research a tradition of clinician-led initiatives as an immediate first-line response to quality and safety issues.

3.1.3 Cognitive Systems Engineering

Cognitive Systems Engineering (CSE) emerged in the early 1980s as a response to high-profile industrial accidents such as the Three-Mile Island and Bhopal accidents. Such accidents indicated that the operation of complex, automated, technical systems presented new challenges and involved new forms of complexity for human operators and their managers [88–90]. From the earliest days, CSE's proponents have insisted that analysis should focus not on the technology alone or human alone, but on the combination of the two as a "joint cognitive system", where overall performance emerges from the interaction amongst multiple agents [91,92]. The key purpose of CSE is to redesign the interaction amongst those agents for better operation of the joint cognitive system [91,92].

Accordingly, CSE focuses on analysing how human activity is shaped by properties of the work domain itself, and on identifying how practitioners exercise knowledge and select strategies when coping with complex situations [93,94] such as those in which interruptions occur. Conceptually, CSE takes a systems approach to human work, focusing on factors from

governmental, organisational, social, cognitive, and perceptual perspectives that shape work [95]—interruptions can come from any of these levels. Amongst its many influences, CSE draws on control theory [96], ecological psychology [97–99], and European work psychology [100–102], and it shares perspectives with the proponents of distributed cognition [103], and naturalistic decision making [104,105]. Proponents of CSE argue that analysis must focus on the functions and meaning of work and that investigations must take place in the natural ecology of work where people can draw upon their full repertoire of professional knowledge and strategies to cope with complexity as it occurs [106]. Such a focus helps researchers understand the motivations for interruptions.

There are very few papers in our review that embody all the features of CSE, as described above. However, there are several papers that embody a sufficient number of those features that we have categorised those papers under CSE rather than the other traditions.

Almost all the papers categorised under CSE that report empirical findings have investigated interruptions in the naturalistic work environment [8,10,107–116]; an exception is high-fidelity simulator investigations by Prakash et al. [117]. Researchers within the CSE community acknowledge that interruptions can be positive as well as negative, which indicates an orientation towards the *content* of interruptions [8–10,13,18,107–109,111,113,115–121] and which may lead to a rich analysis of the constraints and semantics of work [10,108,109,116,120]. A subset of papers expand the view further to refer to the *purpose* of the interruption for the work context or for workflow—some clearly [10,13,18,108,109,111,114,116,118,120] and others in a more nuanced way [9,107,119]—and some papers capture the knowledge of strategies workers use to handle interruptions [10,13,107–109,112,113]. The recent emergence of resilience engineering [122] is reflected in one paper from the CSE community by noting that interruptions contribute to organisational resilience [109].

As noted, a key feature of CSE is its focus on the "joint cognitive system", but the papers reviewed still focused largely on the "interruption dyad" of interrupter and interruptee, with only occasional papers mentioning of the role of supporting artefacts and technologies [10,113] or of the interleaving of work amongst team members [9,108,115,116]. Only a subset of papers describe how agents cope with complexity [9,10,107,108,112,119]. Further key features of CSE emerging in

the interruptions papers are its focus on redesign [9,10,108,111,114,118–120] and its preference for systems-based changes to avoid the need for interruptions over person-based changes that prevent interruptions at the point where they occur [10,13,108,116,118]. In summary, CSE brings to interruptions research a broad systems approach that focuses on the functions of interruptions and on the potential for design to provide solutions where needed.

3.1.4 Applied Cognitive Psychology

Cognitive psychology is concerned with building theories of how people perceive, attend, classify, decide, reason, and remember – these are "cognitive" functions [123]. Cognitive psychologists usually focus on understanding cognition as a mental process within the human individual, rather than as simple stimulus-response associations or as a socially-mediated performance achieved by multiple agents. Inspired by developments in computer science, many cognitive psychologists have modeled the human either as a processor of information (see [124] for a summary), a manipulator of symbols [125], or as a massively parallel processing device [126]. In all cases, the focus is on developing theories and models of human cognitive functioning, highlighting its strengths and limitations. The theories have typically been developed with information gained from tightly controlled and simplified laboratory environments, with some cognitive psychologists arguing that findings from such environments are more likely to generalise than are findings generated in specific contexts [127].

The work of *applied* cognitive psychology is described under various labels, reflecting the breadth of applications that are possible: some examples are 'human-computer interaction', 'engineering psychology', 'cognitive ergonomics', 'applied cognition' and 'applied experimental psychology'. As its name suggests, applied cognitive psychology applies the above scientific values and the corpus of theory to areas of activity outside the laboratory, such as the workplace, school, police station, law courts, school, transportation, hospital and so on, or to simulations of the above with various levels of fidelity [128,129]. Topics might cover the challenges such environments pose to cognitive functions, such as attention, memory, decision making, and so on.

There is a vast literature within cognitive psychology investigating the impact of interruptions on task performance. Some of these papers refer to the actual or potential application of the findings

to healthcare [130–136]. Other papers provide excellent reviews of the impact of interruptions on performance from a cognitive psychology perspective [5,16,137,138], again referring to potential applications in healthcare. Even though the majority of these papers do not have a primary healthcare focus, we include them here so that their impact on other traditions can be better appreciated. Further papers (not detailed here) provide insights that are relevant for healthcare, without making explicit reference to healthcare. For example, laboratory studies suggest that interruptions impose demands on working memory and that people with greater working memory capacity are less susceptible to the effects of interruptions [139,140].

A universal feature of the papers in the applied cognitive psychology tradition is that they use cognitive theory to guide discussions of when and how interruptions might influence performance [5,16,130–138]. Therefore they all focus on cognition as a process internal to the individual person (but see the review in [16] which also discusses the role of artefacts in shaping cognition) and none focuses on the systemic purposes of interruptions. Theories of memory for interrupted tasks are most prominent: working memory [133,134,137,138], memory for goals [130,131,134,137], and prospective memory [5,136,137]. The empirical work reported is almost always a highly controllable laboratory task chosen more for its ability to test theory than its ability to represent a particular domain of application.

A further feature of the papers in this tradition is their exclusive focus on interruptions as potentially negative: the focus is on how interruptions disrupt cognitive *processes* rather than the role that the *content* of an interruption might play in a work context [5,16,130–138]. Following on from this, all the papers focus on the interruption dyad of interrupter and interruptee, rather than taking a broader systems perspective on the purpose of interruptions. Interventions suggested usually focus on measures that might protect the individual's cognitive processes from the disruptive effects of interruptions [5,16,130,132–138]. In summary, applied cognitive psychology brings to interruptions research a focus on studying the individual clinician's mental processes with well-controlled experiments, and on identifying factors that might disturb those processes and lead to error.

3.2   Blends – Combining Research Traditions

In the previous section some of the central themes of interruptions research within each research community have been highlighted to reflect the core values of that community. There are areas of agreement but also areas of contrast between the research communities (see Table 2). Key dimensions of comparison and contrast included whether interruptions were considered positive or negative phenomena, the purpose of the investigation into interruptions, situations or contexts in which interruptions were examined, and the locus of actual or potential solutions. In addition, as research grows in the area, researchers in some communities increasingly influence researchers in other communities, leading to a blurring of the lines of distinction between each.

A number of researchers have adopted elements of the other traditions in their own investigations. In the following examples we highlight blends of viewpoint and methodology from one tradition to another (see Figure 2). The 47 papers representing the blends pull together strengths of different areas. In the following sections we outline areas where methodological themes have started to blend.
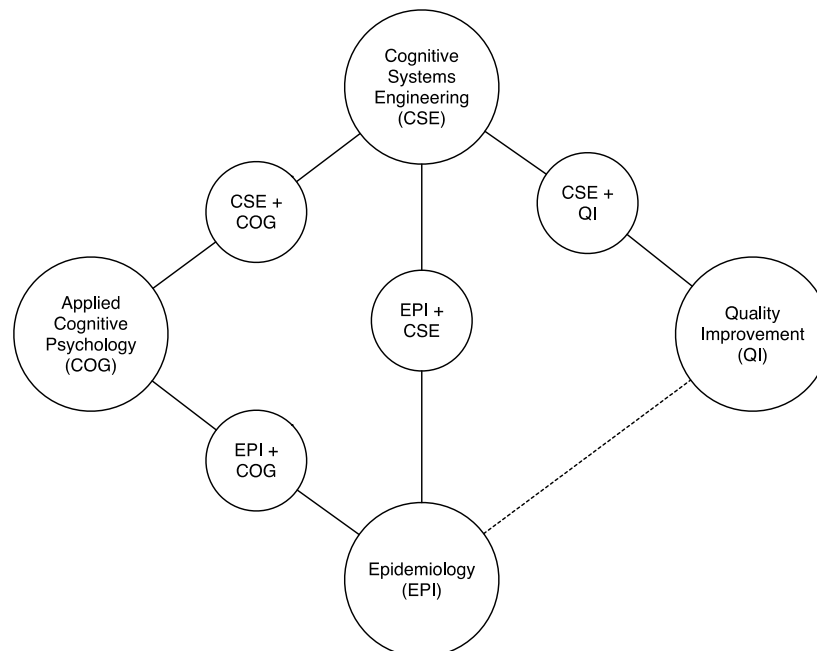

Figure 2: Influences and blends between research traditions emerging from our categorisation. Links are explained in text.

3.2.1 Epidemiology and Cognitive Systems Engineering

We identified a cluster of papers that blend aspects of the epidemiology and CSE traditions. The cluster includes papers that most strongly fit the epidemiology tradition, focusing on counts, classifications, and estimations of rates of interruptions in field contexts, but that have incorporated some of the CSE characteristics. Although the overwhelming focus in this blended cluster is one of interruptions creating the potential for error, a number of papers do note that interruptions are not always negative [14,141–154]. Within this cluster can often be found a broader discussion of the systems context in which interruptions occur [11,14,108,142–146,149,155,156]—there is a strong initial statement in Healey [144] to this effect—and an emerging focus on work semantics and practitioners' knowledge [145–148,150–152,156–158]. In addition, there is more emphasis on discussions of the communicative purpose of interruptions [142,147,150,154,155] and a focus on teams as well as individuals [143,144,153,156,159]. A notable subset of this cluster focus on interruptions to *workflow* rather than to individual people [143,144,153,156], further supporting the notion that the definition of an "interruption" depends on the research question and related processes being investigated [23].

The review by Hopkinson [14] covers many of the papers we have categorised in the epidemiology tradition, but the authors assess the evidence using characteristics typical of the CSE tradition. Not only does the review question whether causal connections have been shown, but it is also sympathetic to a systems view and, unlike many papers in the epidemiology tradition, it strongly rather than parenthetically makes the point that interruptions do not always have negative consequences. The strength of this cluster is that it blends the strong fieldwork and analytic tools of the epidemiology tradition with the functional perspective and interpretive subtlety of the CSE tradition. However there is much less emphasis on redesign than for the cluster of papers solely in the CSE tradition, with the theme of redesign appearing only weakly in a few cases [11,142,150,157,159].

3.2.2 Epidemiology and Applied Cognitive Psychology

The papers in this blended cluster are influenced primarily by epidemiology but to a minor extent also by cognitive theory. As is typical of epidemiologically-motivated research on

interruptions, almost all of the papers report observational fieldwork leading to analyses of interruption rates, rather than reporting laboratory- or simulator-based research. However, many of the papers refer to psychological constructs such as attention [160–163], working memory [160,164–168], prospective memory [169,170], as well as action regulation theory [170], and Norman's seven stages of action [171].

Most of the papers explicitly or implicitly assume that interruptions are fundamentally negative events, although some mention that interruptions can be useful or are part of a clinician's role [162,164,170–172]. A notable feature of the work by Coiera and colleagues in this cluster is the focus on communication needs being the reason for interruptions [160,161,164]. Many of the papers are motivated by a concern that interruptions to cognitive processes will cause error [160–165,169]; however, a few focus instead on the negative emotional responses to interruptions experienced by clinicians [170,172].

This cluster includes six papers not reporting observational fieldwork. Two papers report a simulator-based study on the impact of operating room distractions and interruptions; Feuerbacher and colleagues report on errors and failures of prospective memory [166], and Murji and colleagues investigated the impact of distractions on surgical performance in the form of task completion and operative blood loss [163]. Baethge et al.'s [170] diary study uses hierarchical linear modelling to suggest that mental demands and time pressure are mediating factors between interruptions and both error and irritation. Brixey and colleagues contribute a conceptual framework for describing and recording an interruption event [171] that is based on Trafton's model of interruptions as well as Norman's seven stages of action. Brixey et al.'s goal is to promote use of a shared vocabulary in interruptions research to increase generalizability and usefulness of reports. Finally, Magrabi and colleagues [168], and Walter and colleagues [173] outline frameworks for studying and measuring the impact of interruptions in healthcare. Overall, the strength of this cluster is that it provides a detailed level of analysis of the factors that contribute to people's vulnerability when interrupted in their normal work setting.

3.2.3 Cognitive Systems Engineering and Applied Cognitive Psychology

We identified a further cluster of papers that blend characteristics from the CSE and Applied Cognitive Psychology traditions. The papers are differentiated from most in the epidemiology or QI traditions by their focus on theory, but they vary according to whether they focus on theories of individual cognition or more socially distributed cognition.

In an early review of the unintended consequences of new technologies, Parker [174] notes that new technologies can interrupt established team communication patterns and impose a load on working memory. CSE themes in Parker and Coiera's paper [174] focus on the social environment of healthcare work, the recommendation for mixed-method research including ethnography, and the consideration of design options. Westbrook [175] recommends consideration of interruptions in the broader socio-technical context, and their influence on memory and attention leading to error production. Grundgeiger's [12] review invokes prospective memory theory but also Hutchins' distributed cognition [103] and calls for a better understanding of accident causation models if the impact of interruptions is to be understood—the latter reflecting the systems thinking of CSE. In a more recent review of the state of "interruption science", Coiera [17] notes the questions remaining and the need to understand clinicians' work priorities and work contexts if the impact of interruptions is to be understood, but the paper does not emphasize a systems perspective and the main concern is with the negative effect of interruptions on dyads.

Solid attempts to apply cognitive theory to interruptions are seen in reviews [15,176] that also discuss difficulties of exercising the level of experimental control in healthcare settings that would allow the theories to be extended. However trials in rich field contexts—a key feature of CSE studies—have indicated that cognitive theory can explain [177,178] and predict [179] interruption phenomena and, to a limited extent, interruption management strategies, and two further trials associate the impact of interruptions with constraints on visual attention [180,181].

3.2.4 Cognitive Systems Engineering and Quality Improvement

The most underrepresented research tradition across all of the blends is quality improvement. However, some research reports the translation into practice of design interventions that result from substantial prior CSE research. Only two papers were identified that blended key

dimensions of both CSE and quality improvement. In a mixed-methodology case study, Colligan and colleagues [182] aimed to design an inexpensive, system-based intervention that would naturally reduce interruptions without introducing new error-prone processes. The paper reports three phases of research: (1) evaluation of the existing medication station and tasks required for safe medication preparation, (2) design of the intervention; and (3) collection of pre- and post-intervention data to determine intervention effectiveness. Similarly, a paper by Sasangohar and colleagues [183] also reported a successful design intervention that resulted from substantial prior CSE research. It is notable that both papers representing this blend are recent, published in 2012 and 2015 respectively, highlighting the infancy of this blend.

Some papers in the review that we categorised as epidemiological in motivation also had quality improvement characteristics. These papers suggested possible interventions to reduce interruptions, but the researchers' primary focus was on the frequency, determinants and distribution of interruptions [31–33,36–38]. The connection between the epidemiology and quality improvement traditions is therefore indicated with a dotted line in Figure 2.

3.3 Key Questions in Interruptions Research

Several common interruptions research questions were posed by the varying traditions and blends (see Table 3). The most commonly asked question by researchers across multiple communities was (Q3): what is the impact of interruptions? Researchers measured impact as a function of task time or risk in the epidemiology tradition, situation awareness in the CSE tradition, or resumption lag (time to resume an interrupted task) in the applied cognitive psychology tradition. A related, but more specific, commonly asked question was (Q3a): is there evidence of a relationship between interruptions and error? Table 3 shows that no single question about interruptions in healthcare was shared by all four of the core traditions.

4 Discussion

Our review of different traditions underlying interruptions research in healthcare has exposed for the first time the many different motivations, methods, and messages that exist in the interruptions literature. As a reading of Hopkinson and Jennings [14] would suggest, an important factor discriminating different traditions of research into interruptions in healthcare was researchers'

assumptions about whether or not interruptions are fundamentally negative. However, we found many further factors discriminating different research traditions motivating research into interruptions in healthcare.

4.1 Implications for Interruptions Investigations in Healthcare

In response to Hopkinson and Jennings' [14] call to remove bias from research into interruptions in healthcare, we argue that investigations and deliberations cannot be completely free of bias. However, a greater awareness of the role that research traditions play in framing investigations will certainly help researchers detect assumptions, interpret apparent inconsistencies, and seize opportunities to close gaps.

The implications of our findings are two-fold and important for the ongoing development of the field. First, when reading the literature, researchers might contemplate which research tradition, or which blend of research traditions, guides the research. Researchers can then determine the strengths and limitations of the research being reported, along with what might be missing, based on the aim of the paper. Second, in planning and executing their own investigations, researchers can refer to the perspectives and methods from other research traditions to ask whether their own research could be enriched by embracing those perspectives and methods.

We do not propose that researchers should try to encompass all traditions or perspectives in their research—indeed that is probably impossible. Nor do we propose that research that blends aspects of different research traditions is inherently better than research performed closely within a tradition. By exposing the motivations and theoretical commitments, and relating them to underlying research traditions, we hope to provide a language that researchers can use to describe, compare, and contrast research outcomes more effectively.

Table 3. Common interruptions research questions as posed by traditions and blends of traditions

	Q1. Why do interruptions occur?	Q2. What is the current state of interruptions?	Q3. What is the impact of interruptions?	Q3a. Is there evidence of a relationship between interruptions and error?	Q4. Are interventions successful at reducing negative effects of interruptions?
Research Tradition					
Epidemiology	[31]	[24,28,44,46–49,53,57]	[25,26,29,30,32–34,42,43,45]	[27,41]	
Quality Improvement	[85]				[65–71,73,74,76–84]
Cognitive Systems Engineering	[109,111,113,116]	[118]	[107]	[117,180]	[117]
Applied Cognitive Psychology			[131,132,134]		[133,135]
Blends					
EPI+CSE	[142,149,151]	[141,143,146,148]	[147,150]	[145,156]	
EPI+COG		[172]	[162,167,169]	[166]	
CSE+COG			[175,178,181]		
CSE+QI					[182,183]

Researchers working within each of the identified traditions have made important advances in understanding interruptions. For example, epidemiology methods may indicate the clinical tasks or locations where interruptions seem to be particularly prevalent, and may provide quantitative information about personnel and tasks involved. CSE researchers can use those results to guide more focused investigations to understand why those interruptions occur—the functions they serve and the organisational challenges they reflect. The insights that CSE researchers uncover may then provide a more solid basis for quality improvement researchers to decide whether or not to intervene. A research investigation based in the epidemiology tradition and focused on assessing the burden of interruptions may operationalize the term "burden" as a demand for excessive services or resources in a healthcare system. Applied cognitive psychology can extend the assessment by offering ways to measure the cognitive or emotional burden of interruptions once they have occurred.

Research investigations that blend motivations, methods and messages from different research traditions reflect the complexity of the phenomenon and the context in which it occurs, and they reflect the value researchers see in other research traditions. It is evident from Figure 2 that we found clusters of papers within the epidemiology, CSE or applied cognitive psychology research traditions that drew upon characteristics of one of the other traditions. However, we did not find substantial clusters of papers representing blends between the quality improvement research tradition and other traditions. On the one hand, this may reflect a missed opportunity for quality improvement. On the other hand, it may be unsurprising, given that researchers in the quality improvement community focus on rapid translation of findings into practice through interventions that address interruptions. Some researchers have argued that interventions can be improved by combining different methodological approaches [184], but adopting methods or principles from other traditions may take too long or it may require an inappropriate focus on a very specific research question [87] or a level of control that is unachievable in practice. Nonetheless, it is important that interactions between the quality improvement community and other researchers studying interruptions in healthcare should grow. Clinician-led quality

improvement research is closest to patient care and clinician-scientists often know how best to convert the latest research findings into practice [87].

Below we elaborate on some of the key questions in interruptions research and contrast how researchers in different research traditions have addressed them. Finally we provide some examples of how researchers might introduce aspects of research traditions beyond their own to answer key research questions about interruptions.

4.2   Key Questions and Perspectives

There has been a lack of overlap across all research traditions and questions as outlined in Table 3; this clearly demonstrates that each research tradition has particular questions it deems legitimate or answerable. For example, researchers in the applied cognitive psychology research tradition have not explored the question of why interruptions occur in the healthcare workplace. This is because researchers in the applied cognitive psychology tradition focus on individual cognitive processes [140] rather than the socially-mediated performance achieved by multiple agents. This reinforces our view that pre-existing beliefs guide researchers towards certain questions, therefore influencing how their research is operationalized.

To illustrate the interplay of research traditions and questions when addressing interruptions, we highlight three areas of focus in interruptions research—the relationship between interruptions and undesirable outcomes (Q3a), the issue of what needs to be understood about interruptions to decide how to handle them, and the question of whether interventions generalise across contexts (Q4).

First, there is a tension across research traditions in the degree to which interruptions are held to "cause" undesirable outcomes. If interruptions could be shown to "cause" undesirable outcomes with an unacceptable level of regularity, then handling them is clear—reduce interruptions. The applied cognitive psychology research tradition offers process theories of how interruptions lead to cognitive failures. However, healthcare is a complex work domain with many factors at play. As a result, the evidence for a direct causal connection between interruptions and undesirable outcomes is not strong [12,14,15]. Large-scale studies in the epidemiology research tradition have demonstrated that statistical associations between interruptions and undesirable

outcomes exist, but the mediating and moderating factors that make undesirable outcomes more likely or less likely are difficult to identify [173]. Until more is known about the latter issue, interventions to suppress interruptions rather than to control the mediating and moderating factors may be misguided. For quality improvement research communities wanting to increase patient safety and improve outcomes, it may be more effective to support resilience and buffer the consequences of interruptions. The CSE research tradition offers strategies for both the latter.

Second, different research traditions have contributed to what is known about interruptions, and what needs to be known to decide how to handle them. Research in the epidemiology tradition has provided basic quantitative information at the so-called "sharp end" of an interruption – who is more likely to interrupt whom, and tasks that are more likely to be interrupted than others. A key concern has been the potential negative impact of interruptions on the cognitive processes of the interrupted person—a natural concern from the perspective of applied cognitive psychology. Recent work has moved closer to representing the relevance of the content of interruptions for people's tasks by classifying interruptions as positive vs. negative, or necessary vs. unnecessary for the interrupted person [8,109,150]. Such classifications have emerged from the more interpretive research typical of the quality improvement and CSE research traditions, and they are needed as a first step before interventions can be considered. They have led researchers to considering the value or necessity of an interruption for the interrupting person, as well as for the interrupted person. Intervention strategies must weigh the needs of both parties, and must weigh their ability to complete not only current tasks, but also future tasks. However, the "stopping rule" for considering the positive vs. negative impact of an interruption is still unclear. CSE can offer conceptual tools for analysing the functions of interruptions for organisational stakeholders, but it offers little perspective on the level of organisational risk—a perspective more likely to be offered by tools within the epidemiology tradition.

Third, after recognising a potential risk, can quality improvement researchers successfully implement solutions that appear to have worked elsewhere? As noted, attempts to apply the "sterile cockpit" principle have not always been successful or sustainable. It is very hard to predict the full impact of design interventions in complex work organisations—this has been termed the

"envisioned worlds" problem [185]. The impact of changes is highly conditioned by the individual work contexts. Small differences in work practices may render some interventions ineffective or even counterproductive. Another approach, originating in the applied cognitive psychology tradition, is to train people in strategies for handling interruptions more effectively, both in terms of managing their own cognitive vulnerabilities more effectively, and evaluating the vulnerabilities of others' cognitive tasks more accurately [131]. Such training has been successful in laboratory contexts, but it may be impractical to introduce to the field, given the amount of theoretical awareness required and the greater complexity of tasks in healthcare than in the laboratory. Likewise, non-invasive brain stimulation has been found to significantly decrease resumption lag after a task is interrupted [133], but such methods would undoubtedly be unsuitable in the field for ethical and practical reasons.

4.3   Conclusion

We have identified different research traditions motivating and enabling the study of interruptions in healthcare. Researchers have conceptualized and studied interruptions in ways that are inextricably linked to their pre-existing biases and beliefs, and much research on interruptions in healthcare can be discriminated in terms of fundamental values of distinct research communities. However we have also identified gaps and opportunities, as well as investigations indicating mutual influence between research traditions. The purpose of this review was not to promote the tenets of a single research tradition or to propose that all perspectives should be combined or bias removed, but to offer an opportunity for those studying interruptions to contemplate and question their own assumptions, and to remain open to opportunities offered by other perspectives and methods when addressing some of the difficult questions in interruption research.

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References

1   Fuqua RA, Stevens KR. What we know about medication errors: A literature review. *J Nurs Qual Assur* 1988;**3**:1–17.

2   Scholz DA. Establishing and monitoring an edemic medication error rate. *J Nurs Qual Assur* 1990;**4**:71–85.

3   Walters JA. Nurses' perceptions of reportable medication errors and factors that contribute to their occurrence. *Appl Nurs Res* 1992;**5**:86–8. doi:10.1016/S0897-1897(05)80019-9

4   Elganzouri ES, Standish CA, Androwich I. Medication Administration Time Study (MATS): nursing staff performance of medication administration. *J Nurs Adm* 2009;**39**:204–10. doi:10.1097/NNA.0b013e3181a23d6d

5   Dismukes RK. Prospective Memory in workplace and everyday situations. *Curr Dir Psychol Sci* 2012;**21**:215–20. doi:10.1177/0963721412447621

6   Elfering A, Grebner S, Ebener C. Workflow interruptions, cognitive failure and near-accidents in health care. *Psychol Health Med* 2014;**20**:139–47. doi:10.1080/13548506.2014.913796

7   Dearden A, Smithers M, Thapar A. Interruptions during general practice consultations - The patients' view. *Fam Pract* 1996;**13**:166–9. doi:10.1093/fampra/13.2.166

8   Sasangohar F, Donmez B, Trbovich P, *et al.* Not all interruptions are created equal: Positive interruptions in healthcare. *Proc Hum Factors Ergon Soc Annu Meet* 2012;**56**:824–8. doi:10.1177/1071181312561172

9   Walji M, Brixey J, Johnson-Throop K, *et al.* A theoretical framework to understand and engineer persuasive interruptions. *Proc Twenty-Sixth Annu Conf Cogn Sci Soc* 2004;:1417–22.

10   Laxmisan A, Hakimzada F, Sayan OR, *et al.* The multitasking clinician: Decision-making and cognitive demand during and after team handoffs in emergency care. *Int J Med Inform* 2007;**76**:801–11. doi:10.1016/j.ijmedinf.2006.09.019

11   Biron AD, Lavoie-Tremblay M, Loiselle CG. Characteristics of work interruptions during medication administration. *J Nurs Scholarsh* 2009;**41**:330–6. doi:10.1111/j.1547-5069.2009.01300.x

12   Grundgeiger T, Sanderson P. Interruptions in healthcare: theoretical views. *Int J Med Inform* 2009;**78**:293–307. doi:10.1016/j.ijmedinf.2008.10.001

13   Rivera-Rodriguez AJ, Karsh B-T. Interruptions and distractions in healthcare: review and

reappraisal. *Qual Saf Health Care* 2010;**19**:304–12. doi:10.1136/qshc.2009.033282

14   Hopkinson SG, Jennings BM. Interruptions during nurses' work: A state-of-the-science review. *Res Nurs Health* 2013;**36**:38–53. doi:10.1002/nur.21515

15   Li SYW, Magrabi F, Coiera E. A systematic review of the psychological literature on interruption and its patient safety implications. *J Am Med Inform Assoc* 2011;**19**:6–12. doi:10.1136/amiajnl-2010-000024

16   Boehm-Davis DA, Remington R. Reducing the disruptive effects of interruption: a cognitive framework for analysing the costs and benefits of intervention strategies. *Accid Anal Prev* 2009;**41**:1124–9. doi:10.1016/j.aap.2009.06.029

17   Coiera E. The science of interruption. *BMJ Qual Saf* 2012;**21**:357–60. doi:10.1136/bmjqs-2012-000783

18   Westbrook JI. Interruptions to clinical work: How frequent is too frequent? 2013;:337–9. doi:10.1136/bmjqs-2012-000783.12

19   Raban MZ, Westbrook JI. Are interventions to reduce interruptions and errors during medication administration effective?: a systematic review. *BMJ Qual Saf* 2013;:414–21. doi:10.1136/bmjqs-2013-002118

20   Greenhalgh T, Robert G, MacFarlane F, *et al.* Storylines of research in diffusion of innovation: A meta-narrative approach to systematic review. *Soc Sci Med* 2005;**61**:417–30. doi:10.1016/j.socscimed.2004.12.001

21   Greenhalgh T, Potts HWW, Wong G, *et al.* Tensions and paradoxes in electronic patient record research: A systematic literature review using the Meta-narrative Method. *Milbank Q* 2009;**87**:729–88. doi:10.1111/j.1468-0009.2008.00538.x

22   Kuhn TS. *The Structure of Scientific Revolutions*. 1970. doi:10.1119/1.1969660

23   Grundgeiger T, Dekker S, Sanderson P, *et al.* Obstacles to research on the effects of interruptions in healthcare. *BMJ Qual Saf* 2015;:bmjqs – 2015–004083. doi:10.1136/bmjqs-2015-004083

24   Allard J, Wyatt J, Bleakley A, *et al.* 'Do you really need to ask me that now?': a self-audit of interruptions to the 'shop floor' practice of a UK consultant emergency physician. *Emerg Med J* 2012;**29**:872–6. doi:10.1136/emermed-2011-200218

25   Persoon MC, Broos HJHP, Witjes JA, *et al.* The effect of distractions in the operating room during endourological procedures. *Surg Endosc Other Interv Tech* 2011;**25**:437–43. doi:10.1007/s00464-010-1186-8

26   Westbrook JI, Coiera E, Dunsmuir WTM, *et al.* The impact of interruptions on clinical task completion. *Qual Saf Health Care* 2010;**19**:284–9. doi:10.1136/qshc.2009.039255

27   Westbrook JI, Woods A, Rob MI, *et al.* Association of interruptions with an increased risk and severity of medication administration errors. *Arch Intern Med* 2010;**170**:683–90. doi:10.1001/archinternmed.2010.65

28   Kosits L, Jones K. Interruptions experienced by registered nurses working in the emergency department. *J Emerg Nurs* 2011;**37**:3–8. doi:10.1016/j.jen.2009.12.024

29   Blum NJ, Lieu TA. Interrupted care. The effects of paging on pediatric resident activities. *Am J Dis Child* 1992;**146**:806–8.

30   Brixey JJ, Tang Z, Robinson DJ, *et al.* Interruptions in a level one trauma center: A case study. *Int J Med Inform* 2008;**77**:235–41. doi:10.1016/j.ijmedinf.2007.04.006

31   McGillis Hall L, Pedersen C, Fairley L. Losing the moment: understanding interruptions to nurses' work. *J Nurs Adm* 2010;**40**:169–76. doi:10.1097/NNA.0b013e3181d41162

32   McGillis Hall L, Ferguson-Paré M, Peter E, *et al.* Going blank: Factors contributing to interruptions to nurses' work and related outcomes. *J Nurs Manag* 2010;**18**:1040–7. doi:10.1111/j.1365-2834.2010.01166.x

33   McGillis Hall L, Pedersen C, Hubley P, *et al.* Interruptions and pediatric patient safety. *J Pediatr Nurs* 2010;**25**:167–75. doi:10.1016/j.pedn.2008.09.005

34   Trbovich P, Prakash V, Stewart J, *et al.* Interruptions during the delivery of high-risk medications. *J Nurs Adm* 2010;**40**:211–8.

35   Randmaa M, Mårtensson G, Swenne CL, *et al.* An observational study of postoperative handover in anesthetic clinics; The content of verbal information and factors influencing receiver memory. *J PeriAnesthesia Nurs* 2015;**30**:105–15. doi:10.1016/j.jopan.2014.01.012

36   Palese A, Sartor A, Costaperaria G, *et al.* Interruptions during nurses' drug rounds in surgical wards: Observational study. *J Nurs Manag* 2009;**17**:185–92. doi:10.1111/j.1365-2834.2007.00835.x

37   Redding D, Robinson S. Interruptions and geographic challenges to nurses' cognitive workload. *J Nurs Care Qual* 2009;**24**:194–200; quiz 201–2. doi:10.1097/01.NCQ.0000356908.72205.5e

38   Pape TM, Dingman SK. Interruptions and distractions during anesthesia induction: a pilot study. *Plast Surg Nurs* 2011;**31**:49–56. doi:10.1097/PSN.0b013e31821b5b84

39   Scott-Cawiezell J, Pepper GA, Madsen RW, *et al.* Nursing home error and level of staff credentials. *Clin Nurs Res* 2007;**16**:72–8. doi:10.1177/1054773806295241

40   Kalisch BJ, Aebersold M. Interruptions and multitasking in nursing care. *Jt Comm J Qual Patient Saf* 2010;**36**:126–32.

41   Flynn EA, Barker KN, Gibson JT, *et al.* Impact of interruptions and distractions on dispensing errors in an ambulatory care pharmacy. *Am J Heal Pharm* 1999;**56**:1319–25.

42   Sevdalis N, Forrest D, Undre S, *et al.* Annoyances, disruptions, and interruptions in surgery: The Disruptions in Surgery Index (DiSI). *World J Surg* 2008;**32**:1643–50. doi:10.1007/s00268-008-9624-7

43   Cole G, Stefanus D, Gardner H, *et al.* The impact of interruptions on the duration of nursing interventions: a direct observation study in an academic emergency department. *BMJ Qual Saf* 2015;:bmjqs – 2014–003683. doi:10.1136/bmjqs-2014-003683

44   Johnson KD, Motavalli M, Gray D, *et al.* Causes and occurrences of interruptions during ED triage. *J Emerg Nurs* 2014;**40**:434–9. doi:10.1016/j.jen.2013.06.019

45   Jothiraj H, Howland-Harris J, Evley R, *et al.* Distractions and the anaesthetist: A qualitative study of context and direction of distraction. *Br J Anaesth* 2013;**111**:477–82. doi:10.1093/bja/aet108

46   Kreckler S, Catchpole K, Bottomley M, *et al.* Interruptions during drug rounds: an observational study. *Br J Nurs* 2008;**17**:1326–30.

47   Weigl M, Müller A, Zupanc A, *et al.* Hospital doctors' workflow interruptions and activities: an observation study. *BMJ Qual Saf* 2011;**20**:491–7. doi:10.1136/bmjqs.2010.043281

48   Lee LY, Tiu MM, Charm CY, *et al.* An observational study on work interruptions during medication administration in residential care homes for older people. *J Clin Nurs* 2015;:1–4. doi:10.1111/jocn.12966

49   Duruk N. Interruption of the medication preparation process and an examination of factors causing interruptions. *J Nurs Manag* 2015;:1–8. doi:10.1111/jonm.12331

50   Raban MZ, Walter SR, Douglas HE, *et al.* Measuring the relationship between interruptions, multitasking and prescribing errors in an emergency department: a study protocol. *BMJ Open* 2015;**5**:e009076. doi:10.1136/bmjopen-2015-009076

51   Broeck J van den, Brestoff JR. *Epidemiology: principles and practical guidelines*. Dordrecht; New York: : Springer 2013. doi:10.1007/978-94-007-5989-3

52   Westbrook JI, Duffield C, Li L, *et al.* How much time do nurses have for patients? A

longitudinal study quantifying hospital nurses' patterns of task time distribution and interactions with health professionals. *BMC Health Serv Res* 2011;**11**:319. doi:10.1186/1472-6963-11-319

53   Shvartzman P, Antonovsky A. The interrupted consultation. *Fam Pract* 1992;**9**:219–21.

54   Dante A, Andrigo I, Barone F, *et al.* Occurrence and duration of interruptions during nurses' work in surgical wards: Findings from a multicenter observational study. *J Nurs Care Qual* 2016;**31**:174–82. doi:10.1097/NCQ.0000000000000159

55   Ratwani RM, Wang E, Fong A, *et al.* A human factors approach to understanding the types and sources of interruptions in radiology reading rooms. *J Am Coll Radiol* 2016;:1–4. doi:10.1016/j.jacr.2016.02.017

56   Westbrook JI, Ampt A, Kearney L, *et al.* All in a day's work: an observational study to quantify how and with whom doctors on hospital wards spend their time. *MJA* 2008;**188**.

57   Schulte TE, Roberts EK, Birch K, *et al.* Assessing electronic interruptions experienced by an anesthesiology clinical director. *J Clin Anesth* 2016;**34**:658–60. doi:10.1016/j.jclinane.2016.07.004

58   FAA. Flight crewmember duties. ;:Sec. 121.542.

59   Davis NM. Concentrating on interruptions. *Am J Nurs* 1994;**94**:14.

60   Beyea SC. Distractions, interruptions, and patient safety. 2007;**86**:109–11.

61   Hohenhaus SM, Powell SM. Distractions and interruptions: Development of a healthcare sterile cockpit. *Newborn Infant Nurs Rev* 2008;**8**:108–10. doi:10.1053/j.nainr.2008.03.012

62   Capasso V, Johnson M. Improving the medicine administration process by reducing interruptions. *J Healthc Manag* 2012;**57**:384–90.

63   Clark GJ. Strategies for preventing distractions and interruptions in the OR. *AORN J* 2013;**97**:702–7. doi:10.1016/j.aorn.2013.01.018

64   Connor JA, Ahern JP, Cuccovia B, *et al.* Implementing a distraction-free practice with the Red Zone Medication Safety initiative. *Dimens Crit Care Nurs* 2016;**35**:116–24. doi:10.1097/DCC.0000000000000179

65   Flynn F, Evanish JQ, Fernald JM, *et al.* Progressive care nurses improving patient safety by limiting interruptions during medication administration. *Crit Care Nurse* 2016;**36**.

66   Relihan E, O'Brien V, O'Hara S, *et al.* The impact of a set of interventions to reduce interruptions and distractions to nurses during medication administration. *Qual Saf Health Care* 2010;**19**:e52. doi:10.1136/qshc.2009.036871

67   Klejka DE. Shhh! Conducting a Quiet Zone pilot study for medication safety. *Nursing (Lond)* 2012;**42**:18. doi:10.1097/01.NURSE.0000418623.06842.59

68   West P, Sculli G, Fore A, *et al.* Improving patient safety and optimizing nursing teamwork using crew resource management techniques. *JONA J Nurs Adm* 2012;**42**:15–20. doi:10.1097/NNA.0b013e31823c17c7

69   Nguyen EE, Connolly PM, Wong V. Medication safety initiative in reducing medication errors. *J Nurs Care Qual* 2010;**25**:224–30. doi:10.1097/NCQ.0b013e3181ce3ae4

70   Freeman R, McKee S, Lee-Lehner B, *et al.* Reducing Interruptions to Improve Medication Safety. *J Nurs Care Qual* 2012;**28**:1. doi:10.1097/NCQ.0b013e318275ac3e

71   Fore AM, Sculli GL, Albee D, *et al.* Improving patient safety using the sterile cockpit principle during medication administration: A collaborative, unit-based project. *J Nurs Manag* 2013;**21**:106–11. doi:10.1111/j.1365-2834.2012.01410.x

72   Conrad C, Fields W, McNamara T, *et al.* Medication room madness: calming the chaos. *J Nurs Care Qual* 2010;**25**:137–44. doi:10.1097/NCQ.0b013e3181c3695d

73   Thomas I, Nicol L, Regan L, *et al.* Driven to distraction : a prospective controlled study of a simulated ward round experience to improve patient safety teaching for medical students. 2014;:1–8. doi:10.1136/bmjqs-2014-003272

74   Anthony K, Wiencek C, Bauer C, *et al.* No interruptions please: Impact of a no interruption zone on medication safety in intensive care units. *Crit Care Nurse* 2010;**30**:21–9. doi:10.4037/ccn2010473

75   Kliger J, Singer S, Hoffman F, *et al.* Spreading a medication administration intervention organizationwide in six hospitals. *Jt Comm J Qual Patient Saf* 2012;**38**:51–60.

76   Pape TM. Applying airline safety practices to medication administration. *Medsurg Nurs* 2003;**12**:77–93; quiz 94.

77   Pape TM, Guerra DM, Muzquiz M, *et al.* Innovative approaches to reducing nurses' distractions during medication administration. *J Contin Educ Nurs* 2005;**36**:108–16; quiz 141–2.

78   Craig J, Clanton F, Demeter M. Reducing interruptions during medication administration: the White Vest study. *J Res Nurs* 2014;**19**:248–61. doi:10.1177/1744987113484737

79   Verweij L, Smeulers M, Maaskant JM, *et al.* Quiet please! Drug round tabards: Are they effective and accepted? A mixed method study. *J Nurs Scholarsh* 2014;**46**:340–8. doi:10.1111/jnu.12092

80   Tomietto M, Sartor A, Mazzocoli E, *et al.* Paradoxical effects of a hospital-based, multi-intervention programme aimed at reducing medication round interruptions. *J Nurs Manag* 2012;**20**:335–43. doi:10.1111/j.1365-2834.2012.01329.x

81   Peleg R, Froimovici M, Peleg A, *et al.* Interruptions to the physician-patient encounter: An intervention program. *Isr Med Assoc J* 2000;**2**.

82   Federwisch M, Ramos H, Adams SC. The sterile cockpit: an effective approach to reducing medication errors? *Am J Nurs* 2014;**114**:47–55. doi:10.1097/01.NAJ.0000443777.80999.5c

83   Weigl M, Hornung S, Glaser J, *et al.* Reduction of hospital physicians' workflow interruptions: A controlled unit-based intervention study. *J Healthc Eng* 2012;**3**.

84   Nelms T, Jones J, Treiber L. A study to reduce medication administration errors using Watson's Caring Theory. *Int J Hum Caring* 2011;**15**.

85   Stamp KD, Willis DG. Nurse interruptions pre- and postimplementation of a point-of-care medication administration system. *J Nurs Care Qual* 2010;**25**:231–9. doi:10.1097/NCQ.0b013e3181d4a13f

86   Berwick DM. A primer on leading the improvement of systems. *BMJ Br Med J* 1996;**312**:619–22. doi:10.1136/bmj.312.7031.619

87   Powell K. Nursing research: Nurses know best. *Nature* 2015;**522**:507–9. doi:10.1038/nj7557-507a

88   Hollnagel E, Woods DD. Cognitive Systems Engineering: New wine in new bottles. *Int J Man Mach Stud* 1983;**18**:583–600. doi:10.1016/S0020-7373(83)80034-0

89   Rasmussen J. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. North-Holl. Elsevier Science Inc. 1986.

90   Woods DD, Roth EM. Cognitive Engineering: Human Problem Solving With Tools. *Hum Factors J Hum Factors Ergon Soc* 1988;**30**:415–30. doi:10.1177/001872088803000404

91   Hollnagel E, Woods DD. *Joint cognitive systems: Foundations of cognitive systems engineering*. Boca Raton, FL: : CRC Press / Taylor & Francis 2005.

92   Woods DD, Hollnagel E. *Joint cognitive systems: Patterns in cognitive systems engineering*. Boca Raton, FL: : CRC Press / Taylor & Francis 2006.

93   Rasmussen J, Pejtersen AM, Goodstein LP. *Cognitive Systems Engineering*. New York: : Wiley-Interscience 1994.

94   Vicente KJ. *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-*

Based Work. Mahwah, NJ: : Lawrence Erlbaum Associates, Inc. 1999.

95   Vicente KJ. From patients to politicians: a cognitive engineering view of patient safety. *Qual Saf Health Care* 2002;**11**:302–4.

96   Jagacinski RJ, Flach JM. *Control theory for humans: Quantitative approaches to modeling performance*. Mahwah, NJ: : Lawrence Erlbaum Associates 2003.

97   Brunswik E. *Perception and the Representative Design of Psychological Experiments*. Berkeley and Los Angeles, California: : University of California Press 1956.

98   Gibson JJ. *The Ecological Approach to Visual Perception*. Boston: : Houghton Mifflin 1979.

99   Flach JM (Ed), Hancock PA (Ed), Caird J (Ed), *et al. Global perspectives on the ecology of human–machine systems*. Hillsdale, NJ: : England: Lawrence Erlbaum Associates, Inc 1995.

100   Grosdeva T, de Montmollin M. Reasoning and knowledge of nuclear power plant operators in case of accidents. *Appl Ergon* 1994;**25**:305–9. doi:10.1016/0003-6870(94)90045-0

101   Leplat J. Skills and tacit skills: A psychological perspective. *Appl Psychol* 1990;**39**:143–54. doi:10.1111/j.1464-0597.1990.tb01042.x

102   Leplat J, Rasmussen J. Analysis of human errors in industrial incidents and accidents for improvement of work safety. *Accid Anal Prev* 1984;**16**:77–88. doi:10.1016/0001-4575(84)90033-2

103   Hutchins E. *Cognition in the Wild*. Cambridge, MA: : MIT Press 1995.

104   Klein GA. *Decision making in action: models and methods*. Norwood, N.J: : Ablex Pub 1993.

105   Klein G. Naturalistic decision making. *Hum Factors* 2008;**50**:456–60. doi:10.1518/001872008X288385.

106   Rasmussen J, Lind M. Coping with Complexity. Roskilde, Denmark: 1981.

107   Sitterding MC, Ebright P, Broome M, *et al.* Situation Awareness and interruption handling during medication administration. *West J Nurs Res* 2014;**36**:891–916. doi:10.1177/0193945914533426

108   Tucker AL, Spear SJ. Operational failures and interruptions in hospital nursing. *Health Serv Res* 2006;**41**:643–62. doi:10.1111/j.1475-6773.2006.00502.x

109   Rivera AJ. A socio-technical systems approach to studying interruptions: Understanding the interrupter's perspective. *Appl Ergon* 2014;**45**:747–56. doi:10.1016/j.apergo.2013.08.009

110   Ebright PR, Patterson ES, Chalko B a, *et al.* Understanding the complexity of registered nurse work in acute care settings. *J Nurs Adm* 2003;**33**:630–8. doi:10.1097/00005110-200312000-00004

111   Nguyen V, Okafor N, Zhang J, *et al.* Using TURF to understand the functions of interruptions. In: *AMIA Annu Symp Proc.* 2014. 917–23.

112   Colligan L, Bass EJ. Interruption handling strategies during paediatric medication administration. *BMJ Qual Saf* 2012;**21**:912–7. doi:10.1136/bmjqs-2011-000292

113   Yang Y, Rivera AJ. An observational study of hands-free communication devices mediated interruption dynamics in a nursing work system. *Heal Policy Technol*;:1–9. doi:10.1016/j.hlpt.2015.08.003

114   Srinivas P, Faiola A, Mark G. Designing guidelines for mobile health technology: Managing notification interruptions in the ICU. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.* 2016. 4502–8. doi:10.1145/2858036.2858553

115   Berg LM, Källberg AS, Ehrenberg A, *et al.* Factors influencing clinicians' perceptions of interruptions as disturbing or non-disturbing: A qualitative study. *Int Emerg Nurs* 2015;:1–6. doi:10.1016/j.ienj.2016.01.003

116   McCurdie T, Sanderson P, Aitken LM, *et al.* Two sides to every story: The Dual Perspectives Method for examining interruptions in healthcare. *Appl Ergon* 2017;**58**:S115–8. doi:10.1016/j.apergo.2016.05.012

117   Prakash V, Koczmara C, Savage P, *et al.* Mitigating errors caused by interruptions during medication verification and administration: interventions in a simulated ambulatory chemotherapy setting. *BMJ Qual Saf* 2014;:1–10. doi:10.1136/bmjqs-2013-002484

118   Hillel G, Vicente KJ. Nursing interruptions in a post-anesthetic care unit: A field study. In: *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting.* 2003. 1443–7.

119   Walji M, Johnson-Throop K, Malin JT, *et al.* The case for persuasive interruptions in healthcare. In: Fieschi M, ed. *MEDINFO 2004.* Amsterdam: : IOS Press 2004.

120   Werner NE, Holden RJ. Interruptions in the wild: Development of a sociotechnical systems model of interruptions in the emergency department through a systematic review. *Appl*

Ergon 2015;**51**:244–54. doi:10.1016/j.apergo.2015.05.010

121   Hayes C, Power T, Davidson PM, *et al.* Interruptions and medication: Is 'Do not disturb' the answer? *Contemp Nurse* 2014;**47**:3–6. doi:10.1017/CBO9781107415324.004

122   Hollnagel E, Woods DD, Leveson NG. *Resilience engineering: concepts and precepts.* Burlington, VT; Aldershot, England: : Ashgate 2006.

123   Anderson J. *Cognitive Psychology and its Implications.* Third Edit. New York: : Freeman 1990.

124   Lachman R, Lachman JL, Butterfield EC. *Cognitive Psychology and Information Processing: An Introduction.* Hillsdale, NJ: : Lawrence Erlbaum Associates 1979.

125   Newell A, Simon HA. *Human problem solving.* Prentice-Hall 1972.

126   Rumelhart DE, McClelland JL. Interative Processing Through Spreading Activation. In: Lesgold AM, Perfetti CA, eds. *Interactive Processes in Reading.* Hillsdale, NJ: : Lawrence Erlbaum Associates 1981. 37–60.

127   Banaji MR, Crowder RG. The bankruptcy of everyday memory. *Am Psychol* 1989;**44**:1185–93.

128   Hoffman RR, Deffenbacher KA. A brief history of applied cognitive psychology. *Appl Cogn Psychol* 1992;**6**:1–48. doi:10.1002/acp.2350060102

129   Wright DB. Issues for applied cognitive psychology. *Theory Psychol* 1996;**6**:287–91. doi:10.1177/0959354396062005

130   Brumby DP, Cox AL, Back J, *et al.* Recovering from an interruption: investigating speed-accuracy trade-offs in task resumption behavior. *J Exp Psychol Appl* 2013;**19**:95–107. doi:10.1037/a0032696

131   Monk CA, Trafton JG, Boehm-Davis DA. The effect of interruption duration and demand on resuming suspended goals. *J Exp Psychol Appl* 2008;**14**:299–313. doi:10.1037/a0014402

132   Nees MA, Fortna A. A comparison of human versus virtual interruptions. *Ergonomics* 2015;**58**:852–6. doi:10.1080/00140139.2014.990934

133   Blumberg EJ, Foroughi CK, Scheldrup MR, *et al.* Reducing the disruptive effects of interruptions with noninvasive brain stimulation. *Hum Factors J Hum Factors Ergon Soc* Published Online First: 2014. doi:10.1177/0018720814565189

134   Foroughi CK, Werner NE, Nelson ET, *et al.* Do interruptions affect the quality of work? *Proc Hum Factors Ergon Soc Annu Meet* 2013;**57**:154–7.

doi:10.1177/1541931213571035

135   Altmann EM, Trafton JG. Brief lags in interrupted sequential performance: Evaluating a model and model evaluation method. *Int J Hum Comput Stud* 2015;**79**:51–65. doi:10.1016/j.ijhcs.2014.12.007

136   Cook GI, Meeks JT, Clark-Foos A, *et al.* The role of interruptions and contextual associations in delayed-execute prospective memory. *Appl Cogn Psychol* 2014;**28**:91–103. doi:10.1002/acp.2960

137   Trafton GJ, Monk CA. Task interruptions. *Rev Hum Factors Ergon* 2007;**3**:111–26. doi:10.1518/155723408X299852

138   Skaugset LM, Farrell S, Carney M, *et al.* Can you multitask? Evidence and limitations of task switching and multitasking in emergency medicine. *Ann Emerg Med* 2015;:1–7. doi:10.1016/j.annemergmed.2015.10.003

139   Foroughi CK, Barragán D, Boehm-Davis DA. Interrupted reading and working memory capacity. *J Appl Res Mem Cogn* Published Online First: 2016. doi:10.1016/j.jarmac.2016.02.002

140   Foroughi CK, Werner NE, Mckendrick R, *et al.* Individual differences in working-memory capacity and task sesumption following interruptions. *J Exp Psychol Learn Mem Cogn* Published Online First: 2016. doi:10.1037/xlm0000251

141   Chisholm CD, Collison EK, Nelson DR, *et al.* Emergency department workplace interruptions: are emergency physicians 'interrupt-driven' and 'multitasking'? *Acad Emerg Med* 2000;**7**:1239–43. doi:10.1111/j.1553-2712.2000.tb00469.x

142   Friedman S, Elinson R, Arenovich T. A study of emergency physician work and communication: a human factors approach. *Isr J Emerg Med* 2005;**5**:35–42.

143   Healey AN, Sevdalis N, Vincent CA. Measuring intra-operative interference from distraction and interruption observed in the operating theatre. *Ergonomics* 2006;**49**:589–604. doi:10.1080/00140130600568899

144   Healey AN, Primus CP, Koutantji M. Quantifying distraction and interruption in urological surgery. *Qual Saf Health Care* 2007;**16**:135–9. doi:10.1136/qshc.2006.019711

145   Biron AD, Loiselle CG, Lavoie-Tremblay M. Work interruptions and their contribution to medication administration errors: An evidence Review. *Worldviews Evidence-Based Nurs* 2009;**6**:70–86. doi:10.1111/j.1741-6787.2009.00151.x

146   Trbovich PL, Griffin MC, White RE, *et al.* The effects of interruptions on oncologists' patient assessment and medication ordering practices. *J Healthc Eng* 2013.

147   Berg LM, Källberg A-S, Göransson KE, *et al.* Interruptions in emergency department work: an observational and interview study. *BMJ Qual Saf* 2013;**22**:656–63. doi:10.1136/bmjqs-2013-001967

148   Sorensen EE, Brahe L. Interruptions in clinical nursing practice. *J Clin Nurs* 2013;**23**:1274–82. doi:10.1111/jocn.12329

149   Sasangohar F, Donmez B, Easty AC, *et al.* The relationship between interruption content and interrupted task severity in intensive care nursing : an observational study. *Int J Nurs Stud* 2015;**52**:1573–81.

150   Myers RA, McCarthy MC, Whitlatch A, *et al.* Differentiating between detrimental and beneficial interruptions: a mixed-methods study. *BMJ Qual Saf* 2015;:1–8. doi:10.1136/bmjqs-2015-004401

151   Sasangohar F, Donmez B, Easty A, *et al.* Interruptions experienced by cardiovascular intensive care unit nurses: An observational study. *J Crit Care* 2014;**29**:848–53. doi:10.1016/j.jcrc.2014.05.007

152   Hayes C, Jackson D, Davidson PM, *et al.* Medication errors in hospitals: a literature review of disruptions to nursing practice during medication administration. *J Clin Nurs* 2015;**24**:3063–76. doi:10.1111/jocn.12944

153   Allers JC, Hussein AA, Ahmad N, *et al.* Evaluation and impact of workflow interruptions during bobot-assisted surgery. *Urology* 2016;**92**:33–7. doi:10.1016/j.urology.2016.02.040

154   Walter SR, Raban MZ, Dunsmuir WTM, *et al.* Emergency doctors' strategies to manage competing workload demands in an interruptive environment: An observational work flow time study. *Appl Ergon* 2017;**58**:454–60. doi:10.1016/j.apergo.2016.07.020

155   Fairbanks RJ, Bisantz AM, Sunm M. Emergency department communication links and patterns. *Ann Emerg Med* 2007;**50**:396–406. doi:10.1016/j.annemergmed.2007.03.005

156   Wiegmann DA, ElBardissi AW, Dearani JA, *et al.* Disruptions in surgical flow and their relationship to surgical errors: An exploratory investigation. *Surgery* 2007;**142**:658–65. doi:10.1016/j.surg.2007.07.034

157   Walter SR, Li L, Dunsmuir WTM, *et al.* Managing competing demands through task-switching and multitasking: a multi-setting observational study of 200 clinicians over 1000 hours. *BMJ Qual Saf* 2014;**23**:231–41. doi:10.1136/bmjqs-2013-002097

158   Lea VM, Corlett SA, Rodgers RM. Describing interruptions, multi-tasking and task-switching in community pharmacy: a qualitative study in England. *Int J Clin Pharm* 2015;**37**:1086–94. doi:10.1007/s11096-015-0155-7

159 France DJ, Levin S, Hemphill R, *et al.* Emergency physicians' behaviors and workload in the presence of an electronic whiteboard. *Int J Med Inform* 2005;**74**:827–37. doi:10.1016/j.ijmedinf.2005.03.015

160 Coiera E, Tombs V. Communication behaviours in a hospital setting: an observational study. 1998;**316**.

161 Coiera EW, Jayasuriya RA, Hardy J, *et al.* Communication loads on clinical staff in the emergency department. *Med J Aust* 2002;**176**.

162 Weigl M, Muller A, Vincent C, *et al.* The association of workflow interruptions and hospital doctors' workload: a prospective observational study. *BMJ Qual Saf* 2012;**21**:399–407. doi:10.1136/bmjqs-2011-000188

163 Murji A, Luketic L, Sobel ML, *et al.* Evaluating the effect of distractions in the operating room on clinical decision-making and patient safety. *Surg Endosc* Published Online First: 2016. doi:10.1007/s00464-016-4782-4

164 Alvarez G, Coiera E. Interruptive communication patterns in the intensive care unit ward round. *Int J Med Inform* 2005;**74**:791–6. doi:10.1016/j.ijmedinf.2005.03.017

165 Potter P, Wolf L, Boxerman S, *et al.* Understanding the cognitive work of nursing in the acute care environment. *J Nurs Adm* 2005;**35**:327–35.

166 Feuerbacher RL, Funk KH, Spight DH, *et al.* Realistic distractions and interruptions that impair simulated surgical performance by novice surgeons. *Arch Surg* 2012;**147**. doi:10.1001/archsurg.2012.1480

167 Collins S, Currie L, Patel V, *et al.* Multitasking by clinicians in the context of CPOE and CIS use. *Stud Health Technol Inform* 2007;**129**:958–62.

168 Magrabi F, Li SYW, Dunn AG, *et al.* Challenges in measuring the impact of interruption on patient safety and workflow outcomes. *Methods Inf Med* 2011;**50**:447–53. doi:10.3414/ME11-02-0003

169 Drews FA. The frequency and impact of task interruptions in the ICU. *Proc Hum Factors Ergon Soc Annu Meet* 2007;**51**:683–6. doi:10.1177/154193120705101117

170 Baethge A, Rigotti T. Interruptions to workflow: Their relationship with irritation and satisfaction with performance, and the mediating roles of time pressure and mental demands. *Work Stress* 2013;**27**:43–63. doi:10.1080/02678373.2013.761783

171 Brixey JJ, Robinson DJ, Johnson CW, *et al.* A concept analysis of the phenomenon interruption. *ANS Adv Nurs Sci* 2007;**30**:E26–42. doi:00012272-200701000-00012 [pii]

172 Chisholm CD, Dornfeld AM, Nelson DR, *et al.* Work interrupted: A comparison of workplace interruptions in emergency departments and primary care offices. *Ann Emerg Med* 2001;**38**:146–51. doi:10.1067/mem.2001.115440

173 Walter SR, Dunsmuir WTM, Westbrook JI. Studying interruptions and multitasking in situ: The untapped potential of quantitative observational studies. *Int J Hum Comput Stud* 2015;**79**:118–25. doi:10.1016/j.ijhcs.2015.01.008

174 Parker J, Coiera E. Improving clinical communication: a view from psychology. *J Am Med Inform Assoc* 2000;**7**:453–61. doi:10.1136/jamia.2000.0070453

175 Westbrook JI. Interruptions and multi-tasking: moving the research agenda in new directions. *BMJ Qual Saf* 2014;:1–3. doi:10.1136/bmjqs-2014-003372

176 Magrabi F, Li SYW, Day RO, *et al.* Errors and electronic prescribing: a controlled laboratory study to examine task complexity and interruption effects. *J Am Med Inform Assoc* 2010;**17**:575–83. doi:10.1136/jamia.2009.001719

177 Grundgeiger T, Liu D, Sanderson PM, *et al.* Effects of interruptions on prospective memory performance in anesthesiology. *Proc Hum Factors Ergon Soc Annu Meet* 2008;**52**:808–12. doi:10.1177/154193120805201209

178 Weigl M, Stefan P, Abhari K, *et al.* Intra-operative disruptions, surgeon's mental workload, and technical performance in a full-scale simulated procedure. *Surg Endosc* 2015;**Published** . doi:10.1007/s00464-015-4239-1

179 Grundgeiger T, Sanderson P, MacDougall HG, *et al.* Interruption management in the intensive care unit: Predicting resumption times and assessing distributed support. *J Exp Psychol Appl* 2010;**16**:317–34. doi:10.1037/a0021912

180 Liu D, Grundgeiger T, Sanderson PM, *et al.* Interruptions and blood transfusion checks: lessons from the simulated operating room. *Anesth Analg* 2009;**108**:219–22. doi:10.1213/ane.0b013e31818e841a

181 He Z, Marquard JL, Henneman PL. How do interruptions impact nurses' visual scanning patterns when using barcode medication administration systems? In: *AMIA Annu Symp Proc.* 2014. 1768–76.

182 Colligan L, Guerlain S, Steck SE, *et al.* Designing for distractions: a human factors approach to decreasing interruptions at a centralised medication station. *BMJ Qual Saf* 2012;**21**:939–47. doi:10.1136/bmjqs-2011-000289

183 Sasangohar F, Donmez B, Easty AC, *et al.* Mitigating nonurgent interruptions during high-severity intensive care unit tasks using a task-severity awareness tool: A quasi-controlled

observational study. *J Crit Care* Published Online First: 2015.
doi:10.1016/j.jcrc.2015.05.001

184   Janssen CP, Gould SJJ, Li SYW, *et al.* Integrating knowledge of multitasking and
interruptions across different perspectives and research methods. *Int J Human-Computer
Stud* 2015;**79**:1–5. doi:10.1016/j.ijhcs.2015.03.002

185   Woods D, Dekker S. Anticipating the effects of technological change: A new era of
dynamics for human factors. *Theor Issues Ergon Sci* 2000;**1**:272–82.
doi:10.1080/14639220110037452