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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.

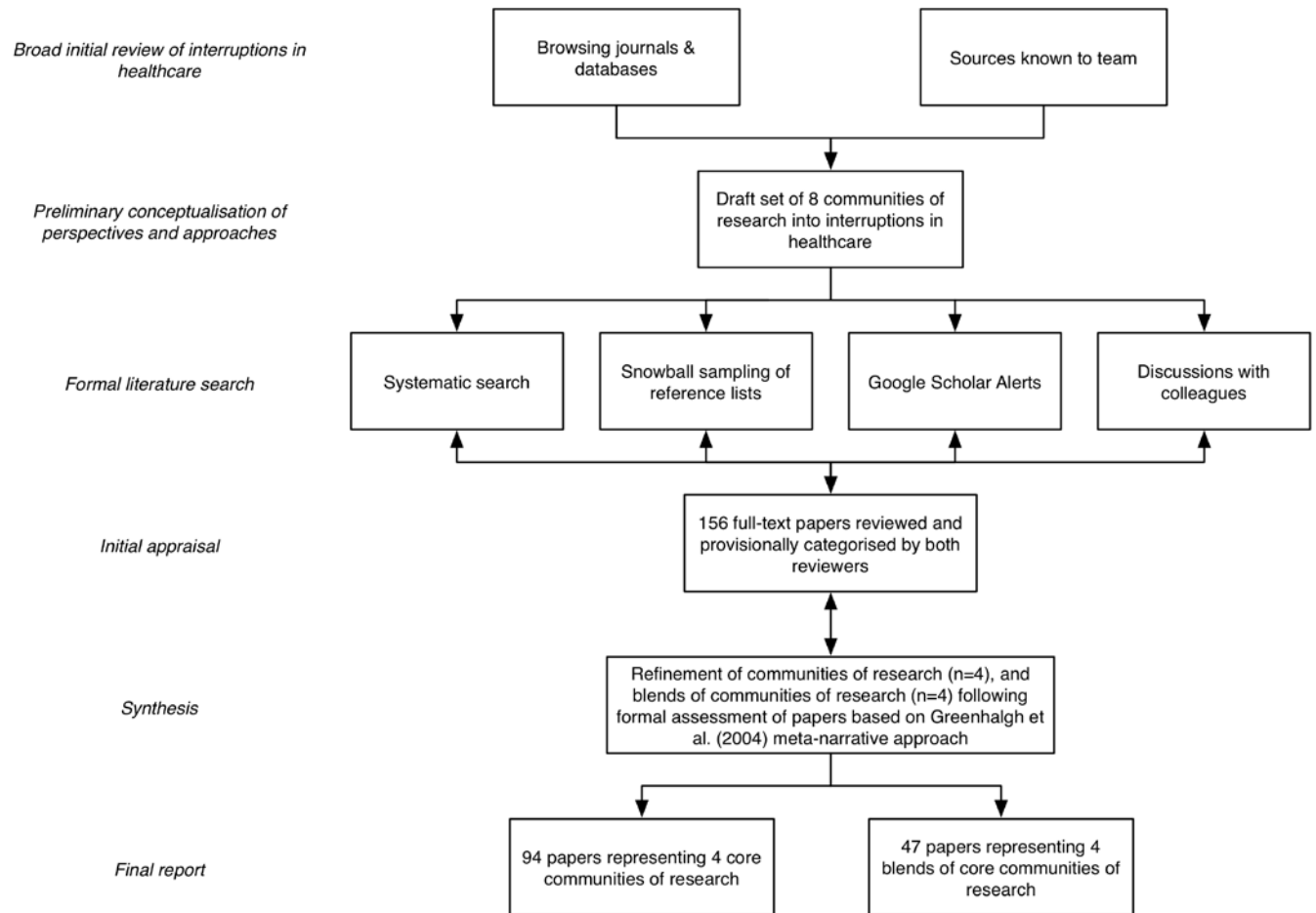


Figure 1: Illustration of the critical review process (adapted from [21])

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.

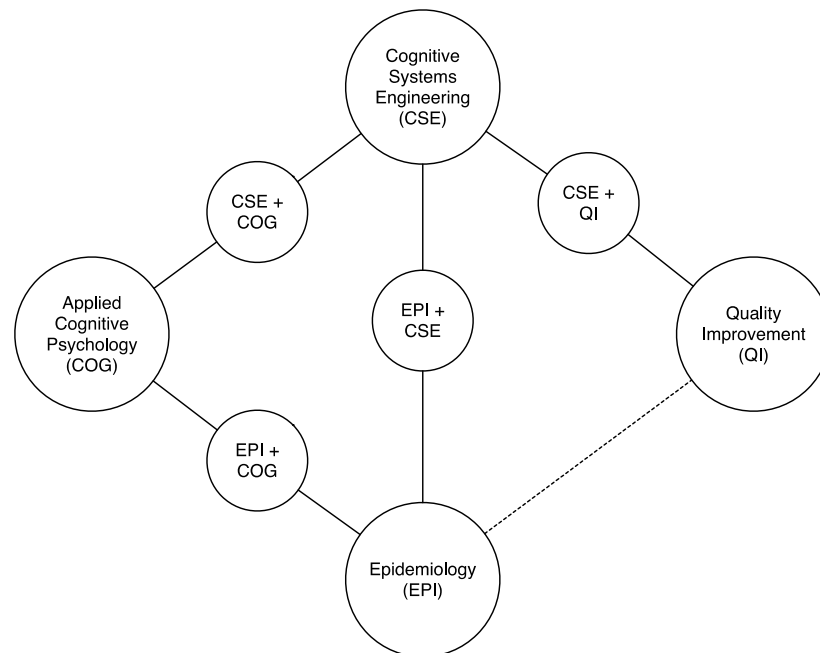


Figure 2: Influences and blends between research traditions emerging from our categorisation.

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]	[4,28,44,46–49,53,57]	[5,26,29,30,32–34,42,43,45]	[27,41]	
Quality Improvement	[35]				[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	[42,149,151]	[11,141,143,146,148]	[47,150]	[45,156]	
EPI+COG		[172]	[62,167,169]	[66]	
CSE+COG			[5,178,181]		
CSE+QI					[82,183]

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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