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Review

Interruptions in healthcare: Theoretical views

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ABSTRACT

Background: Researchers in healthcare have begun to investigate interruptions extensively, given evidence for the adverse effects of work interruptions in other domains and given the highly interruptive hospital environment. In this paper, we reviewed literature on interruptions in critical care and medication dispensing settings in search of evidence for a relationship between interruptions and adverse events.

Methods: The literature search included the databases MEDLINE, CINAHL + Pre CINHAL, Health Sources: Nursing Academic Edition, EMBASE, PsycINFO, ISI Web of Science and Ergonomics Abstracts. The paper titles and abstracts were subsequently reviewed. After the initial search, we reviewed paper titles and abstracts to define the subset for review.

Results: We currently lack evidence in healthcare of the extent to which interruptions lead to adverse effects. The lack of evidence may be due to the descriptive rather than causal nature of most studies, the lack of theory motivating investigations of the relationship, the fact that healthcare is a complex and varied domain, and inadequate conceptualizations of accident aetiology. We identify two recent accident theories in which the relationship between activity and medical errors is complex, indicating that even when it is sought, causal evidence is hard to find.

Discussion: Future research on interruptions in healthcare settings should focus on the following. First, prospective memory research and distributed cognition can provide a theoretical background for understanding the impact of interruptions and so could provide guidance for future empirical research on interruptions and the planning of actions in healthcare. Second, studying how interruptions are successfully rather than unsuccessfully overcome may better help us understand their effects. Third, because interruptions almost always have positive and adverse effects, more appropriate dependent variables could be chosen.

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1. Introduction

There are many aspects of healthcare working conditions that, if changed, could reduce the incidence of medical errors. In 2003 the *Agency for Healthcare Research and Quality* (AHRQ) published an evidence report which states that reducing interruptions and distractions will probably reduce the number of medical errors [1]. However, the AHRQ's conclusion is based on evidence from aviation [2] and from a study on medication dispensing errors [3]. The AHRQ authors add that the "evidence of the association between interruptions and distractions and errors in other areas of medicine is insufficient" [1, p. 34].

Given that medical staff are interrupted frequently [4–6], given that interruptions disrupt human cognition [7,8], and given the evidence from other domains [2], it may be that the research approaches chosen are inappropriate rather than that there is no relation between interruptions and medical errors. Therefore, it is more likely that there is absence of evidence than evidence of absence [9,10] for an effect of interruptions on medical errors.

In Section 2, we summarize recent studies on interruptions and distractions in critical care areas and medication dispensing. We conclude that (1) evidence for a relation between interruptions and medical errors is still weak, probably more because of methodological approaches than because there is evidence that the relation is absent, (2) different definitions of interruptions are used by different researchers, making it hard to compare studies, (3) the papers reviewed lack theoretical background that could be useful when investigating interruptions, and (4) generalizations from the aviation to the medical domain may not always be appropriate.

In Section 3, first we discuss *prospective memory*, which is the ability to recall a previously formed intention at a specific time or cue in the future without being encouraged to do so [11]. Second, because 21 out of the 35 papers reviewed consider memory failures to be a direct result of interruptions, we use prospective memory as theoretical background to interpret the effects of interruptions. Third, we discuss differences and similarities between the medical and aviation domain that influence the effect of interruptions on memory. The section ends with implications of prospective memory for information technology (IT) systems.

In Section 4, we address the role of interruptions in adverse events. First, we contrast the evidence-based approach in the papers reviewed with Reason's Swiss cheese model [12] and Hollnagel's systemic accident model [13]. We conclude that the accident models capture the complex nature of interruptions better. Second, in line with Hollnagel's systemic accident model [13], we suggest that observing how people overcome interruptions could offer new insights into the processes affected by interruptions. Third, we argue that interruptions are not generally "bad" or "good". To understand the effects of interruptions, researchers need to choose appropriate dependent variables. The final part of the section addresses implications of the systemic accident model for healthcare informatics.

2. Review on interruptions in the medical domain

We undertook a broad review of recent papers published on interruptions in the medical domain. The AHRQ report covers the period up to 2002, so our search was restricted to papers in English written after 2002. An initial search was conducted in the databases MEDLINE, CINAHL + Pre CINHAL, Health Sources: Nursing Academic Edition, EMBASE, PsycINFO, ISI Web of Science and Ergonomics Abstracts. We conducted two separate searches. The first search was done to retrieve healthcare papers on interruptions with the term [(communicat* OR interrupt* OR distract*) AND ("human error*" OR "adverse event*" OR "patient safety") NOT hiv NOT respirat* NOT drug NOT genetic NOT resection NOT traumatic]. The second search was done specifically to retrieve papers on medication dispensing with the term [medication dispensing AND (error* OR "patient safety" OR interrupt* OR distract*)]. Because interruptions are studied under a variety of topics, we conducted the initial search with broad search terms and subsequently reviewed paper titles and abstracts to define the subset for review. Although our main interest is areas other than medication dispensing, where a relation is believed to be reasonably well-established [1], we included medication dispensing to evaluate any growth of evidence since 2002.

After the above search we added further relevant citations from the initial papers, we searched for papers in press, and in the case of conference papers we sought follow-up archival publications. To avoid duplication we excluded conference contributions or papers that present the same data or part of the data. For the purpose of discussion, selected papers from the AHRQ report were also included.

First, the results of 26 descriptive papers in critical care areas are presented that investigate who interrupts whom, interruption time, and other details. In addition, eight papers on medication dispensing are reported which rely mainly on subjective impressions of pharmacists. Second, nine cause and effect studies are reported that investigate if there is a causal relation between interruptions and medical errors.

2.1. *Descriptive studies*

In descriptive studies, researchers count interruptions and report their properties, such as the length of interruptions, who is involved, and so on. The available definitions used in 14 of the descriptive studies and the results are summarized in Table 1 . The aims of the researchers were to see if the emergency department is an interrupted work place [4,14], to investigate communication patterns in various medical domains [15–22], to evaluate the effect of IT products [23], to observe how nurses handle their workload [24], and to understand the effects of interruptions on surgical teams [25,26]. For the purpose of this summary, however, only the part of each paper that deals with the relation between interruptions and medical errors is of interest. In addition, four papers report subjective data on medication errors in critical care settings from questionnaires [27] and accident and incident reports [28–30].

The eight papers on medication dispensing errors and interruptions mainly rely on subjective data. Three papers reporting interview data reveal frequent interruptions [31] and reveal that interruptions and distractions were considered to have contributed to errors in 14 out of 106 responses [32] and 3 out of 21 medication errors [33]. The results of a survey sent out to pharmacy technicians showed interruptions as a contributing factor [34]. Accident and incident reports show that in 11.4% of all cases, interruptions were reported as contributing to dispensing errors [35]. A root cause analysis on incident reports revealed that interruptions were a contributing factor to errors [36]. Finally, two observational studies report that distraction and interruptions were frequent [37] and that telephone interruptions correlated negatively with the pharmacy's dispensing rate [38].

Overall, there is an absence of evidence for a causal relationship between interruptions and medical errors in the descriptive studies. First and most important, only the incident reports collect information about errors, which provides only associative evidence. The empirical studies do not collect information about errors, so there is no basis to find associations between interruptions and errors, let alone causal connections. Many studies assume the causal connection and suggest that interruptions should be reduced.

Second, in the critical care studies several different definitions of interruptions are used, probably as a result of the differing research aims (see Table 1). This makes it more difficult to compare and generalize results. For example, one needs to be careful when comparing the results of Chisholm et al.'s [4,14] studies with results from studies on clinical communication [15,16,19,21,22]. Chisholm et al.'s [4] definition of a "break-in-task" is closer to others' definition of an interruption. They defined "break-in-task" as "an event that not only required the attention of the physician for more than 10 s, but subsequently resulted in changing tasks" (p. 1239). In the definition of interruptions used by communication studies, however, such a discontinuity in task performance is missing (e.g., "a communication event in which the subject did not initiate the conversation, and which used a synchronous communication channel" p. 416 [19]). In addition, an alarm or an equipment malfunction could cause a "break-in-task", which has been allowed by some studies on communication [15,16,19,22] but not all [20,21].

It is also important to examine carefully how interruptions are operationalized when comparing studies. France et al. [23] used the framework of Chisholm et al. [4,14] to observe "break-in-tasks" and "interruptions", added them up, and compared the result with the simple "interruptions" count of Chisholm and colleagues. Another study by Fairbanks et al. [21] compared the initiated plus received interruptions with studies which only counted the received interruptions. Overall, the counts are due to differing definitions, which needs to be considered when comparing studies.

Third, the studies on medication dispensing do not give explicit definitions of interruptions or distractions and, compared to the critical care studies, differ in their general research approaches. The studies use data reported by pharmacists rather than observational or experimental methods. Since the paper by Flynn et al. [3], there has apparently been little attempt to investigate further the quantitative or functional relation between distractions and interruptions and dispensing errors.

Fourth, when investigating the effect of interruptions, researchers should choose a definition that takes into account the underlying construct being investigated (e.g., memory). For example, it is unclear whether "break-in-tasks" and "interruptions" as defined by Chisholm et al. [4] have different effects on human memory and whether the effects can be empirically distinguished. A theoretical framework is needed to investigate such possibilities, which we will address in the section about PM.

Fifth, the reviewed studies were conducted in different healthcare settings (emergency departments, operating theater, intensive care units, general wards) and with different healthcare staff (medical, nursing). Such heterogeneity in settings poses another challenge when we try to relate interruptions to errors; different tasks carried out by different personnel have been studied in different environments, which might be differently affected by interruptions.

2.2. *Cause and effect studies*

Researchers have tried to relate interruptions to medical errors in cause and effect studies (see Table 2). Three studies are prospective observations [39–41], three are exploratory field observations [5,42,43], one is a controlled experimental study [44], one is an ethnographic study [45], and one is a retrospective analysis [46]. We provide a brief summary of their findings.

Table 1 – Overview of descriptive observational studies of interruptions. Rightmost columns provide the definition of interruptions and of other events in the study cited at left. Figures are frequency counts (events per hour) for events defined as interruptions and events defined otherwise for the study cited (ED = emergency department, PC = primary care, ICU = intensive care unit).

Author	Participants	Definition of interruption	Other definitions
Chisholm et al. [4]		"Any event that briefly required the attention of the subject but did not result in switching to a new task"	"A 'break-in-task' was defined as an event that not only required the attention of the physician for more than 10 s, but subsequently resulted in changing tasks"
	ED physicians	10.3/h	6.9/h
Chisholm et al. [14]		"An event that diverted the physician's attention from the task at hand"	"A 'break-in-task' was a specific type of interruption that preempted one task, resulting in a different task being performed"
	ED physicians	9.7/h	5.4/h
	PC physicians	3.9/h	1.8/h
Alvarez and Coiera [15]		"A conversation-initiating interruption (CII) is a communication event that is not initiated by the observed subject, and occurs using a synchronous communication channel such as face-to-face conversation or the telephone"	"A turn-taking interruption (TTI) occurs within an individual communication event, when one individual begins speaking before the other finishes. Two criteria: (a) the interrupter does not allow the other speaker to finish his/her utterance; (b) the interrupter was able to finish or continue his/her utterance"
	ICU nurses	Could not be calculated	1.39/h
	ICU junior registrars	Could not be calculated	9.5/h
	ICU senior registrars	Could not be calculated	16.43/h
Brixey et al. [17]		"A break in the performance of a human activity initiated by a source internal or external to the recipient with occurrence situated within the context of a setting or location. This break results in the suspension of an initial task to perform an unplanned task with the assumption that the initial task will be resumed."	
	ED nurses	11.65/h	
	ED doctors	10.58/h	
Brixey et al. [18]		"A break in the performance of a human activity initiated by a source internal or external to the recipient with occurrence situated within the context of a setting or location. This break results in the suspension of an initial task to perform an unplanned task with the assumption that the initial task will be resumed."	
	ED nurses	Approx. 11.8/h	
	ED physicians	Approx. 10.2/h	
Fairbanks et al. [21]		"The initiation of a synchronous communication event when either a synchronous or an asynchronous communication event was already in progress." Exclusion from wholly social or personal content.	
	ED attendings (adult section)	3.2/h (6.9/h)[a]	
	ED Y3 residents (adult section)	3.2/h (4.9/h)[a]	

Table 1 (*Continued*)

Author	Participants	Definition of interruption	Other definitions
	ED Jnr residents (adult section)	1.3/h (1.8/h)[a]	
	ED nurses (adult section)	.5/h (.5/h)[a]	
	ED charge nurse (adult section)	3.6/h (3.8/h)[a]	
Friedman et al. [20]		No exact definition given	
	ED physicians	4.4/h	
Coiera et al. [19]		"A communication event in which the subject did not initiate the conversation, and which used a synchronous communication channel"	
	ED nurses	11.2/h	
	ED doctors	11.1/h	
Spencer et al. [22]		"A communication event that was not initiated by the observed party and occurred using a synchronous communication channel such as face-to-face conversation or the telephone"	
	ED registrars	23.5/h	
	ED nurse shift coordinators	24.9/h	
	ED nurses	9.2/h	
	ED junior physicians	8.3/h	
Woloshynowych et al. [16]		"Communications that were not initiated by the person being observed when having a synchronous communication. Synchronous communication is when 2 individuals exchange information at the same time."	
	ED nurses in charge	42/h	
France et al. [23]		"A temporary interruption was an interruption that momentarily diverted the physician's attention away from the task at hand but did not result in a break-in-task"	"A 'break-in-task' was a type of interruption that pre-empted one task, resulting in another task being performed"
	ED physicians	3.48/h	1.47/h
Ebright et al. [24]		"Every time the participant was distracted from the immediate task or issue on which she was focused"	
	Nurses (multiple domains)	6.3/h	
Healey et al. [25]		"A distraction resulting in a break in primary task activity"	Distraction: "as observed behaviour such as orienting away from a primary task or verbally responding to a secondary task"
	Surgical team	17.5/h (for interruptions and distractions, no separate value for each definition is given)	
Healey et al. [26]		"A distraction resulting in a break in primary task activity"	Distraction: "as observed behaviour such as orienting away from a primary task or verbally responding to a secondary task"
	Surgical team (urology)	27/h (for interruptions and distractions, no separate value for each definition is given)	

[a] Values calculated by adding received and given interruptions divided by time observed.

Table 2 – Overview of cause and effect studies of interruptions. Rightmost columns provide research questions, definitions used, results and evaluation (regarding interruption-error relations) of the studies cited at left (OR = operation room, CPOE = computerized provider order entry, ICU = intensive care unit).

Author	Study question	Definition of interruption	Results (regarding interruptions)	Methodological evaluation (regarding interruptions)
Christian et al. [39]	Obtain description of (1) system (OR) and (2) its interacting components to identify features that influence patient safety.	No definition given.	An interruption contributed to 1 of 11 safety-compromising events. Other factors had stronger influences (patient factors, hand offs, inexperience of staff, high workload, hierarchy among team).	Categorisation of interruptions not clear; no definition of interruption.
Collins et al. [41]	Distractions and resulting interruptions, multitasking or deferred tasks during CPOE entries. Are there effects on task at hand or delayed tasks?	Cessation of productive activity before the current task was completed for an externally imposed reason.	Interrupted tasks ($n = 32$): 6.25% lack of recall, 9.38% incomplete, 3.12% change in plan. Deferred tasks ($n = 13$): 15.38% incomplete. Multitasking ($n = 30$): 6.67% lack of recall.	No non-interrupted baseline to compare to; strong relation.
Wiegmann et al. [40]	Is there a relation between surgical flow disruptions and surgical errors?	"Extraneous interruptions". Disruptions occurring during a procedure that did not directly pertain to the treatment of the patient and resulted in disruption of surgical flow.	341 surgical flow disruptions: 52% teamwork/communication, 17% external/extraneous observations, 12% supervisory/training-related, 11% equipment/technology, 7% resource accessibility; Only sig. factor in multiple regression was teamwork/communication.	Definition limited to case irrelevant distractions; possibility of redundancy in regression model; small sample size.
Drews [5]	Interruption frequency in ICU? Do interruptions contribute to problems in patient safety?	Event that required an attention shift from the primary task towards some external event.	29.4% activities interrupted; in 5 out of 6 cases of compromised patient safety an interruption directly preceded.	Only nine subjects and ~32.5 h of observation; strong relation.
Hillel and Vicente [43]	Do interruptions have an influence on or do they lead to error in infusion pump programming?	No definition given (all interruptions were attended immediately and resulted in task-switching).	All interrupted tasks were resumed; no errors observed.	No exact definition given; only 10 nurses for 25 h observed; no relation.
Hillsden and Fenton [42]	Identify areas of practice that could be improved to reduce medication errors.	No definition given.	28 interruptions across 5 medicine rounds; 15 avoidable, 13 unavoidable; 2 errors observed, 1 caused by interruption.	No definition given; small study (5 rounds; ~3 h observed).
Ginsburg [44]	Do interruptions cause infusion pump programming errors?	Interrupted every 6 s by asking the nurse a patient-related question while nurse programs pump.	Higher workload score when interrupted; longer time on task; no explainable result pattern for committed errors.	Controlled experiment with nurses; small N in experiments; "unrealistic" implementation of interruption.
Potter et al. [45]	How do environmental factors create disruptions that pose risks for medical errors?	Human factors view: activity that stops nurse from performing her task. Nurse view: activity that disrupts nurse and is not relevant to the nursing process.	Human factors count: 5.9 interruptions/h. Nurse researcher count: 3.4 interruptions/h.	Considers positive and negative interruptions; method did not allow drawing conclusions about relation of interruptions and omissions in care.
Liu et al. [46]	Can the failure to check a blood transfusion label due to an interruption be explained by using prospective memory?	An external intrusion of a secondary, unplanned, and unexpected task, which leads to a discontinuity in task performance.	2 out of 12 participants forgot the check; prospective memory theory explains the pattern of results successfully [47].	Only post hoc analysis; no non-interrupted baseline to compare to; small N; strong relation.

First we consider the prospective observations. The results reported by Christian et al. [39] show just one incident in which an interruption contributes to compromised patient safety. Overall, other factors seem to have a bigger impact. Collins et al. [41] observed the consequences of distractions during computerized provider order entry (CPOE) entries (task interruption, multitasking, and defer task) and the effect on the task (lack of recall, incomplete task, and change in plan). In total, 13.33% of all distractions affect the task. Wiegmann et al. [40] did not find a significant contribution of "external/extraneous interruptions" to surgical errors in their multiple regression model.

Second, we consider the exploratory field observations. Drews [5] reported that in five out of six cases of compromised patient safety, an interruption immediately preceded, which suggests that interruptions affect patient safety. Hillsden and Fenton [42] observed medication administration rounds and one of the two observed errors was caused by an interruption. In contrast to the above, Hillel and Vicente [43] observed that interruptions did not lead to any errors in infusion pump programming.

Third, in two controlled experiments Ginsburg (née Hillel) [44] manipulated whether nurses were interrupted or not while programming an infusion pump. Although the programming errors observed did not appear to be related to interruptions, the study is of high value because it is the only prospective randomized controlled trial.

Fourth, in their ethnographic study, Potter et al. [45] presented an innovative method for investigating interruptions but also had difficulties in establishing a relationship between interruptions and omissions.

Finally, in their retrospective analysis, Liu et al. [46] analyzed video data of a full-scale patient simulator study in which all anesthesiologist participants were interrupted while supervising a blood transfusion. Out of 12 participants, it was only the two participants who engaged with the interrupter who forgot to check the blood bag label with the patient data. In a subsequent analysis, Liu et al.'s [46] pattern of results has been explained with prospective memory theory [47].

Taking the study results together, the evidence for a causal relation between interruptions and medical errors is mixed. However, some methodological issues need to be considered (see also Table 2 rightmost column). First, five studies show an absence of evidence. In two studies, no definition of interruptions is given [39,42] and in one study a definition with a limited scope is used [40]. A further study found no evidence but operationalized interruptions in an unrealistic way [44] and in a final study no clear conclusions could be drawn [45]. In general, as for the descriptive studies, different definitions were used, causing the problems described earlier.

Second, one study indicates evidence of absence; Hillel and Vicente [43] found that interruptions did not affect performance. Third, three studies show evidence of a relationship. Two show an effect of interruptions on memory [41,46] and one shows an effect on medical errors [5]. The results of the latter three studies show some evidence for an adverse effect of interruptions. Overall, it appears that under certain circumstances interruptions can lead to medical errors.

Of all 35 descriptive and cause and effect studies, 21 studies were motivated by the presumed disruptive effects of interruptions on memory processes. However, there appear to be only two healthcare studies that show memory failures as the result of interruptions [41,46] and only one study is guided by memory theory [47]. In addition, in ten of the 35 papers, the fact that interruptions led to adverse effects in the aviation domain is given as a motivation to study interruptions in the medical domain. We will address these points in the next section.

3. Interruptions and memory

In this section, first we discuss prospective memory (PM) theories and point out the general use and need for research on PM in healthcare. Second, we discuss a model by Parker and Coiera [48] who explain PM failures by limited working memory resources. We show that PM is a useful theory to investigate interruptions. Third, we indicate differences between the medical and the aviation domains that might influence the effect of interruptions on PM.

3.1. *Prospective memory processes*

Prospective memory (PM) refers to a memory performance in which a person must recall an intention or plan in the future without an agent telling them to do so [11]. PM is important in planning our daily life [11] and in resuming interrupted tasks [49].

To understand how interruptions influence PM performance it is necessary to introduce two theoretical views on PM. The *monitoring* view proposes that when a person forms an intention, they use attentional and/or working memory capacity to monitor the environment for a specific cue that will remind them to act [50]. In contrast, the *automatic association* view proposes that when a person forms an intention, an association is formed automatically between the intention and the reminding cue [51]. When the cue is later encountered, a spontaneous retrieval process brings the intention into mind. McDaniel and Einstein [11] proposed a *multiprocess* view of PM which incorporates both the automatic association and monitoring views. In any situation, the PM process used depends on factors such as the importance of the intention, parameters of the PM retrieval cue, parameters of the task a person is doing, planning, and individual differences [11].

As an example of the importance of intentions, a nurse who must give a patient an important medication at a specific time will rely more upon monitoring than upon being reminded automatically from external cues. Parameters of the task could include whether the nurse continues working in the room where the patient is vs. doing a task elsewhere. In the room, the patient would be a constant reminder of the intention so that less monitoring would be needed. Overall, according to the multiprocess view, PM relies on both long-term memory processes (automatic association) and working memory processes (active monitoring) [11,52].

It is surprising that PM has not been investigated in healthcare until recently although its relevance has been noted [48]. Dieckmann et al. [53] claim to be the first to study PM failures with a study of PM performance in a patient simulator. This neglect is even more surprising given our knowledge of the PM-demanding strategies that nurses use to cope with high workload. For example, nurses “stack” activities in memory—moving on to a next activity and coming back to stacked activity later—to prevent down times [24]. Nurses partition care for each patient, switch back and forth between patients, continually adapt their work plan to manage time-sensitive high workload [54], and constantly prioritize their tasks [55]. Furthermore, Rothschild et al. [56] found that almost 75% of all serious medical errors happened during “ordering or execution of treatment”. A study of surgical malpractice claims relating to communication failures showed that in 49% of all 81 communication breakdowns the information was never transmitted [57]. Data from an ICU patient safety-reporting system showed that “incorrect or incomplete delivery of care” was the second most common form of error [58]. Clearly, many breakdowns have a PM element.

Results from laboratory research on PM can identify factors that will influence PM performance and can point out situations that will be more vulnerable to memory failures. For example, it has been shown that if an ongoing task is important, people are more likely to forget to execute an additional attention-demanding PM task [59]. This is relevant given that clinicians immediately suspend their work when encountering a more highly prioritized interruption [55]. Resuming the original ongoing task turns into a PM task and the interrupting task becomes an important ongoing task. Of course, how such factors play out in healthcare needs to be tested, taking into account the interaction between task, medical environment and staff skills [25].

Another line of research investigates interruptions by recording the time it takes to get back to the task at hand after an interruption (the resumption lag) [60]. The resumption lag is a very sensitive measure that might be useful for fast-changing environments such as driving [61]. However, the resumption lag may be too fine-grained to be sensitive in loosely coupled healthcare systems. Moreover, the resumption lag cannot be measured unless the interrupted task is resumed at some point. Measuring the resumption lab therefore might be not as relevant as measuring PM, where the dependent variable is whether or not a person forgets to resume the task. A further dependent variable when investigating changes of tasks is task-switching cost [62]. As for the resumption lag, task-switching costs may be too fine-grained and not as relevant as PM when investigating interruptions in healthcare.

In summary, understanding PM is critical to understanding the impact of interruptions on healthcare workers' performance and to creating a more effective cognitive environment for healthcare workers. However, more appropriate measures need to be developed to capture PM performance in the healthcare environment.

3.2. *Prospective memory and interruptions*

For most researchers the main reason for investigating interruptions is the potentially disruptive effect of interruptions on memory processes and the possible consequences for patient safety. Surprisingly, few researchers attempt to explain the underlying cognitive processes. One exception is Parker and Coiera [48] who assume that plans must be held in an active state in working memory by rehearsal but that working memory capacity is limited. Interruptions affect working memory by interfering with rehearsal and generating new tasks that might displace the oldest task(s) in working memory. The recall of a plan is then mediated by a cue.

The above is a simple model that needs to be reconsidered with respect to research on PM. Following from the multi-process view of PM described earlier [11], challenges to both long-term and working memory processes should be taken into account.

First, in PM tasks that rely mostly on long-term memory processes, little active monitoring is assumed, so the retrieval cue is of high importance. It has been shown that people are more likely to remember their intention if the context in which they must retrieve the intention is similar to the context in which they encoded the intention [63,64]. Therefore an interruption—for example a call to an emergency which leaves a nurse at a different location at the end of the interruption—decreases the chance that the nurse will remember to finish the interrupted task.

Second, in PM tasks that depend on monitoring there is relatively more reliance on working memory processes. Einstein et al. [65] noted that an intention often cannot be executed immediately but must be delayed until its performance is possible or appropriate. For example, a nurse preparing an infusion pump may be told of a medication change for one of her patients. The nurse must delay acting on the medication change until he or she has finished setting up the infusion pump (the other possibility would be to interrupt the pump set up and return to it later, which also is PM-demanding). In laboratory studies, a delay of as short as 10 s worsens PM performance, which worsens further if participants have to do a task during the delay [65,66] or if the delay period is interrupted [8]. Interruptions apparently reduce the availability of resources needed to keep an intention active during a delay. Overall, successful PM performance of delayed intentions seems to depend either upon keeping the intention active in working memory or upon relying on long-term processes which, in turn, depend on cue availability.

Third, interruptions can interfere with habitual PM tasks [67]. Habitual tasks consist of multiple task steps which have been strongly associated with each other because they have been executed many times in the same sequence. If preceding task steps are missed due to an interruption [47] or if it is necessary to delay a single task step [68], the next task step is no longer cued by the preceding steps and is therefore more prone to forgetting.

With regard to PM, the inference drawn by Alvarez and Coiera [69] that “more interruptions may equal more medical errors” may be misleading and could lead to interventions that might be inappropriate. First, a person has to have an intention when interrupted in order to forget the intention. Second, remembering to get back to the interrupted task must depend mostly on monitoring processes and not on automatic processes. As we mention above, only monitoring processes rely on working memory resources which can be affected by interruptions [8]. Third, as we will discuss in later sections, interruptions can also have positive effects and errors seldom have a single contributing cause.

Regarding how we should define interruptions, PM findings suggest that the source of an interruption (communication, equipment, and so on) is less important than the effect of the interruption on the task at hand. This suggests that we need a general definition of interruption that is relevant for any interrupting source, such as the definition developed by Brixey et al. [70]. Brixey et al. define an interruption as (1) a human experience, (2) an intrusion of a secondary, unplanned, and unexpected task, (3) a discontinuity in task performance, (4) externally or internally initiated, and (5) situated within a context.

To summarize, laboratory research has identified situations in which interruptions disrupt memory systems underlying PM. Besides helping to explain why and how interruptions affect PM performance, these findings help researchers guide their observations in the real world. With this perspective, we now consider what healthcare might learn from aviation when workplace interruptions are studied.

3.3. *Interruptions in the medical and aviation domain*

Investigators have studied interruptions in the aviation and medical domains but have not performed a systemic comparison of the outcomes. The work performed in the two domains has similarities and differences that influence the effect of interruptions on memory processes.

Similarities between the domains have been shown in tasks consisting of multiple well-defined steps. Research shows that removing preceding task steps in a sequence of steps makes people more likely to forget crucial task steps in anesthesia [47] and in aviation [68].

Differences in work structure may exert a stronger effect on whether an interrupted task is resumed. As discussed earlier, task resumption and other PM tasks depend heavily on cues from the environment. First, the medical environment is much richer in cues than aviation, which increases the likelihood that personnel will receive reminders. Second, the cue-task association is often better in healthcare. For example, if a pilot is interrupted while setting the flaps, the cues for task resumption are limited (checklist, one control element). In contrast, if a nurse is interrupted before administrating IV medication, there are more and stronger associated cues available (medication, IV equipment, IT work-list). A cue with a strong association to the task is more likely to remind a person of a task [64].

In general, investigating interruptions in healthcare is more difficult than in aviation for two reasons. First, aviation deals with a single work area (cockpit) and one or two actors (pilots) whereas healthcare usually involves multiple work areas (patient room, ward desk, medication room, etc.), different kind of wards (ED, ICU, OR, etc.) and multiple actors (nurses, doctors, etc.). The multiple, heterogeneous, work areas and multiple actors found in healthcare require more differentiated studies with more complex data collection demands. Second, pilots have a highly structured workplace that supports the use of work flow tools and checklists [68,71,72]. Such structure lets the researcher foresee the pilot's next step and judge how reliably the pilot moves to that step. In contrast, the hospital workplace is usually much less predictable due to patient status changes and the many ways in which tasks can be accomplished [24,45,54]. Such factors make it harder to evaluate the reliability with which successive tasks are performed [45].

Overall, the more complex, distributed, and loosely coupled healthcare domain makes research on interruptions more difficult than it is in aviation. The analogy between healthcare and aviation is mainly motivated by and applied to anesthesia [73] and its relevance for critical care has recently been questioned [74]. In case of interruptions, researchers must understand how interruptions affect the work process of healthcare staff if they are to design appropriate studies and countermeasures.

3.4. *Informatics implications of prospective memory*

Several implications for IT systems follow from PM research. In general, designers of IT systems should be aware of possible adverse side effects of IT innovations, as pointed out by Ash et al. [75]. For example, Collins et al. [41] observed that when a CPOE was used during a medical round, the CPOE user was interrupted and had to interrupt others in order to use the CPOE effectively. New IT systems should be tested for their potential to interrupt and to cause additional interruptions.

First, IT systems could remind people what they were doing before the interruption by providing cues on the display. Second, IT systems either should be designed in a way that makes them sensitive to the possibility of interfering with working memory processes or they should use non-interfering means of output. For example, tasks on work lists could be highlighted rather than being signaled by obligatory reminders that pop up.

Third, so far developers of IT systems have focused on delivering information to support sensing and deciding [76]. As reported above, Rothschild et al. [56] found that over 50% of all healthcare errors noted were slips and lapses, such as not executing an intended action. Rothschild et al. [56] concluded that "medicine has focused more on what to do than on ensuring that plans are effectively executed" (p. 1697). IT systems could offer solutions that help healthcare workers execute plans. For example, electronically accessible work lists that integrate system inputs from different healthcare workers in a timely fashion would provide non-disturbing reminders. In addition, IT could support *tailoring*—the possibility for the user to make modifications that preserve awareness of intended actions or that produce reminders on demand [77]. Such "user-initiated notifications" have been used in other industries [78].

Fourth, no conclusion can be drawn about memory failures and interruptions without taking the worker's situation into account. The limitations of human memory are well known, but the situation might often mitigate memory limitations by providing cues or explicit reminders. *Distributed cognition* is an approach that highlights the fact that humans are supported by their physical and social ecology as they perform cognitive tasks [79] which has been translated to health informatics by Hazlehurst and colleagues [80] and others [81]. Distributed cognition is a promising approach in understanding and designing support for many kinds of tasks involving PM.

Fifth, if a person uses a synchronous technological communication channel, such as a telephone, he or she has no awareness of the situation of the person being contacted. The AWARE Architecture described by Bardram and Hansen [82] produces *context-mediated social awareness*, which gives the interrupter information to decide when and how to contact the other person. The AWARE Architecture includes text messages that notify a person without interrupting him, so removing the load of remembering from the sender and creating a reminder for the recipient. Designing for context-mediated social awareness is different from designing *attention aware systems* [83] which try to capture the user's situation and, for example, interrupt him after completing a task. Currently, attention aware systems may not be as helpful in healthcare as context-mediated social awareness.

Overall, healthcare IT systems should be designed and evaluated with regard to their potential disruptiveness (especially on working memory processes) and their potential to provide cues and non-interruptive reminders for intended tasks.

4. Logical connection of interruptions to incidents

As the literature review shows, interruptions do not always lead to adverse events—indeed, they do so very seldom. If we are to make a connection between interruptions and adverse events, we need to take into account current thinking about how adverse events occur.

In the last 25 years, accident models have shifted from "one cause leads to one effect" models to models that assume that accidents have multiple causes. In contrast, the evidence-based approach underlying the AHRQ report [1] and many subsequent papers appears to be based on "one cause leads to one effect" reasoning. Evidence is valued if it is based on a significant difference achieved in a well-controlled study, such as the study by Flynn et al. [3] on medical dispensing errors. Flynn et al.'s results show that the interrupted trials included more errors than the non-interrupted. However, not all interruptions lead to errors, not all interruptions are preventable, and the content of the interruption might have a positive effect on case progression. Therefore, more sophisticated approaches are needed to understand when interruptions are disruptive and when not.

In the remainder of this section, first we discuss two accident models and outline their advantages and disadvantages for interruptions research. Second, we point out that by observing how people successfully manage interruptions we may better understand how interruptions function in context. Third, we note that interruptions can have disruptive effects on human cognition but may also have positive effects on higher-order goals such as eventual patient outcomes.

4.1. *The role of interruptions in the genesis of errors*

Reason's Swiss Cheese model [12] may have limited scope for explaining how interruptions function to produce errors. In Reason's model it is presumed that a system has many defensive layers that prevent adverse events happening, such as procedures, physical barriers, and the vigilance of staff members. The defensive layers can be compromised by active failures and latent conditions. *Active failures* are unsafe acts caused by people involved at the "sharp end" of the system (e.g., forgetting to administer or administering the wrong medicine). Active failures always have a context and history that are influenced by *latent conditions* which lie dormant in the system and which are usually consequences of decisions at the "blunt end". Latent conditions contribute to errors by setting up error prone working conditions (e.g., time pressure, understaffing) and creating long-lasting safety threats (e.g., untrustworthy alarms).

Alvarez and Coiera [69] noted the potential relevance of Reason's model for interruptions and they suggested that interruptions are a kind of latent condition. However, not all interruptions fit Reason's description of latent conditions. For example, not all interruptions are built into the system, as Reason would require for a latent condition. Furthermore, a logical consequence of Reason's view would be to construct defensive layers that eliminate interruptions. However, interruptions can also have positive effects (see next section). Moreover, there is a well-recognized need to improve clinical communication [69] and trying to eliminate all interruptions would inhibit rather than improve communication [6].

Although Reason's model can be applied to contemporary healthcare systems, it may not be as apt in healthcare as it is in its original process control domain. Healthcare workers are often the (only) defence against unwanted outcomes whereas in other domains procedures and build-in safety devices provide defence as well [84]. For healthcare systems, the recently introduced model by Hollnagel [13] and perspectives from so-called resilience engineering [85] may be a more useful way to understand the relationship between interruptions and adverse events.

As in Reason's model, in Hollnagel's [13] model it is assumed that accidents emerge from an unexpected combination of events that might include technological failures, latent conditions, human performance variability, and missing barriers. In contrast to Reason's model, however, in Hollnagel's model it is assumed that accidents in complex systems cannot be captured adequately in causal sequences because of the dynamic nature of complex systems and the non-linearity of effects. A small change in one part of a system might affect another part of the system in an unexpected and much stronger way. Every part of the system exhibits performance variability and the output of different parts of the system combines in a non-linear way (*functional resonance*). When functional resonance produces system performance below acceptable levels we have an accident, whereas when functional resonance produces system performance at or above acceptable levels, we have success. Variation that leads to human performance dropping below acceptable levels is not seen as an active failure but instead as the result of normal variability in performance, when workers' normal need to trade off efficiency vs. thoroughness in their performance happens to encounter an unusually cognitively demanding situation.

Hollnagel's functional resonance model [13] has several advantages for understanding the potential impact of interruptions in healthcare. First, it helps to explain how interruptions can have both negative and positive effects. Second, it accounts better for the relationship between interruptions and adverse outcomes since not every interruption will lead to an accident. For example, if a nurse is interrupted by a patient's family member at the patient's bed while setting up an infusion pump, she is likely to finish the task. If the nurse is interrupted by an emergency, however, and has to hurry to another room, she is less likely to finish the task (note that each case contains normal performance with intact defences). Third, the Hollnagel model helps analysts focus on controlling performance variability in a way that retains and even enhances positive variability.

Overall, it seems that both models can be useful. In Reason's model [12] the goal of eliminating uninformative interruptions or interruptions of highly vulnerable tasks [27] is appropriate. In Hollnagel's systemic accident model [13], the complex nature of interruptions is captured better, indicating that analysts should find a way to buffer rather than to remove negative performance variability of healthcare staff.

4.2. How are effects of interruptions prevented?

If analysts decide to buffer the adverse effects of interruptions rather than to remove interruptions, how might this be achieved? Recently Cook et al. [86] described the medical domain as having "gaps" in care that must be constantly bridged by healthcare workers, such as shift handovers or the need to divide attention between different patients. Cook et al. [86] argue that in order to understand how failures to bridge these gaps might happen, one has to understand how success usually happens.

Applying such thinking to interruptions research, researchers may gain richer perspectives by moving away from the current practice of studying only the *adverse* consequences of interruptions. For example, Drews [5] reports 335 interruptions but only five adverse events as a result of interruptions. It is unclear what was different about the 330 interruptions that were not followed by an adverse event. The answer matters for two reasons. First, observing how staff members deal successfully with interruptions might tell researchers more about the cognitive and social processes involved in, and affected by, interruptions [86]. Second, artifacts used to manage the effect of interruptions might be useful for designing new technological products. For example, IT products could support cognitive processes disrupted by interruptions or the results could be used for interruption management [86]. Again, the concept of distributed cognition [79,80] might be a powerful approach for understanding how staff members handle interruptions and how the system might buffer the effects of interruptions.

4.3. "Good" or "bad" interruptions

Most interruptions research to date has focused on the adverse outcomes of interruptions and therefore how interruptions might be reduced. This focus neglects possible benefits for the interrupted person [87] such as gaining new information [45], or receiving an alert if the person is about to commit an error [88]. It also neglects benefits to the interrupter, who gets immediate acknowledgement for delivering information [6] or who secures information that let them proceed with an otherwise suspended task.

To understand whether an interruption has a positive or negative effect we must know what aspects of performance are affected by the interruption. Negative effects might emerge more strongly from the interruption of cognitive processes, leading to longer times on task [89], longer lags before resuming a task [90], more PM failures [8], and effects on other intrapersonal processes such as emotions [7], stress [91], and frustration [54]. Positive effects might emerge more strongly from the content of the interruption, such as when receiving new information on which to base interventions, hearing alarms that warn about hazardous patient states, or receiving an interruption that prevents an error as mentioned above.

Therefore, as long as the information delivered is important, we might speculate that there are no intrinsically "good" or "bad" interruptions. Such a realization might make it harder to relate interruptions to medical errors because the disruptive effect on cognition might be outweighed by the effect that the content of the interruptions might have on the higher-order aim of promoting patient well-being. From this point of view the variable "adverse event" or "medical error", as used in the studies reviewed above, might be too remote from the immediate effects of interruptions for a cause–effect relationship to be easily found.

4.4. Informatics implications of performance variability

Researchers have suggested that IT can play the role of one of Reason's defense barriers and so help to prevent clinical communication errors [92]. As mentioned earlier, new technology may itself cause new interruptions [75]. The challenge posed to IT systems by the systemic accident model is to determine how negative performance variability can be prevented without adding further problems, and how positive variability can be fostered. The ideas mentioned in the previous section "Informatics implications of PM" fit these demands.

The systemic accident model implies that healthcare workers must trade off between potentially negative and potentially positive effects of interruptions, rather than avoiding all interruptions. For example, alarms disrupt the task at hand, yet despite literature on their uninformative and annoying nature they are still required to preserve patient safety [93]. The same holds true for IT systems that have positive effects.

5. Conclusions

The AHRQ report of 2003 [1] rated the evidence as insufficient that interruptions and distractions jeopardize patient safety in healthcare domains other than medication dispensing errors. Five years later, solid evidence is absent. The descriptive studies do not relate interruptions to medical error in any way, which constitutes absence of evidence. Three cause-and-effect studies provide evidence of a connection between interruptions and error (evidence of presence); one study provides evidence of no connection between interruptions and errors (evidence of absence); and five studies are inconclusive for methodological reasons (absence of evidence).

One methodological reason may be that the lack of consistent definitions makes it difficult to accumulate evidence across studies [70]. A second reason may be that the healthcare domain is loosely coupled, making it harder to find such relationships as it is in, for example, the cockpit. A third reason may be that medical errors are an insensitive dependent variable. In principle, interruptions could have positive effects on the patient status but negative effects on healthcare practitioners' cognitive processes.

Prospective memory research coupled with an understanding of accident models can help researchers understand the relation between interruptions and medical errors. First, PM research offers mechanisms through which interruptions lead to memory failures. Second, PM research provides a basis for understanding differences in the cognitive demands of different tasks and therefore why results from aviation cannot be applied directly to healthcare. Third, and most importantly, PM is relevant for understanding performance in healthcare beyond the context of interruptions and further research is needed urgently. We suggest that future research on interruptions should be driven more strongly by theory and should address the specific context of healthcare work more analytically. The crucial step is to arrive at a better understanding of the cognitive and particularly the PM processes involved in, and affected by, interruptions.

While researchers determine the exact relation between interruptions and adverse events, we can offer three recommendations for practice that avoid simply exhorting healthcare workers not to interrupt each other. The first recommendation is to reduce the need for interruptions where possible by implementing resources, artifacts, or information systems that provide the information or support that is otherwise missing and that motivates an interruption. This approach has been advocated by other researchers before [e.g., 6,81,92].

The second recommendation is to help personnel decide whether to interrupt by making the possible effect of interruptions obvious. For example, a nurse may wear an apron while preparing medications, indicating that she prefers not to be interrupted [27]. The apron offers a visible indication that an interruption might jeopardize safe execution of the medication task.

The third recommendation is to make the workplace resilient to the effects of interruptions. This recommendation has the advantage of preserving the potential positive effects of interruptions, because it does not prevent interruptions. Resilience is enhanced if the burden of resuming an interrupted task is not the PM task of just a single person (e.g., a nurse), but of the interrupter as well, or of the unit as a whole. The PM task needs to be a *distributed prospective memory* task in the sense that multiple agents (other nurses, equipment, IT) remind the nurse of the intended task.

In summary, the study of the impact of workplace interruptions on patient well-being raises a host of methodological, conceptual, and practical issues that we have outlined and discussed. We look forward to a future phase of research in which the above issues are addressed more effectively, providing a more solid basis for our views about the impact of workplace interruptions on patient well-being.

Summary points

"What was already known before the study was done"

- Interruptions were associated with medical errors but the evidence for a relation was largely absent.
- Interruptions research in the medical domain did not fully investigate the role of memory.
- Alternative views of how interruptions might cause errors were neglected.

"What this study has added to our knowledge"

- A few studies have strengthened the evidence for a relation between interruptions and medical errors.
- Research on prospective memory adds useful theoretical perspective to interruptions research.
- Recent models of accident causation help explain why the relation between interruptions and medical errors is weak and they explain the beneficial vs. adverse effects of interruptions.

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