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Review article

Improving our understanding of multi-tasking in healthcare: Drawing together the cognitive psychology and healthcare literature

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ABSTRACT

Multi-tasking is an important skill for clinical work which has received limited research attention. Its impacts on clinical work are poorly understood. In contrast, there is substantial multi-tasking research in cognitive psychology, driver distraction, and human-computer interaction. This review synthesises evidence of the extent and impacts of multi-tasking on efficiency and task performance from health and non-healthcare literature, to compare and contrast approaches, identify implications for clinical work, and to develop an evidence-informed framework for guiding the measurement of multi-tasking in future healthcare studies. The results showed healthcare studies using direct observation have focused on descriptive studies to quantify concurrent multi-tasking and its frequency in different contexts, with limited study of impact. In comparison, non-healthcare studies have applied predominantly experimental and simulation designs, focusing on interleaved and concurrent multi-tasking, and testing theories of the mechanisms by which multi-tasking impacts task efficiency and performance. We propose a framework to guide the measurement of multi-tasking in clinical settings that draws together lessons from these siloed research efforts.

Contents

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1. Background

In the contemporary workplace individuals are often called upon to multi-task (Salvucci and Taatgen, 2011a). This is particularly true of healthcare where clinicians are required to manage multiple patients at once in environments characterised by time pressure (Chisholm et al., 2000; Kobayashi et al., 2007). In a study examining over 1000 h of observational data of doctors and nurses in teaching hospitals, the rates at which clinicians performed two tasks in parallel ranged from 9.2 multi-tasking events per hour in an emergency department, to 17.3 on hospital wards (Walter et al., 2013). The introduction of information technology (IT) further increases the opportunity to multi-task (Appelbaum et al., 2008), and healthcare is undergoing a rapid increase in the adoption of IT to support care delivery (Jones et al., 2014). However, the impact of multi-tasking on clinical work remains under-explored.

Research from non-healthcare areas such as that addressing the safety implications of driver distraction (Ishigami and Klein, 2009), the distracting potential of computer-based instant messaging (Bowman et al., 2010), and the discipline of cognitive psychology (Pashler et al., 2000) demonstrates that multi-tasking typically results in increased time to task completion, increased stress, possible memory lapses and subsequent errors and accidents (Appelbaum et al., 2008). Studies of interruptions to clinical work have demonstrated potential problems associated with interruptions, and possible strategies for dealing with them, just as the aviation industry recognised and introduced the sterile cockpit (Loukopoulos et al., 2009; Sumwalt, 1993). Failure to examine multi-tasking with the same degree of attention as interruptions may have missed an important element in understanding the clinical work context.

In this review our objective was to draw together the empirical research literature on multi-tasking from healthcare and non-healthcare sources, to inform future investigations of multi-tasking in healthcare. Our aims were to: (1) synthesise the evidence of the impacts of multi-tasking on efficiency and performance from the cognitive psychology, driver distraction, and human-computer interaction (HCI) literature; (2) examine and compare what is known about multi-tasking in clinical settings with these bodies of literature; and (3) propose a framework to guide the measurement of multi-tasking in healthcare building on evidence generated from these fields of investigation.

2. Method

2.1. Search strategy

The literature databases PsycINFO, PsycArticles, Web of Science and Scopus were searched to identify the cognitive psychology literature on multi-tasking. Since this literature examines two forms of multi-tasking – *concurrent* (or dual-task interference) and *interleaved* (or task-switching) – search terms were used to cover both forms (definitions in Box 1). These searches identified two areas of research with substantive bodies of literature on multi-tasking in applied domains: driver distraction and HCI. An additional two search strategies were applied targeting these topics. Studies of multi-tasking in clinical settings were identified through searches of PubMed. Furthermore, the reference lists of four recent reviews of interruptions in clinical settings were hand searched (Grundgeiger et al., 2010; Li et al., 2012; Raban and Westbrook, 2013; Rivera-Rodriguez and Karsh, 2010), as multi-tasking is often reported in studies examining interruptions. PubMed searches were conducted in September 2015 and limited to journal articles in English. The remaining searches were conducted in April 2015. Table 1 shows the search terms used.

2.2. Inclusion and exclusion criteria

From the cognitive psychology, driver distraction, and HCI literature, studies examining the impact of multi-tasking on performance and efficiency in general population samples were included. All study methodologies (experimental, simulator, and observational) were included. Inclusion criteria for studies in healthcare settings were empirical studies reporting quantitative data on the frequency and/or effects of multi-tasking. Studies relying on self-report to measure the incidence or frequency of multi-tasking were excluded, since self-report of workflow is prone to measurement error (Ampt et al., 2007; Bratt et al., 1999; Burke et al., 2000).

2.3. Data extraction

Data extracted from the 29 included clinical studies comprised

Box 1
Definitions of types of multi-tasking.

Concurrent multi-tasking (or dual-task interference, dual-tasking, dual-task performance) is the performance of two or more actions simultaneously (Pashler et al., 2000) e.g. a doctor continuing to write an order while also answering a colleague's question.

Interleaved multi-tasking (or task-switching) is the management of multiple tasks in which there is switching between tasks that are progressing in parallel (Pashler et al., 2000; Adler and Benbunan-Fich, 2012; Rogers and Monsell, 1995; Rubinstein et al., 2001) e.g. a doctor stopping writing notes to speak to a colleague and then returning to writing the notes. Several definitions of interruptions in the healthcare literature (see Table 2) are consistent with interleaved multi-tasking which is externally prompted.

Concurrent and ***interleaved*** multi-tasking have been combined under a unifying theory in which their location on a continuum is characterised by the frequency of attention switching: at one end, concurrent task performance (dual-tasking) involves frequent attention switching giving the impression of simultaneous action, while at the other tasks are completed sequentially without overlap or switching (Salvucci and Taatgen, 2011b).

Table 1
Search terms used to identify cognitive psychology and healthcare literature on multi-tasking.

Literature	Terms
Concurrent (dual-task interference)	bottleneck AND dual-task OR dual task OR dual task performance[a] OR interference (learning)[b] OR task complexity[a]
Interleaved (task-switching)	cognitive processes[a] OR task complexity[a] OR task switching[a] AND task set AND performance[a] OR reaction time[a] OR response latency[a]
Driver distraction	cellular phones[a] OR telephone systems[a] AND distraction[a] OR distractibility[a] AND drivers[a] OR driving behaviour[a]
Human-Computer Interaction	multitasking[a] AND computer mediated communication[a] OR electronic communication[a] OR internet[a] OR mobile devices[a] OR communications media[a]
Healthcare	multi-task[c] OR multitask[c] OR concurrent task[c] OR dual-task[c] OR dual task[c] OR task-switch[c] OR task switch AND doctor OR physician OR nurse OR clinician OR pharmacist

[a] Terms searched as both subject headings and free text.
[b] Subject heading terms.
[c] Indicates a search 'wild card'.

the type of multi-tasking examined (i.e. concurrent or interleaved), and the impact of multi-tasking on efficiency and performance. Any other reported impacts were also recorded, as was the multi-tasking rate, type of clinical setting, and type of clinician studied (e.g. nurse, doctor, pharmacist). The volume of literature on cognitive psychology, driver distraction, and HCI prevented a systematic data extraction. Key research findings were instead synthesised in a narrative overview format.

3. Results

The results start with a consideration of the experimental cognitive psychology literature. The difference between concurrent performance, where two tasks are carried out at the same time, and interleaved task performance, where an individual must choose to perform one task and then switch to another (Pashler et al., 2000), is first addressed. The evidence from this literature indicates that the dual-task decrement using both concurrent and interleaved multi-tasking is smaller when individuals choose to multi-task (Vandierendonck et al., 2010) as opposed to being compelled to do so by an outside stimulus. The sensory input of the task, or the type of output required, referred to as the task modality, also has an impact on multi-tasking performance and is discussed below (Wickens, 2002).

3.1. Concurrent multi-tasking

Executing two tasks together carries a performance cost in terms of decreased accuracy (Rohrer and Pashler, 2003), and increased reaction time to environmental stimuli (Nijboer et al., 2013). Experimental studies have typically investigated this by presenting two tasks in close proximity and observing the participant's response to both (Pashler et al., 2000). The response to the task presented second is usually delayed (Pashler et al., 2000; Telford, 1931). Increasing the time between presentation of the first and the second task reduces the delay in responding to the second task (Pashler et al., 2000). In contrast, the time between presentation of the first task and the research participants' response to it remains constant.

The reason for the slower response to the second task is thought to result from a bottleneck in retrieving the appropriate response to tasks (Pashler et al., 2000). Experimental studies overwhelmingly indicate increased time to produce a response to the second task (Rohrer and Pashler, 2003; Carrier and Pashler, 1995; Ruthruff et al., 2003). The concurrent multi-tasking effect has been observed in tasks combining different response modalities, such as manual and vocal responses (Osman and Moore, 1993; Pashler, 1990; Pashler et al., 1993). It has also been found when two stimuli involve different sensory modalities, for example visual and auditory stimuli (Borger, 1963; Creamer, 1963). This effect has also been demonstrated in driver simulator studies of braking in response to brake lights from a leading vehicle, even when participants are instructed to give priority to the braking response (Levy and Pashler, 2008; Levy et al., 2006).

3.2. Interleaved multi-tasking

In contrast to concurrent task performance, interleaved multi-tasking experiments examine how individuals switch between tasks and the impact of switching on subsequent performance (Jersild, 1927; Monsell, 2003). Task set is commonly referred to in task-switching paradigms and is defined as the configuration of one's mental state to be compatible with the current task requirements (Rogers and Monsell, 1995). When an individual switches tasks, they have to 'reconfigure', or activate a new task set. This is called task set reconfiguration, and it results in an increased response time to the new task, and an increased likelihood of errors (Pashler et al., 2000; Rubinstein et al., 2001; Karayanidis et al., 2010; Kiesel et al., 2010).

Jersild is credited with the first study of interleaved multi-tasking. This study identified that participants took 34% longer to complete each task when they were required to alternate between adding six and subtracting three to a two-digit number (Jersild, 1927). In addition to the longer reaction time incurred when individuals engage in interleaved multi-tasking, there is also an increased likelihood of a task error with every switch (Rogers and Monsell, 1995). These results have been replicated using a variety of experimental paradigms and different stimuli (Rogers and Monsell, 1995; Rubinstein et al., 2001; Allport et al., 1994; Biederman, 1973; Gopher et al., 2000; LaBerge et al., 1977; Logan and Zbrodoff, 1982; Meiran, 1996; Meyer and Kieras, 1997a, 1997b; Spector and Biederman, 1976; Sudevan and Taylor, 1987). Furthermore, a residual cost associated with interleaved multi-tasking occurs regardless of the amount of time available to participants to prepare for the switch (Rogers and Monsell, 1995; Monsell and Mizon, 2006). Interleaved multi-tasking results in greater difficulty coping with the conflict between reading out a printed word for a colour and naming the colour it is printed in (Kalanthroff and Henik, 2014), and interferes with identifying a reminder to perform a previously suspended task (West et al., 2011). It also increases the difficulty participants experience in redirecting attention from a previously relevant stimulus to a currently relevant one (Longman et al., 2013, 2014).

3.3. Choosing to multi-task versus being explicitly prompted

Voluntary, or internally prompted, multi-tasking has different implications for efficiency and errors than being externally prompted. Voluntary multi-tasking refers to when an individual decides whether and when to multi-task. In voluntary interleaved multi-tasking experimental studies, the participants themselves decide which task to perform on each trial, so long as every task is completed equally often and at least some switching between tasks occurs. A review of interleaved multi-tasking identified that the cost of voluntarily switching tasks was smaller than if participants were forced to switch tasks (Vandierendonck et al., 2010). However, the cost of switching tasks still remained compared to trials where the task had been repeated. A study comparing voluntarily and externally prompted switching found that task errors (executing the wrong task on a trial) were more frequent for externally prompted subjects compared to voluntary-switch subjects (1.5% of trials with errors versus 0.3% errors respectively) (Masson and Carruthers, 2014).

Voluntary multi-tasking allows the individual to control the amount of cognitive load they impose upon themselves. In a study asking participants to first generate their own plan for the order they will complete tasks (including at least one switch between tasks), and then execute the tasks in the order their plan dictated, participants tended to generate the least complex sequence of tasks to perform. This finding suggested that voluntary task switching might enable individuals to use strategic organisation of tasks to lower their cognitive load (Reiman et al., 2015). A recent experimental study investigated the influence of forced task-switching on individuals who were otherwise expecting to choose when they switched tasks (Weaver et al., 2014). Participants planned which task they wanted to perform, and then were presented with a task that did not match their choice. Participants demonstrated longer reaction times and a higher likelihood of errors when forced to perform a task. This effect was largest when they expected to switch tasks, but had to unexpectedly repeat the previous task. The evidence overall suggests that individuals choosing to multi-task might do so in a way that reduces their cognitive load, however they will still take a longer time to complete tasks and exhibit a higher frequency of errors when they multi-task.

3.4. Task modality

The influence of task modality, in other words whether the task requires sensing or responding to spatial locations, tactile stimuli (i.e. vibrations or button presses), or visual/linguistic signals, can also have implications for the efficiency with which individuals multi-task (Scerra and Brill, 2012). Wickens' (Wickens, 2008) multiple resource theory argues that multi-tasking will be less effective where tasks share modalities. In other words, an individual listening to a news report while completing a jigsaw puzzle (auditory-visual) will be more effective at both tasks than an individual listening to a news report and conducting a conversation (auditory-auditory). Scerra and Brill (Scerra and Brill, 2012) found that pairing a tactile stimulus signalling the primary task with a tactile secondary task (in both cases a vibration applied to the torso) resulted in a reduction in accuracy and an increase in reaction time on both tasks, compared to tactile-visual and tactile-auditory pairings. The participants in this study also rated workload in the tactile-tactile condition as much higher than in the other two dual-task conditions. A recent study on multi-tasking and brain activation levels found that when tasks performed together used the same resources (both tasks used visual and motor skills), an observed overlap in brain activation correlated with an increased reaction time on the tasks (Nijboer et al., 2014).

3.5. Studies using applied task domains

The research addressed above forms the corpus of cognitive experimental work on multi-tasking. Performance decrements were identified using experimental tasks conducted in highly controlled laboratory environments. Further, speed and accuracy issues identified were generally modest, and thus the impacts when considering real-world multi-tasking are not readily apparent. It is not clear from these studies whether such decrements in both speed and accuracy will translate in highly practiced tasks more closely linked with real-world situations. Researchers in the areas of driver distraction and HCI address instances of applied multi-tasking using experiments (Bowman et al., 2010; Levine et al., 2012), simulator studies (Briggs et al., 2011; Haque and Washington, 2014; Rudin-Brown et al., 2013), and naturalistic observational studies (Bakiri et al., 2013; Klauer et al., 2014) which more closely approximate the environmental conditions under which multi-tasking takes place.

3.5.1. Driver distraction studies

Driver distraction has been defined as the diversion of attention away from activities critical for safe driving towards a competing activity (Klauer et al., 2014; Redelmeier and Tibshirani, 1997). Typical studies in this area investigate the detrimental effects of using a phone while driving (Ishigami and Klein, 2009; Caird et al., 2008; Horrey and Wickens, 2006; Young and Salmon, 2012). Driving while using a phone can be thought of as concurrent multi-tasking with two tasks in different modalities (i.e. the driving task is visual-manual, while the phone task is auditory). Epidemiological analysis of car accident data indicates that a conversation on the phone while driving produces a fourfold risk of having an accident, and is estimated to be equivalent to driving with a 0.08% blood alcohol level (Strayer et al., 2006).

Being distracted by a phone conversation while driving increases reaction times, regardless of phone type (handheld or hands-free) (Haque and Washington, 2014; Berg and Dessecker, 2013; Charlton, 2009; Kass et al., 2010). The results of two meta-analyses showed that reaction time to events is most affected by phone conversations, with hand-held and hands-free phones producing longer reaction times to events outside the car than driving without having a phone conversation (Caird et al., 2008; Horrey and Wickens, 2006). In-car use of both mobile phone types also produced significant reductions in drivers' lane-keeping ability (Briggs et al., 2011; Rudin-Brown et al., 2013; Stavrinos et al., 2013), speed maintenance (Briggs et al., 2011; Rudin-Brown et al., 2013; Stavrinos et al., 2013; Garrison and Williams, 2013; Reimer et al., 2011), ability to detect and recall hazards on the road (Briggs et al., 2011; Garrison and Williams, 2013; Nabatilan et al., 2012), and an increased likelihood of accidents compared to a control group not using the phone while driving (Klauer et al., 2014; Redelmeier and

Tibshirani, 1997). These findings generalise across simulators, instrumented vehicles, and observations of individuals driving a car in traffic.

3.5.2. Human-computer interaction

The impact of multi-tasking is readily apparent in studies investigating the concurrent use of information technology (IT) in educational and workplace settings (Levine et al., 2012). This research suggests that most individuals find it difficult to divide their attention among ongoing tasks (Bluedorn et al., 1992). A study of the use of instant messaging (IM) among military personnel controlling a new Tactical Tomohawk missile found that IMs essential for communication between Navy ships regarding the control of the missile, also distracted individuals from the primary task of missile control. This distraction resulted in an overall degradation of team mission performance, as well as a loss of individual situation awareness (Cummings, 2004). Knowledge workers required to complete tasks of varying complexity while switching to videotapes of world news or a social interaction with four individuals took up to three times longer to complete their main task (Nicholson et al., 2009). Students attempting to complete parts of their coursework were similarly affected by instant messages, and spent up to 50% longer reading a passage from a textbook than individuals who did not IM during reading (Bowman et al., 2010). A recent study of students performing two tasks on the computer found that individuals showed a strong preference to complete one task until the workload of the primary task had been minimised (Salvucci and Bogunovich, 2010). This evidence suggests that individuals use strategies to mitigate the effects of multi-tasking on performance.

3.6. Evidence of multi-tasking in healthcare

In contrast with the cognitive psychology literature, which focuses on the impact of multi-tasking on performance, the healthcare literature has focused on identifying how often clinicians multi-task. Twenty-nine studies reporting multi-tasking in clinical settings, predominantly hospitals, were identified (Table 2) (Chisholm et al., 2000; Walter et al., 2013; Grundgeiger et al., 2010; Arabadzhiyska et al., 2013; Carayon et al., 2015; Berg et al., 2012; Chisholm et al., 2001; Coiera et al., 2002; Collins et al., 2007; Drews, 2007; Edwards et al., 2009; Kalisch and Aebersold, 2010; Laxmisan et al., 2007; Lo et al., 2010; Mache et al., 2011a, 2011b, 2012; Munyisia et al., 2011; Spencer et al., 2004; Tipping et al., 2010; van Rensen et al., 2012; Weigl et al., 2009, 2013; Westbrook and Ampt, 2009; Westbrook et al., 2007,2008,2010a,2010b,2011; Woloshynowych et al., 2007). All used direct observation methods, with some studies also using mobile eye trackers, video recording, or audio recording with direct observation (Grundgeiger et al., 2010; Coiera et al., 2002; Spencer et al., 2004; van Rensen et al., 2012; Woloshynowych et al., 2007). The majority of studies defined multi-tasking as conducting two or more tasks simultaneously. One study examined the number of patients managed in parallel by one doctor. Emergency department doctors were found to manage a single patient in only 16% of their time compared to 59% for primary care physicians (Chisholm et al., 2001). ED doctors were found to spend 37.5 min per hour managing three or more patients compared with 0.9 min per hour for doctors in primary care (Chisholm et al., 2001), reflecting the different clinical settings in which they worked.

Table 3 shows the frequency with which clinicians have been found to multi-task according to the two most commonly reported multi-tasking measures, the percentage of total time spent multi-tasking, and instances of multi-tasking per hour. The variation in these figures is likely due to the heterogeneity of definitions and approaches to measurement of multi-tasking in these studies. Thus comparison of rates across studies should be undertaken with caution. Only four studies attempted to assess the effects of multi-tasking (Table 2) on work efficiency, stress or errors. One study observed the practices of patient handover from the operating room to the post-anaesthesia care unit in six hospitals (van Rensen et al., 2012). The researchers compared handovers involving the simultaneous transfer of equipment and information (i.e a nurse connecting monitoring equipment, while at the same time receiving verbal information about the patient), with sequential handovers, where equipment is first connected, then followed by verbal communication to another health professional. The researchers found that 65% of the 101 observed handovers involved the simultaneous transfer of equipment and verbal communication of patient-specific information. This was despite only 11% of healthcare practitioners reporting that they preferred simultaneous handovers. Simultaneous handovers were found not to be significantly quicker than sequential handovers (1.8 vs. 2.0 min, $p = 0.38$).

A study in a German hospital examined the relationship between multi-tasking and doctors' self-reported strain and performance (Weigl et al., 2013). Observations were carried out over 40 entire shifts, with doctors asked to rate their strain and self-assessed performance (according to productivity, efficiency and quality) twice during their shift. As the rate of multi-tasking, defined as performing two or more activities simultaneously, increased, the level of reported strain increased; however, so did their ratings of their own performance. These studies provide some evidence that individuals do not perceive that multi-tasking might result in decreased performance, even though they do perceive that it places them under increased pressure.

Two studies attempted to ascertain if there was an association between multi-tasking and errors (Collins et al., 2007; Kalisch and Aebersold, 2010). In one study hospital nurses' errors were observed and documented (Kalisch and Aebersold, 2010). An error was defined as "a mistake, inadvertent occurrence, or unintended event in health care delivery" and included violations of hospital policies such as washing hands, checking patient identification, and wearing gowns and gloves. No significant association between multi-tasking and the 200 observed errors was found. In the second study, clinicians were observed using computer provider order entry and clinical information systems. Errors in work were recorded by observers, and included "lack of recall" (the inability to recall previously verbalised information) and "incomplete task" (a task not completed during the observed session). Only nine such errors were observed (Collins et al., 2007). There was no evidence of an association between multi-tasking and error frequency detected by the investigators of either study.

4. Discussion

The healthcare literature has examined multi-tasking differently to the cognitive psychology, driver distraction, and HCI literature. While studies in healthcare have focused on clinician multi-tasking rates, other discipline areas have primarily attended to identifying the mechanisms by which multi-tasking produces reduced performance. The cognitive experimental literature has focused on multi-tasking in two separate bodies of research addressing concurrent and interleaved multi-tasking. Cognitive psychologists investigating both types of multi-tasking have examined the benefits of voluntarily multi-tasking, and the increased difficulty of multi-tasking when both tasks make use of the same modality (in either sensation or response). Both concurrent and interleaved multi-tasking have been shown in experimental studies to result in slower task completion and an increased risk of error. The literature

Table 2
Definitions and dimensions of multi-tasking measured by studies in clinical settings.

Author (year), country	Types of clinician/s (healthcare setting)	Outcomes of MT examined	Multi-tasking definition	Type/s of MT measured	Report both prompted and self-initiated MT separately?	Type of secondary task reported?
Arabadzhiyska et al. (2013), Australia	Doctors (hospital)	–	Simultaneous task performance	Concurrent	No	No
Berg et al. (2012), Sweden	Nurses, doctors (hospital)	–	Carrying out tasks simultaneously with other assignments	Concurrent	No	No
Carayon et al. (2015), US	Doctors (hospital)	–	Simultaneous task performance;	Concurrent	No	No
Chisholm et al. (2000), US	Doctors (hospital)	–	Management of multiple patients	Interleaved	No	No
Chisholm et al. (2001), US	Doctors (hospital & primary care)	–	Tasks performed at the same time; Management of multiple patients	Concurrent; interleaved	No	No
Coiera et al. (2002), Australia	Nurses, doctors (hospital)	–	A period when two or more concurrent communication events occur	Concurrent	No	No
Collins et al. (2007), US	Nurses, doctors physical therapists, OT, med students (hospital)	Lack of recall	Continued interaction in two or more concurrent communication events or tasks	Unclear	Only prompted MT	No
Drews (2007), US	Nurses (hospital)	–	Performing both tasks simultaneously	Concurrent	Only prompted MT	No
Edwards et al. (2009), US	Nurses, doctors (hospital)	–	Attending to at least one duty while also attempting to communicate with another clinician	Concurrent	No	No
Grundgeiger et al. (2010), Australia	Nurses (hospital)	–	Continuous work on both the primary and the distracting task	Concurrent	Only prompted MT	No
Kalisch and Aebersold (2010), US	Nurses (hospital)	Observable errors[b,a]	Being involved in two or more overlapping tasks at one time	Concurrent	No	No
Laxmisan et al. (2007), US	Doctors (hospital)	–	No definition provided	Unclear	No	Yes
Li et al. (2015), Australia	Doctors (hospital)	–	Tasks conducted in parallel	Concurrent	No	No
Lo et al. (2010), Australia	Pharmacists (hospital)	–	Tasks conducted in parallel	Concurrent	No	No
Mache et al. (2011a), Germany	Doctors (hospital)	–	Performing tasks simultaneously	Concurrent	No	Yes
Mache et al. (2011b), Germany	Doctors (hospital)	–	Performing activities simultaneously	Concurrent	No	No
Mache et al. (2012), Germany	Doctors (hospital)	–	Performing two tasks at the same time	Concurrent	No	Yes
Munyisia et al. (2011), Australia	Nurses (nursing home)	–	Performance of two or more duties at the same time	Concurrent	No	Yes
Spencer et al. (2004), Australia	Nurses, doctors (hospital)	–	A period of two or more concurrent communication events	Unclear	No	Yes
Tipping et al. (2010), US	Doctors (hospital)	–	More than one activity occurring simultaneously	Concurrent	No	No
van Rensen et al. (2012), Netherlands	Nurses, doctors (hospital)	Time taken to complete handover	Transfer of equipment and patient/procedure information occurring simultaneously	Concurrent	No	Yes
Walter et al. (2013), Australia	Nurses, doctors (hospital)	–	Adding a secondary task to the primary task in response to either an internal or external stimulus	Concurrent	No	Yes
Weigl et al. (2009), Germany	Doctors (hospital)	–	Two activities were obviously performed in a timely concurrent manner	Concurrent	No	Yes
Weigl et al. (2013), Germany	Doctors (hospital)	Self-reported strain; self-reported performance	Two activities were observed to be evidently carried out in a timely concurrent manner	Concurrent	No	Yes
Westbrook et al. (2007), Australia	Nurses (hospital)	–	Undertaking two tasks at the same time	Concurrent	No	No
Westbrook et al. (2008), Australia	Doctors (hospital)	–	Undertaking two tasks at the same time	Concurrent	No	No
Westbrook and Ampt (2009), Australia	Nurses (hospital)	–	Undertaking two tasks at the same time	Concurrent	No	No
Westbrook et al. (2010a), Australia	Doctors (hospital)	–	Carrying out multiple tasks simultaneously	Concurrent	No	No
Westbrook et al. (2011), Australia	Nurses (hospital)	–	Undertaking two tasks at the same time	Concurrent	No	Yes
Woloshynowych et al. (2007), UK	Nurses (hospital)	–	Concurrently active communication tasks	Unclear	No	No

MT is multi-tasking.
[a] Only provides the number of patients managed concurrently per hour, but not with associated tasks.
[b] Examples include policy violations (e.g. omission of hand washing), writing orders on wrong patient's chart, and performing/ordering tests for wrong patient.

Table 3
Multi-tasking prevalence in healthcare settings by clinician and setting type.

Clinician and setting type	Percentage of time spent multi-tasking	Multi-tasking instances per hour
Hospital		
Doctors		
Emergency department	30.6 (Weigl et al., 2009)	9.2 (Walter et al., 2013)
	12.8 (Westbrook et al., 2010a)	4.9 (Edwards et al., 2009)
	14.6[a] (Coiera et al., 2002)	
	14.8 (Edwards et al., 2009)	
	10.7 (Chisholm et al., 2001)	
Ward	21 (Weigl et al., 2013)	17.3 (Walter et al., 2013)
	20 (Westbrook et al., 2008)	
	6.4[b] (Arabadzhiyska et al., 2013)	
Intensive care unit	24.4 (Li et al., 2015)	40.1 (Li et al., 2015)
	17.1 (Weigl et al., 2009)	
	12.0 (Carayon et al., 2015)	
Internist	17.3 (Weigl et al., 2009)	
Surgeon	20.3 (Weigl et al., 2009)	
Nurses		
Emergency department	14[c] (Woloshynowych et al., 2007)	5.6 (Edwards et al., 2009)
	7.6[a] (Coiera et al., 2002)	
	14.8 (Edwards et al., 2009)	
Ward	5 (Westbrook et al., 2011)	14.1 (Walter et al., 2013)
	11.8 (Westbrook et al., 2007)	
Intensive care units		5.5 (Grundgeiger et al., 2010)
Pharmacists	5.6 (Lo et al., 2010)	
Primary care		
Doctors	19.0 (Chisholm et al., 2001)	

Note: Due to variations in definitions and study methodology, comparison of rates between studies should be undertaken with caution.
[a] Percent of communication time, where communication was defined as 'passing of information from one individual to another' either verbally or in writing.
[b] Doctors on night shift.
[c] Percent of communication occasions spent multi-tasking.

on driver distraction has further demonstrated that multi-tasking causes decrements in performance on driving tasks and is associated with a higher likelihood of car accidents. The HCI literature has demonstrated associations between multi-tasking and reductions in end-of-semester GPA, and poorer performance at controlling important workplace equipment. In contrast, healthcare studies have determined the rate at which clinicians multi-task, and predominantly only measured concurrent multi-tasking. Few healthcare studies have investigated the prevalence of interleaved multi-tasking, or have distinguished between voluntary (self-initiated) and involuntary (prompted) multi-tasking, or the modality of the tasks involved (Table 2).

From the studies in healthcare we can conclude that multi-tasking in hospital wards and emergency departments is frequent. However, the cognitive psychology and real-world multi-tasking literature suggests that multi-tasking in any form ultimately reduces the efficiency and accuracy with which individuals complete tasks. The non-healthcare literature reviewed has three major lessons relevant to investigators attempting to quantify and understand the potential implications of multi-tasking in healthcare, each of which are addressed in turn.

First, concurrent and interleaved multi-tasking both result in increased time to task completion and an increased chance of error for at least one of the tasks. Each type of multi-tasking can be captured through observation and can be determined in different ways. Interleaved multi-tasking can be determined by calculating the number of changes from one task to another as a measure of task-switching. In contrast, concurrent multi-tasking can be measured by calculating the percentage of overlapping tasks as a function of total tasks. Using quantitative observational studies as is common in healthcare studies, attention should be placed on identifying both multi-tasking types.

The second lesson from the non-healthcare literature is that voluntary multi-tasking will likely reduce the time to complete tasks, and reduce the chances of error compared to being forced to multi-task. In situations where multi-tasking is an important part of clinical workflow, allowing clinicians control over their multi-tasking may reduce the likelihood of an error. An example of this is the use of interventions such as 'no interruption zones' and 'no interruption vests' for nurses preparing and administering medications (Raban and Westbrook, 2013). Such interventions allow clinicians some control over their task flow which might also leave them less vulnerable to errors resulting from external prompts.

The third lesson from the non-healthcare research on multi-tasking is related to the modality of the tasks involved. We identified no healthcare studies that investigated task modality. Extrapolating from the non-healthcare literature, if clinicians are receiving information from competing tasks in the same modality, or are required to respond to competing tasks in the same modality, their multi-tasking is likely to take longer and they may be more likely to make an error. In contrast, if information from competing tasks is in a different modality, or the responses to them require different formats, the likelihood of errors and augmented response times may be decreased. For example, while speaking to a ward registrar on the phone about a patient, the doctor might pause to ask another doctor on the progress of a critical patient. In this situation the response modality for both tasks is verbal, and the responses the doctor will get from both are also verbal. This could interfere with the doctor's ability to effectively process one or both of the tasks. Drawing upon evidence from studies outside healthcare may assist researchers to identify factors that contribute to errors, including the modality of each task.

4.1. Drawing siloed research efforts together: a framework for guiding the measurement of multi-tasking in healthcare

Studies in psychology and healthcare have been making independent contributions to understanding multi-tasking using different research methods. The challenge is to combine the lessons from these previously independent research traditions, to enhance our understanding of multi-tasking in the real world, its cognitive mechanisms, its consequences, and the environments in which such consequences are more likely. We propose a framework for identifying (measuring) instances of multi-tasking to assist in the design of future studies in healthcare settings (Table 4). The framework aims to draw out the key factors (type of multi-tasking, modality, prompted or self-initiated) that influence multi-tasking impact on effectiveness and efficiency evidenced from the cognitive psychology, driver distraction and HCI literature combined. Using this framework to quantify these different forms of multi-tasking, will enable researchers to more readily examine the impact of these different forms on task efficiency and performance in healthcare. Findings from this framework can then be investigated in light of existing theories such as that presented by Salvucci and Taatgen (Salvucci and Taatgen, 2011a). The examples given in the table illustrate the array of situations in which emergency department doctors might multi-task, however this framework can be applied to any healthcare or wider workplace situation in which multi-tasking is suspected to have an impact on task errors. Having a clearer understanding of the types and the frequency of multi-tasking that occur in clinical settings will allow us to measure them more effectively, and subsequently to evaluate the implications of each for patient safety.

Observational studies could be designed to identify multi-tasking that was preceded by a prompt versus those that appeared to occur spontaneously (Walter et al., 2013). We additionally suggest that doctors conceive of their tasks as organised by patient. We have included this in the framework under the label 'same versus different patient'. For example, in an emergency department, a doctor follows a particular process for each patient: examination, documentation, conducting tests, interpreting results and so on. It is possible that clinicians group this series of tasks into an overall task to treat patient X, versus the overall task to treat patient Y. Therefore, the most meaningful task boundary for clinicians could be all of the care sub-tasks associated with a single patient. The tasks are conducted in sequence for the care of the same patient, however, they are also likely to be interleaved with similar tasks for other patients. Studies in clinical settings have generally recorded the sub-tasks, without details about tasks related to specific patients (Table 2). These studies prevent the examination of patient-level interleaved multi-tasking, where the doctor has to switch between sub-tasks for different patients, as opposed to sub-tasks for the same patient. If we assume that clinicians think of their tasks as divided by patient, the effects of multi-tasking are most likely to appear at the patient level.

4.2. Strengths and limitations

The framework for guiding the measurement of multi-tasking proposed is applicable to any environment in which multi-tasking

Table 4
A framework for guiding the measurement of multi-tasking in healthcare with examples in an emergency department setting.

	Voluntary multi-tasking[a]		Prompted multi-tasking[a]	
Concurrent multi-tasking	Different modalities[b]	Same modality[b]	Different modalities[b]	Same modality[b]
Same patient/subject	Preparing blood samples to send to pathology while telling the nurse to do another ECG for the patient.	Not applicable	While preparing blood samples to send to pathology a nurse asks about appropriate analgesia for the patient in light of medications administered thus far. Discussion occurs while the sample preparation continues.	Not applicable
Different patient/subject	Preparing blood samples to send to pathology while asking a nurse about another patient.	Not applicable	While preparing blood samples to send to pathology a junior doctor asks for advice on a different patient and a discussion occurs while the sample preparation continues.	Not applicable
Interleaved multi-tasking	Different modalities	Same modality	Different modalities	Same modality
Same patient/subject	Pausing preparation of blood samples for pathology to tell the nurse to do another ECG for the patient.	While speaking to a ward registrar on the phone about the potential admission of a patient, the doctor pauses to ask the nurse whether the patient's blood test results have come in.	While preparing blood samples to send to pathology a nurse asks about appropriate analgesia for the patient in light of medications administered thus far. Blood sample preparations are paused while the discussion occurs.	While speaking to a ward registrar on the phone about the potential admission of a patient, a nurse asks if the patient has to be kept nil-by-mouth. The phone conversation is paused to answer the question.
Different patient/subject	Pausing preparation of blood samples for pathology to ask a nurse about the progress of another patient.	While speaking to a ward registrar on the phone about a patient, the doctor pauses to ask another passing doctor on the progress of a critical patient.	While preparing blood samples to send to pathology a junior doctor asks for advice on a different patient and sample preparations are paused while the discussion occurs.	While speaking to a ward registrar on the phone about the potential admission of a patient, a junior doctor asks the doctor to help with another patient as soon as they are free. The phone conversation is paused to answer the question.

'Not applicable' is used to indicate that it is not possible to use concurrent multi-tasking for tasks of the same modality. For example, it is not possible to simultaneously carry out two writing tasks; it is only possible to do this with interleaved multi-tasking, i.e. switching between tasks.

[a] Voluntary multi-tasking refers to when an individual decides whether and when to multi-task. Prompted multi-tasking refers to a cue or prompt that imposes the multi-tasking on an individual.

[b] Modality refers to whether the task requires sensing or responding to spatial locations, tactile stimuli (i.e. vibrations or button presses), or visual/linguistic signals. In our examples, we have used preparation of blood samples which predominantly uses 'tactile stimuli', and verbal communication, which uses visual/linguistic signals.

occurs. Any multi-tasking instance can be categorised as interleaved or concurrent multi-tasking, voluntary or externally prompted, and the same versus a different modality. Evidence from HCI studies, using a computer program to record the time-stamped activity in separate windows, suggest that interleaved and concurrent multi-tasking can be distinguished by calculating the rate of task switches compared to the rate of task overlap over an observation session. Voluntary versus externally prompted multi-tasking can be identified by including a record of any prompts received over the observation session. In the case of human-computer interaction studies, this might be an instant pop-up message, or a spontaneous switch between windows. In the emergency department, this could include a switch between tasks preceded by communication with another clinician, or without the presence of such a prompt. Task modality might be observed by categorising the type of stimulus that signals the task and what modality the doctor uses to complete it. Recording tasks related to the care of specific patients would allow a measure of switching between patients to be calculated (Benbunan-Fich et al., 2011).

The current review was not systematic, suggesting some of the general impacts of multi-tasking on efficiency and performance might have been missed. All major reviews and highly cited studies in each area were incorporated where they were identified, therefore it is unlikely that any major dimension of multi-tasking impact has been overlooked. Second, empirical evidence of the effects of multi-tasking on task errors is very limited and as we argue in this review deserves greater research attention. In general, the non-healthcare literature suggests that multi-tasking could result in a longer time to complete individual tasks. It can also lead to either errors of omission, i.e. forgetting to return to the original task, or errors of commission, i.e. executing the wrong task for the situation. The selection of specific dependent variables to examine the association between multi-tasking and error are likely to vary by the environmental context, and potentially by the practitioner being recruited to the study. For example, we have developed a research protocol to examine the impact of multi-tasking on prescribing error rates in emergency department doctors (Raban et al., 2015). For nurses, a more appropriate dependent variable could be medication administration errors associated with and without multi-tasking activity.

This review did not explicitly address the role of organisational and process design in healthcare. Multi-tasking is often a behavioural response of employees to insufficient process design. For example, a qualitative study of paediatric nurses and medication administration identified that nurses were required to multi-task when paediatric consultants prompted them, because this often represented the only chance to speak with the clinician (Colligan and Bass, 2012). In this situation asynchronous communication between the nurse and the paediatric consultant was not well supported, resulting in an efficiency cost if the nurse blocked the prompt and had to find the clinician later. The benefits and hazards of multi-tasking also need to be carefully identified and put into the context of the multiple objectives of various stakeholders involved in medical care. For example, the rate of multi-tasking by emergency department staff was positively associated with the rated quality of patient information transfer when the patient was admitted to another hospital department, suggesting that the impacts of multi-tasking are not always negative (Weigl et al., 2015). Both the organisational process design issues, and the potential benefits of multi-tasking to healthcare work, should be considered in future research.

Finally, the current literature review did not explicitly consider prominent theories of multi-tasking. However, much of the empirical findings from the cognitive-experimental literature explicitly tested these theories. For example, Wicken's multiple resource theory suggests that an individual has multiple resources that can be tapped simultaneously by different tasks. However, if these tasks require the same resources at the same time, information from each task will be processed sequentially (Wickens, 2002). This is similar to a threaded cognition account of multi-tasking, which suggests that resources are accessed by tasks in sequence (Salvucci and Taatgen, 2008). This has been tested by presenting tasks in different versus the same modalities (in other words tactile-visual versus tactile-tactile) and observing the influence on performance. As reviewed above, tasks requiring the same modality take longer to complete and are more prone to errors than those that use different modalities. This suggests that the modality of the task will have an impact on the efficiency and effectiveness with which clinicians multi-task.

4.3. Implications

The studies of multi-tasking in healthcare have focused largely on measurement of frequency, and have often applied inconsistent definitions and methods in this process, with limited attention to specifically testing and/or articulating theoretical constructs. The non-health care literature has focused on strong experimental designs, with attention to testing specific theories of multi-tasking and their effects on task performance and outcomes. Experimental and simulation studies demonstrate significant effects of multi-tasking on task performance, both in the short and longer term, in relation to reduced task efficiency and increased risk of error. For example, the HCI literature suggests that repeated multi-tasking can result in a loss of situation awareness that enables a team of military personnel to properly operate tactical weapons. Situation awareness has also been implicated in the performance of surgical procedures, suggesting that multi-tasking over longer periods of time can have an impact on the performance of a surgical team (Hazlehurst et al., 2007). As such these non-healthcare studies provide insights into the potential effects of multi-tasking on task performance in clinical environments that are worthy of investigation. The specific consequences of any reduced task performance will depend greatly on the clinical context.

Clinicians deal with substantially greater task complexity than can be represented by cognitive psychology experiments. The complexity of clinical environments thus presents several substantial challenges to researchers seeking to investigate the relationship between multi-tasking and task performance, as seen by the paucity of studies on this topic. The proposed framework presents a first step in developing more robust and consistent research approaches to this problem. The framework draws upon research in non-healthcare disciplines to focus attention on potential target areas and the mechanisms which may be involved. The framework challenges health care researchers to design more theoretically robust studies in this area, but also challenges those in fields such as cognitive psychology to consider the testing of theories beyond the confines of the laboratory.

5. Conclusions

While multi-tasking in clinical settings is common, studies in these settings have been primarily descriptive, with limited evidence of the impact of multi-tasking on work performance or clinical errors. Most clinical studies have used a concurrent definition of multi-tasking, without considering interleaved multi-tasking, whether the individual engages in voluntary multi-tasking rather than being prompted, the modality of the task, or the patient for whom the task is being conducted. There is a pressing need for research that measures multi-tasking behaviours in clinical settings to apply more sophisticated and robust approaches. This will enable researchers to explore the reasons for, and impact of, clinicians' use of multi-tasking in clinical settings and contribute to multi-tasking theory development. A more nuanced measurement of multi-tasking and the conditions under which it occurs will provide important insights into the risks and benefits inherent in this ubiquitous aspect of clinical work.

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