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Integrating Knowledge of Multitasking and Interruptions Across Different Perspectives and Research Methods

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Abstract

Multitasking and interruptions have been studied using a variety of methods in multiple fields (e.g., HCI, cognitive science, computer science, and social sciences). This diversity brings many complementary insights. However, it also challenges researchers to understand how seemingly disparate ideas can best be integrated to further theory and to inform the design of interactive systems. There is therefore a need for a platform to discuss how different approaches to understanding multitasking and interruptions can be combined to provide insights that are more than the sum of their parts. In this article we argue for the necessity of an integrative approach. As part of this argument we provide an overview of articles in this special issue on multitasking and interruptions. These articles showcase the variety of methods currently used to study multitasking and interruptions. It is clear that there are many challenges to studying multitasking and interruptions from different perspectives and using different techniques. We advance a six-point research agenda for the future of multi-method research on this important and timely topic.

Keywords: Multitasking, Interruptions, Experimental Methods, Meta-Analyses, Interdisciplinary Research, quantified self, individual differences, models, theory, practice

Multitasking and interruptions: of theoretical and practical interest in many fields

How people deal with multiple tasks that are competing for attention has been an active area within the fields of human-computer interaction (HCI) and cognitive science. Researchers have been influenced by a variety of disciplines, from computer science, to experimental psychology, and social sciences. Each field brings its own theoretical perspective and methodological approach. The aim of this special issue is to facilitate the integration of results across these different perspectives and research traditions. In this article we argue for the necessity of this integrative approach.

Perhaps one of the core questions driving research into multitasking and interruptions is: how beneficial or harmful is it to multitask? For example, are interruptions disruptive? Researchers have attempted to answer this question using a variety of methods. For example, observational studies have shown that interruptions occur frequently in many workplaces (e.g., González & Mark, 2004), controlled experiments have shown that interruptions take time to recover from and increase the likelihood of errors being made on a task (e.g., Brumby et al., 2014; Li et al., 2008; Monk et al., 2008), modeling and theoretical work has provided detailed explanations of these effects (e.g., Altmann & Trafton, 2002; Salvucci & Taatgen, 2008), which in turn has informed the design of interactive systems to minimize the costs of interruptions (e.g., Böhmer, Lander, Gehring, Brumby, & Krüger, 2014; Iqbal & Bailey, 2010). Some of this work is presented to a dedicated community; other work is presented at interdisciplinary venues. Our aim is to stimulate debates across disciplines.

We start the rest of this article with some general background on multitasking and interruptions research. We then assert the need for multiple techniques and perspectives in the study of this important and timely research topic. We then introduce the papers in this special issue with a focus on how the variety in their approaches furthers our understanding. Finally, we advance a six-

point research agenda for the future of multi-method research into multitasking and interruptions.

Costs and Benefits of Multitasking and Interruptions

Multitasking and interruptions are ubiquitous. In some environments, such as offices (González & Mark, 2004), multitasking and interruptions affect productivity but are unlikely to have direct dangerous consequences. In other settings multitasking and interruptions can impact safety. For example, in aviation (e.g., Dismukes, Loukopoulos, & Jobe, 2001; Latorella, 1996; Loukopoulos, Dismukes, & Barshi, 2001; McFarlane & Latorella, 2002), healthcare (e.g., Li, Magrabi, & Coiera, 2012; Magrabi, Li, Day, & Coiera, 2010; Rajkomar & Blandford, 2012; Walter, Li, Dunsmuir, & Westbrook, 2014; Westbrook, Coiera, et al., 2010; Westbrook, Woods, Rob, Dunsmuir, & Day, 2010), and driving (e.g., Caird, Willness, Steel, & Scialfa, 2008; Horrey & Wickens, 2006; Mccartt, Hellinga, & Bratiman, 2006). There is a need to understand the potential risks (and benefits) that might arise from multitasking in these and other environments. This can provide insight into cognition and behavior, but also inform the design and evaluation of interactive systems that are frequently used by people in these settings.

Engaging in multitasking behavior usually incurs some kind of cost; this is because switching between tasks requires people make changes to physical and mental states. The operations required to make these changes take time and resources and thereby affect performance. For example, in the case of interruptions, we know that when interruptions are particularly long or taxing, people find it harder to resume their original task (Mark, Voida, & Cardello, 2012; Monk, Trafton, & Boehm-Davis, 2008); that people find it easier to recover after interruptions that are relevant to their current activity (Adamczyk & Bailey, 2004; Czerwinski, Cutrell, & Horvitz, 2000; Gould, Brumby & Cox, 2013); that interruptions have selective disruptive effects on different types of procedural errors (Li, Blandford, Cairns, & Young, 2008); and that interruptions are less disruptive when they occur at subtask boundaries (Bailey & Iqbal, 2008; Iqbal & Bailey, 2005; Janssen & Brumby, 2010;

Janssen, Brumby, & Garnett, 2012; Miyata & Norman, 1986; Monk et al., 2008; Payne et al., 2007; Salvucci, 2005). Research has made efforts to make these cognitive costs more quantifiable (e.g., Altmann & Trafton, 2002; Janssen, Brumby, Dowell, Chater, & Howes, 2011; Salvucci & Taatgen, 2011).

In addition to the cognitive costs associated with multitasking, there are also emotional costs. For example, interruptions can increase feelings of stress and frustration by subjective (Mark, Gudith, & Klocke, 2008) and physiological measures (Mark et al., 2012; Brumby, Du Toit, Griffin, Tajadura-Jiménez & Cox, 2014). One approach to reducing these negative emotions is to stop interruptions from occurring, for example by looking at ways to encourage concentration (Shneiderman & Bederson, 2005). However, in practice it might not always be possible to avoid interruptions altogether. Simple changes to the timing of interruptions might then have a significant effect on the extent to which participants have negative feelings about interruptions (Adamczyk & Bailey, 2004).

Given the potentially negative costs of multitasking and interruptions, why then do people seem to exhibit a natural tendency to multitask and self-interrupt themselves (e.g., Dabbish, Mark, González, 2011)? In some settings multitasking and responding to interruptions can be considered adaptive and rational despite the costs incurred (e.g., Janssen et al. 2012; Janssen et al. 2011). For instance, a medic moving from one patient to the next incurs a variety of costs (e.g., moving wards, changing of gloves, reading of charts) but such moving is entirely rational if a patient requires emergency attention. In other settings people might switch activities if they feel they are making insufficient progress on their current activity (e.g., Payne, Duggan, & Neth, 2007) or because switching tasks might reveal some new or useful information (e.g. information about a meeting being rescheduled). In yet other situations, people switch simply because they are bored (Jin & Dabbish, 2009). In monotonous tasks in particular, occasional multitasking can improve vigilance (e.g., Atchley & Chan, 2011).

All of these research findings have the potential to be used in the design of

virtual, physical, and organizational interventions to help people manage tasks effectively. These range from preventing switching (e.g., Mark et al., 2012), to providing information about the context in which an interruption or distraction takes place (e.g., Grandhi, Schuler, & Jones, 2011; Janssen, Iqbal, & Ju, 2014), to providing training so that people better manage interruptions (e.g., Relihan, O'Brien, O'Hara, & Silke, 2010), to designing systems to mediate the interaction between users and other tasks demanding their attention (e.g., Arroyo & Selker, 2011; Iqbal & Bailey, 2010). Of course, despite the potential for the use of theory in practical settings, the link between theory and practice might not always be immediately obvious. For example, critical assumptions or abstractions that are made in a controlled study might not hold in a more applied context. Inversely, the context of a specific applied setting might interfere with generalizing theoretical insights. This tension between theory and practice further motivates a broad perspective on research and practice into multitasking and interruptions.

The need for multiple perspectives and techniques

Preceding work has investigated multitasking and interruptions using different perspectives and methodological approaches. This has also led to the development of interventions for reducing the disruptive effects of interruptions and frequent multitasking. However, more often than not, these interventions are motivated by a single theoretical perspective or research approach.

We argue that interventions can be improved by combining several approaches to produce more nuanced assessments of tasks, users, and environments. For example, could physiological measures of workload such as pupil dilation (e.g., Iqbal, Adamczyk, Zheng, & Bailey, 2005), skin conductance, and heart rate variability (e.g., Healey & Picard, 2005; Mehler, Reimer, & Coughlin, 2012) be combined with subjective measures (e.g., the NASA-TLX, Hart & Staveland, 1988) and objective measures (e.g., error rate, speed of performance), as well as predictive theoretical models (e.g., Hornof & Zhang, 2010; Howes, Lewis, & Vera, 2009; Janssen et al., 2011; 2012; Janssen & Brumby, 2010; Kieras & Meyer, 1997; Salvucci &

Taatgen, 2008; 2011)? How can qualitative observations be quantified to a level that is useful for quantitatively oriented theoretical models?

Approaches that combine insights from different fields and methodological approaches, and that combine various methods and techniques in their own studies have two advantages. First, a broader perspective and study of multitasking and interruptions (e.g., using multiple methods) has the potential to yield a richer description of human multitasking behavior. Second, as multitasking and interruptions occur in a wide variety of settings, different techniques and methods might be more or less appropriate for each setting. Therefore, a heterogeneous approach to the study of multitasking can assist in understanding multitasking and interruptions in a wider range of settings.

Aggregating multiple approaches in this way is not a trivial task: it requires careful evaluation of how various approaches should be combined, particularly when they might conflict (see Gould et al, 2012). Drawing conclusions even from methodologically similar studies can be made difficult by contextual effects. For example, laboratory work has shown that recovery after interruptions can be made more accurate by encouraging people to stop and think (Brumby, Cox, Back & Gould, 2013). However, introducing enforced pauses in a setting free of experimenter oversight can induce *even more* multitasking (Gould, Cox & Brumby, Forthcoming). Making sense of results from disparate paradigms presents an even bigger challenge; how would one go about reconciling conflicts in data collected simultaneously through work shadowing and computer-based activity monitoring? Of course, it might be the conflicts in results that provide the real insight.

Overview of articles in this special issue

The aim of this special issue is to offer a platform to discuss how different approaches to understanding multitasking and interruptions can be combined to provide insights that are more than the sum of their parts. The articles in the issue cover various approaches and highlight the strengths and challenges that each

method has. We will now provide an overview of the papers in this issue, clustered by the main methods that were used.

Three papers adopted questionnaire-based and interview studies. Mattarelli, Bertolotti, and Incerti (this issue) employed a mixture of methods that consists of survey, diary, and semi-structured interviews to examine how individual perceptions and attitudes about a workplace influence one's multitasking behavior. Paul and Komlodi (this issue) adopted a user experience sampling method (User Experience Report) and semi-structured interviews to study the effect of interruptive notifications in desktop environments and to generate design guidelines based on reported user experiences. Grandhi and Jones (this issue) used a combination of qualitative (semi-structured interview) and quantitative (surveys) approaches to study how the negative effects of being interrupted by a phone call might be reduced. They study this by testing an application that provides the context of a phone call to a call receiver to facilitate their decisions on how to handle the call (e.g., pick-up or post-pone).

Three papers use (computational) models to study multitasking and interruptions. Altman and Trafton (this issue) test whether brief interruptions harm or help performance on a sequential task, and develop a model that provides insight into the underlying cognitive mechanisms. Kujala and Salvucci (this issue) use empirical studies and computational models to study eye-glance behavior during in-car tasks. Wickens, Gutzwiller, and Santamaria (this issue) use a meta-analysis of experiments on interruption management and task switching to inform a mathematical model of sequential multitasking behavior.

A related meta-study is that by Sanderson and Grundgeiger (this issue). They review selected key papers on interruptions in healthcare and devise an analytical framework using the concepts of fidelity, control, and potential generalizability. This framework can guide the review of future papers.

Two papers studied novel aspects of interruptions in controlled settings.

Drews and Musters (this issue) investigated how individual differences in working memory capacity and memory strategies affect interrupted task performance. Hodgetts, Tremblay, Vallières, and Vachon (this issue) use a microworld to study what the impact is of two decision support systems on performance when performance is interrupted. The use of a microworld allows them to integrate results from various metrics (e.g., task performance and eye-tracking data, together with self-reports).

Finally, one study looks at human behavior in a more naturalistic context. Walter, Dunsmuir, and Westbrook (this issue) advocate studying interruptions in naturalistic settings and suggested ways to increase the internal validity of quantitative observational studies through the use of workflow time studies and how continuous observation time and motion data can be analyzed with more sophisticated methods.

Taken together, the studies provide an overview of various techniques and methods that are being used in current studies on multitasking and interruptions. Although the papers do not form an exhaustive collection of topics, methods, and techniques it is clear from them that each method has its own strengths and weaknesses. Although each paper has a "core" methodology, all of these papers have been influenced by findings in related domains and by findings that were identified using other techniques and methods.

A research agenda to guide research on multitasking and interruptions

This special issue gives an indication of where we stand in integrating different perspectives to study multitasking and interruptions. But what are the next steps? A truly interdisciplinary perspective might require researchers to adopt a wider set of methods in their own research and to read a wider set of literature. However, this might not be feasible given the limited resources that the average researcher has.

We therefore have identified a six-point research agenda that might benefit multiple researchers and that can assist in better integration of research across

different settings, methods, and techniques with the aim to gain a better, broader, and more detailed understanding of human multitasking and interruptions. Our list is not exhaustive, but provides a useful starting point:

1. **Closing the gap between interruption research and multitasking research.** Interruption studies and multitasking studies are sometimes treated as different fields. In part this is because interruptions are a specific instance of a situation in which people handle two or more tasks. Using specific terminology thereby makes work precise and well defined. However, as interruptions are only one form of the perhaps broader category of multitasking, the use of very specific terminology could hinder the integration of findings across these specific fields. One promising avenue in this regard is to characterize a multitasking (or interruption) setting based on the amount of time that is spent on one (interrupting) task before moving on the next (or main) task. In this way, studies can be classified along a "multitasking continuum" (Salvucci, Taatgen, & Borst, 2009), where studies that are traditionally considered 'multitasking' or 'interruptions' might overlap. Such a common characterization can aid the identification of commonalities between different research efforts.
2. **Using frameworks and guidelines to relate theory and practice.** Multitasking and interruptions are investigated in settings that range from tightly controlled to very applied. Theoretical frameworks and practical guidelines can facilitate integration of results across this wide spectrum. The work by Sanderson and Grundgeiger (this issue) can help in that regard as it provides a way to characterize a study's fidelity, level of control, and potential generalizability. Similarly, Salvucci and Taatgen (2011) discuss three theoretical "continua" to describe multitasking research: How much time is spent on a task before switching tasks, how applied is the setting, and how abstract is the theory? General theoretical frameworks like these can provide a rich vocabulary to describe study settings. They can thereby help to identify commonalities and differences between settings. This in turn can support meta-analyses.

3. **Neuroscience perspectives for practice.**
   A community that is underrepresented in this special issue is the neuroscience community. A wealth of insights has been gathered on multitasking using neuroscience techniques. Although some have used this knowledge in relatively applied settings (e.g., Anguera et al. 2013), relatively little of this work is presented at human-computer interaction venues. There is therefore scope for incorporating insights, techniques, and methods from neuroscience in applied research and practice.
4. **The role of individual differences in practice.**
   Recent studies have gathered evidence for individual differences in multitasking ability (e.g., Ophir, Nass, & Wagner, 2009; Stoet, O'Connor, Conner, & Laws, 2013; Watson & Strayer, 2010, see also Drews & Musters, this issue). These studies have mostly focused on controlled settings. Less is known regarding how individual differences in multitasking ability might affect performance in practice. For example, how do individual differences in multitasking ability affect concentration in the office, or driver safety? There is room for empirical studies to inform this research. Similarly, there is room for technological and design approaches to investigate how these individual differences can be supported. For example, how can technology reduce the potential dangers for people who are not good at multitasking but who are easily distracted? And how can technology inform or correct the perspective of users who over-estimate their multitasking ability?
5. **The role of the quantified self and behavior logging technologies.**
   Are there ways in which technology can help in gathering more information about users' behavior and their multitasking ability in a wider variety of contexts? One way to achieve this is by making use of "quantified self" approaches (Swan, 2013) in which users voluntarily log their behavior. For researchers, quantified self approaches have the potential to gather data in a variety of contexts and to learn about behavior in situ. For users, quantified self approaches to multitasking have the potential to gain insight in their individual

abilities, strengths, and challenges when it comes to handling interruptions and multitasking situations.

6. **The role of theory, models, and (machine learning) algorithms.** Studying multitasking and interruptions in more settings and richer settings has the potential to gather a wide set of data. However, with it comes a challenge to interpret this "big data". Algorithms and models are needed to process such data. Theory is needed to guide a systematic enquiry of it.

Conclusion

Multitasking and interruptions are intertwined, and their effects can manifest on cognitive, individual, and organizational levels. Different research approaches are needed for different levels of investigation. Some approaches are by comparison easier to coordinate within one study (e.g., combining surveys with interviews, or controlled experiments with computational modeling) than others (e.g., observational data with modeling). In effect, this also hinders the integration of results across studies, as this will then rely more strongly on devising analytical frameworks and carrying out meta-analyses. More work is needed to facilitate a fuller integration of research approaches and methods in multitasking. This can increase the insight that is gained within a single setting, but also help in understanding multitasking and interruptions in a wider range of settings. This special issue contributes to this debate in two ways. First, we have advanced a six-point research agenda that can inform such integration. Second, we present a series of papers that uses a variety of methods and techniques to study multitasking and interruptions.

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