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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.

1. 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 and 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 and Trafton, 2002; Salvucci and Taatgen, 2008), which in turn has informed the design of interactive systems to minimize the costs of interruptions (e.g., Böhmer et al., 2014; Iqbal and 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.

2. Costs and benefits of multitasking and interruptions

Multitasking and interruptions are ubiquitous. In some environments, such as offices (González and 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 et al., 2001; Latorella, 1996; Loukopoulos et al., 2001; McFarlane and Latorella, 2002), healthcare (e.g., Li et al., 2012; Magrabi et al., 2010; Rajkomar and Blandford, 2012; Walter et al., 2014; Westbrook et al., 2010a, 2010b), and driving (e.g., Caird et al., 2008; Horrey and Wickens, 2006; Mccartt et al., 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.

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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 et al., 2012; Monk et al., 2008); that people find it easier to recover after interruptions that are relevant to their current activity (Adamczyk and Bailey, 2004; Czerwinski et al., 2000; Gould et al., 2013); that interruptions have selective disruptive effects on different types of procedural errors (Li et al., 2008); and that interruptions are less disruptive when they occur at subtask boundaries (Bailey and Iqbal, 2008; Iqbal and Bailey, 2005; Janssen and Brumby, 2010; Janssen et al., 2012; Miyata and 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 and Trafton, 2002; Janssen et al., 2011; Salvucci and 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 et al., 2008) and physiological measures (Mark et al., 2012; Brumby et al., 2014). One approach to reducing these negative emotions is to stop interruptions from occurring, for example by looking at ways to encourage concentration (Shneiderman and 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 and 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 et al., 2011)? In some settings multitasking and responding to interruptions can be considered adaptive and rational despite the costs incurred (e.g., Janssen et al., 2011, 2012). 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 et al., 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 and Dabbish, 2009). In monotonous tasks in particular, occasional multitasking can improve vigilance (e.g., Atchley and 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 et al., 2011; Janssen et al., 2014), to providing training so that people better manage interruptions (e.g., Relihan et al., 2010), to designing systems to mediate the interaction between users and other tasks demanding their attention (e.g., Arroyo and Selker, 2011; Iqbal and 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.

3. 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 et al., 2005), skin conductance, and heart rate variability (e.g., Healey and Picard, 2005; Mehler et al., 2012) be combined with subjective measures (e.g., the NASA-TLX, Hart and Staveland, 1988) and objective measures (e.g., error rate, speed of performance), as well as predictive theoretical models (e.g., Hornof and Zhang, 2010; Howes et al., 2009; Janssen et al., 2011, 2012; Janssen and Brumby, 2010; Kieras and Meyer, 1997; Salvucci and 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 et al., 2013). However, introducing enforced pauses in a setting free of experimenter oversight can induce *even more* multitasking (Gould et al., 2015). 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.

4. 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 et al. (2015) 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 et al. (2015) 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 (2015) 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. Altmann and Trafton (2015) 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 (2015) use empirical studies and computational models to study eye-glance behavior during in-car tasks. Wickens et al. (2015) 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 (2015). 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 (2015) investigated how individual differences in working memory capacity and memory strategies affect interrupted task performance. Hodgetts et al. (2015) 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 et al. (2015) 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.

5. 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 et al., 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 (2015) 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 et al., 2009; Stoet et al., 2013; Watson and Strayer, 2010, see also Drews and Musters (2015)). 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 inquiry of it.

6. 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.

References

Adamczyk, P.D., Bailey, B.P., 2004. If not now, when?. In: Dykstra-Erickson, E., Tscheligi, M. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 271–278.

Altmann, E., Trafton, J.G., 2002. Memory for goals: an activation-based model. Cogn. Sci. 26 (1), 39–83.

Altmann, E.M., Trafton, J.G., 2015. Brief lags in interrupted sequential performance: evaluating a model and model evaluation method. Int. J. Hum.–Comput. Stud. 79, 51–65. 〈http://dx.doi.org/10.1016/j.ijhcs.2014.12.007〉 (available online 05.01.15).

Anguera, J.A., Boccanfuso, J., Rintoul, J.L., Al-Hashimi, O., Faraji, F., Janowich, J., et al., 2013. Video game training enhances cognitive control in older adults. Nature 501, 97–101.

Arroyo, E., Selker, T., 2011. Attention and intention goals can mediate disruption in human-computer interaction. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, M., Winckler, M. (Eds.), Proceedings of Interact. Springer, Berlin, pp. 454–470.

Atchley, P., Chan, M., 2011. Potential benefits and costs of concurrent task engagement to maintain vigilance: a driving simulator investigation. Hum. Factors 53 (1), 3–12. http://dx.doi.org/10.1177/0018720810391215.

Bailey, B.P., Iqbal, S.T., 2008. Understanding changes in mental workload during execution of goal-directed tasks and its application for interruption management. ACM Trans. Comput.–Hum. Interact. 14 (4), 1–28.

Böhmer, M., Lander, C., Gehring, S., Brumby, D.P., Krüger, A., 2014. Interrupted by a phone call: exploring designs for lowering the impact of call notifications for smartphone users. In: Jones, M., Palanque, P., Schmidt, A., Grossman, T. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 3045–3054. http://dx.doi.org/10.1145/2556288.2557066.

Brumby, D.P., Cox, A.L., Back, J., Gould, S.J.J., 2013. Recovering from an interruption: investigating speed-accuracy trade-offs in task resumption behavior. J. Exp. Psychol.: Appl. 19 (2), 95–107. http://dx.doi.org/10.1037/a0032696.

Brumby, D.P., Du Toit, H., Griffin, H.J., Tajadura-Jiménez, A., Cox, A.L., 2014. Working with the television on: an investigation into media multitasking. In: Jones, M., Palanque, P., Schmidt, A., Grossman, T. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems – Extended Abstracts. ACM, New York, NY, USA, pp. 1807–1812. http://dx.doi.org/10.1145/2559206.2581210.

Caird, J.K., Willness, C.R., Steel, P., Scialfa, C., 2008. A meta-analysis of the effects of cell phones on driver performance. Accid. Anal. Prev. 40 (4), 1282–1293. http://dx.doi.org/10.1016/j.aap.2008.01.009.

Czerwinski, M., Cutrell, E., Horvitz, E., 2000. Instant messaging: effects of relevance and timing. In: Turner, S., Turner, P. (Eds.), People and Computers XIV: Proceedings of HCI 2000. Springer, Sutherland, UK, pp. 71–76. http://dx.doi.org/10.1016/S1361-3723(02)01112-0.

Dabbish, L., Mark, G.J., González, V.M., 2011. Why do i keep interrupting myself?: Environment, habit and self-interruption. In: Tan, D., Fitzpatrick, G., Gutwin, C., Begole, B., Kellogg, W. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, USA, pp. 3127–3130.

Dismukes, R.K., Loukopoulos, L.D., Jobe, K.K., 2001. The challenges of managing concurrent and deferred tasks. In: Jensen, R. (Ed.), Proceedings of the 11th International Symposium on Aviation Psychology. Ohio State University, Columbus, OH.

Drews, F.A., Musters, A., 2015. Individual differences in interrupted task performance: one size does not fit all. Int. J. Hum.–Comput. Stud. 79, 97–105. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.01.003〉 (available online 07.02.15).

González, V.M., Mark, G.J., 2004. "Constant, constant, multi-tasking craziness": managing multiple working spheres. In: Dykstra-Erickson, E., Tscheligi, M. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 113–120.

Gould, S.J.J., Brumby, D.P., Cox, A.L., González, V., Salvucci, D., Taatgen, N., 2012. Multitasking and interruptions: a SIG on bridging the gap between research on the micro and macro worlds, CHI'12 Extended Abstracts on Human Factors in Computing Systems. ACM, New York, NY, USA, pp. 1189–1192. http://dx.doi.org/10.1145/2212776.2212420.

Gould, S.J.J., Brumby, D.P., Cox, A.L., 2013. What does it mean for an interruption to be relevant? An investigation of relevance as a memory effect. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 57(1), pp. 149–153. doi: 10.1177/1541931213571034.

Gould, S.J.J., Cox, A.L., Brumby, D.P., 2015. Task lockouts induce crowdworkers to switch to other activities, CHI'15 Extended Abstracts on Human Factors in Computing Systems. ACM, New York, NY, USA, http://dx.doi.org/10.1145/2702613.2732709 (forthcoming).

Grandhi, S.A. Jones, Q., 2015. Knock, knock! who's there? Putting the user in control of managing interruptions, Int. J. Hum.–Comput. Stud. 79, 35–50. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.02.008〉 (available online 26.02.15).

Grandhi, S.A., Schuler, R., Jones, Q.G., 2011. Telling calls: facilitating mobile phone conversation grounding and management. In: Tan, D., Fitzpatrick, G., Gutwin, C., Begole, B., Kellogg, W. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 2153–2162.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. Hum. Ment. Workload 1 (3), 139–183.

Healey, J.A., Picard, R.W., 2005. Detecting stress during real-world driving tasks using physiological sensors. IEEE Trans. Intell. Transp. Syst. 6 (2), 156–166.

Hodgetts, H.M. Tremblay, S., Vallières, B.R., Vachon, F., 2015. Decision support and vulnerability to interruption in a dynamic multitasking environment. Int. J. Hum.–Comput. Stud. 79, 106–117. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.01.009〉(available online 04.02.15).

Hornof, A., Zhang, Y., 2010. Task-constrained interleaving of perceptual and motor processes in a time-critical dual task as revealed through eye tracking. In: Salvucci, D.D., Gunzelmann, G. (Eds.), Proceedings of the International Conference of Cognitive Modeling. Drexel University, Philadelphia, PA, pp. 97–102.

Horrey, W.J., Wickens, C.D., 2006. Examining the impact of cell phone conversations on driving using meta-analytic techniques. Hum. Factors 48 (1), 196–205.

Howes, A., Lewis, R.L., Vera, A., 2009. Rational adaptation under task and processing constraints: implications for testing theories of cognition and action. Psychol. Rev. 116, 717–751.

Iqbal, S.T., Bailey, B.P., 2005. Investigating the effectiveness of mental workload as a predictor of opportune moments for interruption. In: Kellog, W., Zhai, S., van der Veer, G., Gale, C. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, pp. 1489–1492.

Iqbal, S.T., Bailey, B.P., 2010. Oasis: a framework for linking notification delivery to the perceptual structure of goal-directed tasks. ACM Trans. Comput.–Hum. Interact. 17 (4), 1–28.

Iqbal, S.T., Adamczyk, P.D., Zheng, X.S., Bailey, B.P., 2005. Towards an index of opportunity: understanding changes in mental workload during task execution. In: Kellog, W., Zhai, S., van der Veer, G., Gale, C. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, pp. 311–320.

Janssen, C.P., Brumby, D.P., 2010. Strategic adaptation to performance objectives in a dual-task setting. Cogn. Sci. 34 (8), 1548–1560. http://dx.doi.org/10.1111/j.1551-6709.2010.01124.x.

Janssen, C.P., Brumby, D.P., Garnett, R., 2012. Natural break points the influence of priorities and cognitive and motor cues on dual-task interleaving. J. Cogn. Eng. Decis. Mak. 6 (1), 5–29. http://dx.doi.org/10.1177/1555343411432339.

Janssen, C.P., Brumby, D.P., Dowell, J., Chater, N., Howes, A., 2011. Identifying optimum performance trade-offs using a cognitively bounded rational analysis model of discretionary task interleaving. Top. Cogn. Sci. 3 (1), 123–139. http://dx.doi.org/10.1111/j.1756-8765.2010.01125.x.

Janssen, C.P., Iqbal, S.T., Ju, Y.-C., 2014. Sharing a driver's context with a caller via continuous audio cues to increase awareness about driver state. J. Exp. Psychol.: Appl. 20 (3), 270–284. http://dx.doi.org/10.1037/xap0000020.

Jin, J., Dabbish, L.A., 2009. Self-interruption on the computer: a typology of discretionary task interleaving, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, pp. 1799–-1808. http://dx.doi.org/10.1145/1518701.1518979.

Kieras, D.E., Meyer, D.E., 1997. An overview of the EPIC architecture for cognition and performance with application to human–computer interaction. Hum.–Comput. Interact. 12 (4), 391–438.
Kujala, T., Salvucci, D.D., 2015. Modeling visual sampling on in-car displays: the challenge of predicting safety-critical lapses of control. Int. J. Hum.–Comput. Stud. 79, 66–78. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.02.009〉 (available online 26.02.15).
Latorella, K., 1996. Investigating interruptions: an example from the flightdeck. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, pp. 249–253.
Li, S.Y.W., Blandford, A., Cairns, P., Young, R.M., 2008. The effect of interruptions on postcompletion and other procedural errors: an account based on the activation-based goal memory model. J. Exp. Psychol.: Appl. 14 (4), 314–328. http://dx.doi.org/10.1037/a0014397.
Li, S.Y., Magrabi, F., Coiera, E., 2012. A systematic review of the psychological literature on interruption and its patient safety implications. J. Am. Med. Inform. Assoc. 19, 6–12.
Loukopoulos, L.D., Dismukes, R.K., Barshi, I., 2001. Cockpit interruptions and distractions: a line observation study. In: Jensen, R. (Ed.), Proceedings of the 11th International Symposium on Aviation Psychology. Ohio State University, Columbus, OH.
Magrabi, F., Li, S.Y., Day, R.O., Coiera, E., 2010. Errors and electronic prescribing: a controlled laboratory study to examine task complexity and interruption effects. J. Am. Med. Inform. Assoc. 17 (5), 575–583.
Mark, G.J., Gudith, D., Klocke, U., 2008. The cost of interrupted work: more speed and stress. In: Burnett, M., Costabile, M.F., Catarci, T., De Ruyter, B., Tan, D., Lund, M.C.A. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 107–110.
Mark, G.J., Voida, S., Cardello, A.V., 2012. "A Pace Not Dictated by Electrons": An Empirical Study of Work Without Email. In: Konstan, J.A., Chi, E.H., Höök, K. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 555–564.
Mattarelli, E., Bertolotti, F. Incerti, V., 2015. The interplay between organizational polychronicity, multitasking behaviors and organizational identification: a mixed-methods study in knowledge intensive organizations. Int. J. Hum.–Comput. Stud. 79, 6–19. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.02.002〉 (available online 10.02.15).
Mccartt, A.T., Hellinga, L.A., Bratiman, K.A., 2006. Cell phones and driving: review of research. Traffic Injury Prev. 7 (2), 89–106. http://dx.doi.org/10.1080/15389580600651103.
McFarlane, D.C., Latorella, K.A., 2002. The scope and importance of human interruption in human–computer interaction design. Hum.–Comput. Interact. 17 (1), 1–61.
Mehler, B., Reimer, B., Coughlin, J.F., 2012. Sensitivity of physiological measures for detecting systematic variations in cognitive demand from a working memory task: an on-road study across three age groups. Hum. Factors 54 (3), 396–412. http://dx.doi.org/10.1177/0018720812442086.
Miyata, Y., Norman, D.A., 1986. Psychological issues in support of multiple activities. In: Norman, D.A., Draper, S. (Eds.), User Centered System Design: New Perspectives on Human-Computer Interaction. Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 265–284.
Monk, C.A., Trafton, J.G., Boehm-Davis, D.A., 2008. The effect of interruption duration and demand on resuming suspended goals. J. Exp. Psychol.: Appl. 14 (4), 299–313. http://dx.doi.org/10.1037/a0014402.
Ophir, E., Nass, C., Wagner, A., 2009. Cognitive control in media multitaskers. Proc. Natl. Acad. Sci. 106 (37), 15583–15587.
Paul, C.L. Komlodi, A., Lutters, W., 2015. Interruptive notifications in support of task management. Int. J. Hum.–Comput. Stud., ISSN 1071-5819, 〈http://dx.doi.org/10.1016/j.ijhcs.2015.02.001〉 (available online 07.02.15).
Payne, S.J., Duggan, G.B., Neth, H., 2007. Discretionary task interleaving: heuristics for time allocation in cognitive foraging. J. Exp. Psychol.: Gen. 136 (3), 370–388. http://dx.doi.org/10.1037/0096-3445.136.3.370.
Rajkomar, A., Blandford, A., 2012. A distributed cognition model for analysing interruption resumption during infusion administration. In: Proceedings of the 30th European Conference on Cognitive Ergonomics. ACM, Edinburgh, UK, pp. 108–111. doi: 10.1145/2448136.2448159.
Relihan, E., O'Brien, V., O'Hara, S., Silke, B., 2010. The impact of a set of interventions to reduce interruptions and distractions to nurses during medication administration. Qual. Saf. Health Care 19 (5), 1–6.
Salvucci, D.D., 2005. A multitasking general executive for compound continuous tasks. Cogn. Sci. 29 (3), 457–492. http://dx.doi.org/10.1207/s15516709cog0000_19.
Salvucci, D.D., Taatgen, N.A., 2008. Threaded cognition: an integrated theory of concurrent multitasking. Psychol. Rev. 115 (1), 101–130. http://dx.doi.org/10.1037/0033-295X.115.1.101.
Salvucci, D.D., Taatgen, N.A., 2011. The Multitasking Mind. Oxford University Press, New York, NY.
Salvucci, D.D., Taatgen, N.A., Borst, J.P., 2009. Toward a unified theory of the multitasking continuum: from concurrent performance to task switching, interruption, and resumption. In: Greenberg, S., Hudson, S.E., Hinkley, K., Morris, M.R., Olsen Jr., D.R. (Eds.), Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, New York, NY, pp. 1819–1828.
Sanderson, P.M., Grundgeiger, T., 2015. How do interruptions affect clinician performance in healthcare? Negotiating fidelity, control, and potential generalizability in the search for answers. Int. J. Hum.–Comput. Stud. 79, 85–96. 〈http://dx.doi.org/10.1016/j.ijhcs.2014.11.003〉 (available online 27.11.14).
Shneiderman, B., Bederson, B.B., 2005. Maintaining concentration to achieve task completion. In: Anderson, R., Blau, B., Zapolski, J. (Eds.), Proceedings of the 2005 Conference on Designing for User eXperience (article 9). American Institute of Graphic Arts, New York, NY.
Stoet, G., O'Connor, D.B., Conner, M., Laws, K.R., 2013. Are women better than men at multi-tasking? BMC Psychol. 1 (18), 1–10.
Swan, M., 2013. The quantified self: fundamental disruption in big data science and biological discovery. Big Data 1 (2), 85–99.
Walter, S.R., Dunsmuir, W.T.M., Westbrook, J.I., 2015. Studying interruptions and multitasking in situ: the untapped potential of quantitative observational studies. Int. J. Hum.–Comput. Stud. 79, 118–125. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.01.008〉 (available online 04.02.15).
Walter, S.R., Li, L., Dunsmuir, W.T., Westbrook, J.I., 2014. Managing competing demands through task-switching and multitasking: a multi-setting observational study of 200 clinicians over 1000 h. BMJ Qual. Saf. 23 (3), 231–241.
Watson, J.M., Strayer, D.L., 2010. Supertaskers: profiles in extraordinary multitasking ability. Psychon. Bull. Rev. 17 (4), 479–485. http://dx.doi.org/10.3758/PBR.17.4.479.
Westbrook, J.I., Coiera, E., Dunsmuir, W.T., Brown, B.M., Kelk, N., Paoloni, R., Tran, C., 2010a. The impact of interruptions on clinical task completion. Qual. Saf. Health Care 19 (4), 284–289.
Westbrook, J.I., Woods, A., Rob, M.I., Dunsmuir, W.T., Day, R.O., 2010b. Association of interruptions with an increased risk and severity of medication administration errors. Arch. Intern. Med. 170 (8), 683–690.
Wickens, C.D., Gutzwiller, R.S., Santamaria, A., 2015. Discrete task switching in overload: a meta-analyses and a model. Int. J. Hum.–Comput. Stud. 79, 79–84. 〈http://dx.doi.org/10.1016/j.ijhcs.2015.01.002〉 (available online 27.01.15).

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