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On the impact of new technologies on multitasking

Pedro Cardoso-Leite [a,*], C. Shawn Green [b], Daphne Bavelier [a,c]

[a] *Faculty of Psychology and Educational Sciences, University of Geneva, Bd. du Pont d'Arve 40, 1211 Geneva 4, Switzerland*
[b] *Department of Psychology, University of Wisconsin-Madison*
[c] *Department of Brain and Cognitive Sciences, Meliora Hall, Box 270268, University of Rochester, Rochester, NY 14627, USA*

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ABSTRACT

Interest in multitasking has risen substantially over the past decade, both in the scientific community and the population at large. Large-scale surveys show that multitasking has not only become ubiquitous among adults, but is also increasingly invading the lives of young children. New technological devices promote multitasking allowing for the consumption of multiple types of media at the same time. And while some have argued that such multitasking represents a potential boon to productivity, others have suggested that the growing habit of media multitasking may have adverse effects.

To shed light on these pressing issues, we first review our present understanding of multitasking and the possibility of training individuals to more swiftly multitask in the laboratory setting. We then highlight the varieties of media use and how they may differ in terms of multitasking needs, to finally turn to research documenting the impact of selected media use on multitasking.

Introduction

Over the past decade, advances in technology have dramatically increased the ease of multitasking. On a single device, one can simultaneously examine multiple web browser windows, monitor the current weather and news, have a text conversation, and listen to music. Here we examine the scientific literature surrounding the impact of new media and their use on multitasking abilities. As

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[*] Corresponding author. Faculty of Psychology and Educational Sciences, University of Geneva, Bd. du Pont d'Arve 40, 1211 Geneva 4, Switzerland. Fax: +41 22 37 99020.
E-mail address: Pedro.CardosoLeite@unige.ch (P. Cardoso-Leite).

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we will see – although it is clear that multitasking is a process that can be altered via experience, it is not always trivial to make an a priori prediction about whether a given type of interaction with technology will have an effect on multitasking ability and if so, what the direction will be – that is whether it will be beneficial or harmful. Before considering the impact of technology use on multitasking abilities though, it is worth briefly discussing what it means for a human to multitask and how researchers have gone about showing that this behavior is indeed plastic.

The term multitasking, as we use it today, has its roots in computer science where it refers to using a single processing unit to perform multiple tasks in the same time period. Because, in actuality, a single CPU can only execute instructions for a single task at a time, 'multitasking' is achieved by having the single CPU switch rapidly back and forth between the various tasks. This stands in contrast with 'multiprocessing' – wherein a computer contains multiple processing units and thus task instructions can truly be executed in parallel by having the tasks dispatched to their own individual CPUs. In human beings there appears to be analogs of both types of processing. For instance, it has been suggested that early analysis of perceptual stimuli can progress at least roughly in parallel up to a certain stage, both within a single modality (e.g., the analysis of visual stimuli across space) and across modalities (e.g., the analysis of the visual and auditory features of an object; for a review see Nassi & Callaway, 2009). However, more "executive" aspects of tasks – such as decision-making or response selection – appear to use a common core and thus are more consistent with 'multitasking' whereby tasks progress through a common bottleneck either in a serial fashion or are switched rapidly between (for a review, see Pashler, 2000). A bottleneck of this type can be seen even when individuals attempt to perform two seemingly trivial tasks "simultaneously." For instance, in what is perhaps the seminal paper in this field, Telford (1931) simply had subjects press a key whenever a tone occurred. Although this is an ostensibly effortless task, it was nonetheless found that as the interval between successive tones was decreased, reaction time (RT) to the second tone in a pair increased. The increase in RT that occurred when stimuli were presented close in time was thought to reflect the fact that as the interval was reduced, at some point it became the case that some aspect of the system was still "working on" Tone 1 when Tone 2 appeared (it is worth noting though that the total time to complete the Tone1+Tone2 task was still shorter than the time to complete Tone 1 alone plus Tone 2 alone indicating that some aspects of the task were indeed processed in parallel). This effect was dubbed the "psychological refractory period" (PRP) and the same basic effect has been seen in hundreds of experiments using different stimuli and motor effectors (Pashler, 2000). For example, the PRP is still found even if one response is manual and the other is an eye movement (Pashler, Carrier, & Hoffman, 1993) or if one response is manual and the other is vocal (Pashler, 1990).

A related literature on "task-switching" has shown a similar cost as has been seen in the multitasking literature. The "switch-cost" though occurs when subjects are asked to alternate between two different tasks, rather than when they are asked to perform two tasks (which can be the same base task) simultaneously. For instance, a standard task-switching task might involve showing subjects, on each trial, a number and a letter placed side by side (see Fig. 1). On some trials the subjects are cued to perform the letter task – i.e., to indicate whether the letter that is displayed is a vowel or a consonant – while on other trials they are cued to perform the number task – i.e., to indicate whether the number that is displayed is even or odd. The tasks are pseudorandomly ordered such that the subjects may perform the same task on consecutive, or several consecutive trials, before switching to the other task. In such a paradigm, reaction times on switch trials – those where the participant switches to a new task – are substantially longer than non-switch (i.e., repeat) trials – where the subject performs the same task as they did on the previous trial. This basic result has been seen in hundreds of studies utilizing different tasks, stimuli, and response methods, even when including different response effectors for the two tasks (for a review, see Monsell, 2003). Similar effects are observed across all age ranges (58 months up to older adults; e.g., Dibbets & Jolles, 2006), although studies of the developmental trajectory of these costs remain relatively scarce.

Although historically the literature surrounding dual-tasking has been somewhat distinct from the literature on task-switching, over the past decade or so both the task-switching cost and the dual-task cost have been framed as representing a general deficiency in the ability to simultaneously maintain multiple distinct task-sets, and will thus be covered together within this review of multitasking.

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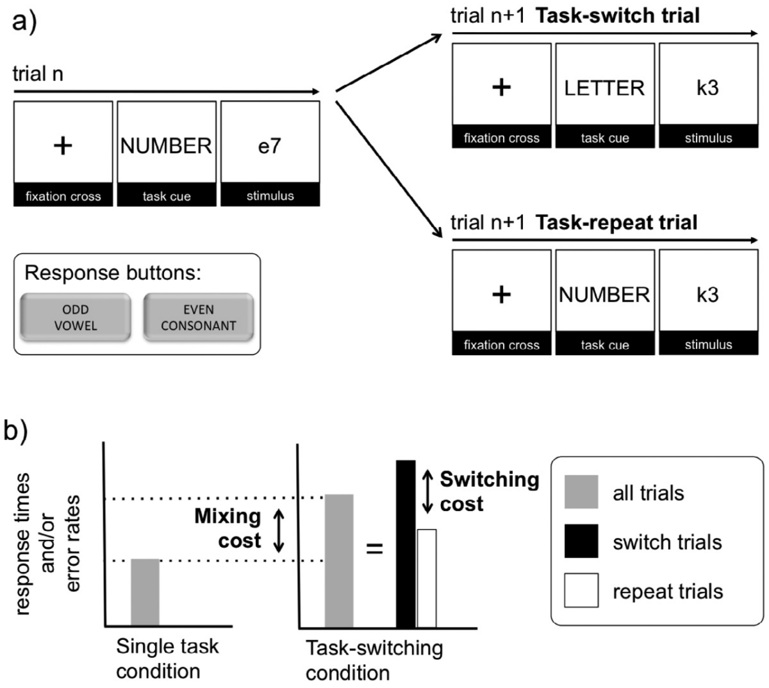

Fig. 1. (a) Illustration of a typical task-switching experiment. Subjects are asked to fixate a central cross. A cue indicates which task to perform on the current trial n (in the example above, NUMBER indicates that the digit portion of the stimulus should be classified as even/odd; the alternative task cue LETTER would have prompted a classification of the letter portion of the stimulus in terms of vowel/consonant). Shortly after the task cue onset, the to-be classified stimulus is displayed (correct answer in this example: odd). (b) Illustration of mixing and switching costs. The left panel represents the hypothetical performance (response times and/or error rates) when performing a task in isolation whereas the middle panel shows hypothetical data for when that same task is embedded in a task-switching design. Comparing the mean performance in the single task condition with the average performance to that same task in the task-switching condition is referred to as "mixing cost". The "switching cost" is measured within the task-switching condition. It is the difference in performance when comparing switch-trials with repeat-trials.

Training multitasking

Multitasking abilities – or perhaps more appropriately, inabilities – are not however, set in stone. There exists an extensive literature showing that specifically training individuals to perform two tasks at the same time does lead to performance benefits – at least in performing those tasks that are trained more efficiently (Bherer et al., 2005, 2010; Lussier, Gagnon, & Bherer, 2012; Strobach, Frensch, Soutschek, & Schubert, 2012b – for a recent review, see Enriquez-Geppert, Huster, & Herrmann, 2013).

Dual-tasking

For example, Schumacher et al. (2001) trained subjects on a classic dual-task paradigm. One task was auditory, wherein subjects heard a low, medium, or high-pitched tone, to which they had to give a vocal response (classifying these tones as tone "one", "two", or "three" respectively). The other task was visual where one of three combinations of two dashes and an upper case O was presented (i.e., either: '- -O', '- O -', or 'O - -'), which participants had to identify and map to the correct button press (index, middle, or ring fingers respectively). Both the auditory and visual stimuli were presented at the same time and the subjects were instructed to complete both tasks simultaneously. Although, as is consistent with the overall literature, a substantial PRP effect was observed early in the training, after around 2000 trials of experience (which also included some number of single-task trials), the

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cost associated with dual-tasking had virtually been eliminated. Following up on this work, Hazeltine, Teague, and Ivry (2002) not only replicated the base finding that training could eliminate the bottleneck, they further showed that the benefits extended to novel stimulus pairs and thus that the effect was not simply due to learning highly specific compound stimulus-response mappings.

Recently, Dux et al. (2009) investigated the neural underpinnings of training-related dual-task performance improvements using fMRI. Their results showed that practice (eight to twelve 1.5 h sessions distributed over the course of 2 weeks) led to speeding of RTs both in single and dual-task conditions: one task was a two alternative force choice (2AFC) visual face discrimination task with a button-press response, the other task was a 2AFC auditory complex tone discrimination task with a vocal response. Furthermore, performance increases in the dual-task condition could be accounted for by assuming that the reductions in RTs in the single task conditions occurred at the level of the response selection stage – the processing bottleneck that limits dual-task performance. In other words, the behavioral data suggested that the dual-task performance improvement resulted not from an increased ability to dual-task per se but from an increased ability to perform the response selection stage within each task. These authors then tested three distinct models of dual-task performance using the fMRI data corresponding to the two behavioral tasks described above. The imaging data matched with the behavioral results. No additional brain areas were recruited in the dual-task condition as compared with the conjunction of the brain activities in the single task condition. Most notably, only the left inferior frontal gyrus – around a region located at the vicinity of the inferior frontal sulcus and the inferior precentral sulcus – showed greater activity in the dual-task condition as compared with the single task condition prior to training as well as a reduction in activity with training that correlated with participants' reductions in dual-task cost. The authors suggest that the inferior frontal gyrus is involved in the central bottleneck stage of response selection and that with practice the information processing in this area increases in efficiency. Buchweitz, Keller, Meyler, and Just (2012) highlighted the role of the inferior frontal gyrus in dual-task performance and furthermore highlighted the importance of changes in functional connectivity and shifts in the timing of the BOLD responses in the dual-task condition. Here the critical comparison was in activity and functional connectivity when individuals listened to a single speech stream, compared with when they had to listen to two independent and simultaneously presented speech streams and had to comprehend both. The results showed that successful dual-tasking was associated with an increase in synchronization of the inferior frontal gyrus with more posterior temporal areas. These results highlight the central position of the inferior frontal gyrus in dual-tasking and the possibility that it may ease dual-task costs by facilitating the flow of information from sensory selection to response selection.

Task-switching

Practice has also been consistently shown to improve performance in task switching, although such practice does not necessarily eliminate the cost entirely. (Cepeda, Kramer, & Gonzalez de Sather, 2001; Berryhill & Hughes, 2009; Kray & Lindenberger, 2000; Meiran, 1996; Strobach, Liepelt, Schubert, & Kiesel, 2012c; for a review, see Enriquez-Geppert et al., 2013; Minear & Shah, 2008). For instance, Kray and Lindenberger (2000), trained groups of young, middle-aged, and elderly subjects on a variety of task-switch paradigms. In one such paradigm, on each trial subjects saw a four-digit number such as 2352; in Task A, the subject had to indicate whether the first two digits made a two-digit number that was larger than the two-digit number made up from the last two digits (is 23 greater than 52); in Task B the subject had to indicate whether any of the four digits were the same or not. Over the course of six sessions of training, switch-costs were reduced dramatically, in some cases by over 200 ms. However, a substantial switch-cost (of at least 100 ms) nonetheless remained after training.

Strobach and colleagues (2012c) showed that practice differentially affects two different types of costs associated with task-switching paradigms – the traditional "switching-cost" (the increase in RT on a trial where one performs a different task than on the previous trial as compared with when the task is a repeat from previous trial) and the "mixing cost" (the overall increase in RT in blocks that contain multiple tasks – i.e., both switch and non-switch trials – as compared with blocks that contain only a single task; see Fig. 1). Over eight sessions of training, both types of costs were substantially reduced – however, only mixing costs were truly eliminated.

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Overall, the existing studies indicate that extensively training on dual-tasking and task-switching tasks does result in some reduction in the associated costs. A key question, however, remains as to whether these gains reflect a general improvement at multitasking or a rather specific learning that applies only to the trained task.

Training and transfer

The extent to which training truly improves the general ability to task-switch and dual-task is still hotly debated. As we have seen above in some case, transfer of training has been observed to new stimuli (Hazeltine et al., 2002). Yet often the benefits of training are only observed for those exact tasks that are trained (for a review, see Enriquez-Geppert et al., 2013).

Minear and Shah (2008) were among the first to investigate to what extent training to switch between tasks would transfer to novel, unrelated tasks using a pre-test vs. post-test design. The pre and post-test tasks comprised a pair of tasks, where subjects were shown letter-number pairs and asked to classify them either into consonant/vowel or into odd/even. All participants ran these two tasks both in isolation (single task condition) as well as in two task-switching variants where task switches either occurred randomly or deterministically with a predictable pattern of every two trials. Participants were randomly assigned to one of three training regimens: single task training, random task-switching training and predictable task-switching training. Crucially, within each training regimen, participants were exposed to the exact same tasks ensuring equal familiarization with each task across training regimen. Training lasted for about two 1 h sessions. The results show that only training in the random task-switching regime led to significant transfer – and even then the transfer was limited to a reduction in mixing cost, as well as to a reduction in task-switching cost but only for the random task-switching condition. The authors argued against an improvement in “multitasking” per se but instead interpreted their results as reflecting an improvement in the recovery from unexpected task switches. They related their findings to studies showing that with practice, it becomes easier to recover from unexpected task interruptions (Trafton, Altmann, Brock, & Mintz, 2003), and discussed possible links to improved attentional control. Similar results were obtained by Zinke, Einert, Pfennig, and Kliegel (2012) who compared the effects of multiple training regimes on task-switching transfer. In their study one group of adolescents were trained in task-switching after physical exercise while another group did the same physical exercise without task-switching training. Both groups were pre- and post-tested on a different set of task-switching tasks as well as on a battery of other tests. The results show that task-switching training transferred in terms of mixing costs, but not switching costs, with very limited transfer to unrelated tasks.

Some investigators though have argued in favor of more substantial transfer. Karbach and Kray (2009) investigated if task-switching training on a set of tasks generalizes to other task-switching tasks (near transfer) as well as to unrelated executive tasks and measures of fluid intelligence (far transfer). By including participants from 8 to 76 years of age, they asked whether these transfer effects varied across the life span. These authors observed evidence for near (both mixing and switching costs) and for far transfer across all age groups, suggesting that task-switching training might impact cognition at a more general level and be efficient at all ages. This conclusion has recently been challenged however (for a discussion including unpublished results, see Pereg, Shahar, & Meiran, 2013). Firstly, recent studies failed to replicate the far transfer effects (Pereg et al., 2013; Von Bastian & Oberauer, 2013). Secondly, Pereg et al. (2013) have shown that the near transfer effects might not result from an improved ability to task-switch but instead seems to be tightly linked to the task statistics. In particular, transfer effects following training to switch tasks every second trial collapsed when in the test phase subjects alternated tasks every third trial instead of every second as in the training phase. Clearly the findings of Karbach and Kray (2009) in terms of transfer remain tentative. Their study is of special interest, however, as it is among the rare studies that look at training multitasking in children. A few studies document the developmental time course of task-switching performance and indicate that mixing costs are largest for children and older adults as compared with young adults, whereas switching costs are stable across the life span (e.g., Cepeda et al., 2001). The study of Karbach and Kray nicely replicates these findings and suggests that to the extent that multitasking is trainable it seems to be so for children and adults.

A qualitatively similar debate can be found in the dual-task literature, where dual-task training has been shown to transfer to untrained tasks (e.g., Hazeltine et al., 2002; Lussier et al., 2012) but only to a limited

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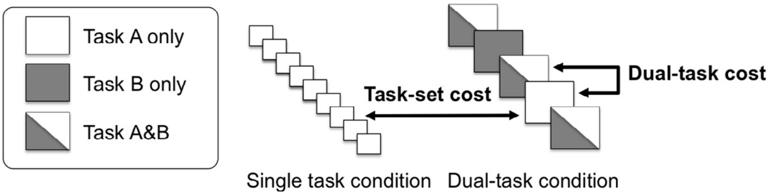

Fig. 2. Illustration of a typical dual-task experiment and of task-set and dual-task costs. In different sets of trials subjects perform two tasks either in the single task or in the dual-task condition. In the single task condition, participants perform only one task for the whole duration of a block (either task A or task B). In the dual-task condition, tasks are randomly interleaved and depending on the stimulus, participants perform task A only, task B only or both tasks A and B (A&B). "Task-set costs" are observed when comparing performance in a given task across the two conditions (e.g., task A only in the single task condition vs. task A only in the dual-task condition). "Dual-task costs" are measured within the dual-task condition by comparing performance on a given task across the two types of trials (single task trials vs. dual-task trials; e.g., A vs. A&B in the dual-task condition).

extent (Liepelt, Strobach, Frensch, & Schubert, 2011; Lussier et al., 2012; Strobach et al., 2012b; for a review, see Enriquez-Geppert et al., 2013). Lussier et al. (2012) for instance, trained participants to discriminate two sets of visual stimuli (left/rightward pointing arrow and/or red/green square) by pressing one of two keys with the left and right hand. In some blocks of trials, these two tasks were performed separately (single-pure trials), while in other blocks they were mixed. Within those mixed trial blocks, participants were required to either perform both tasks at once (dual-mixed trials) or only one of the tasks (single-mixed trails) depending on whether on a given trial both or only one of the stimuli were presented. The performance decrement when comparing single-mixed trials with single-pure trials is called "task-set cost" and is thought to reflect the ability to prepare and maintain multiple task sets. The performance decrement when comparing dual-mixed with single-mixed trials is termed "dual-task cost" and is thought to reflect participant's ability to perceive multiple stimuli and coordinate the execution of two motor responses (Fig. 2). Participants in the training group underwent five 1-h sessions spread over 2–3 weeks and were compared with a no intervention control group. Training led to substantial improvements in both task-set and dual-task costs. Importantly, Lussier et al. (2012) investigated the depth of transfer by having three distinct transfer dual-task tests which differed from the training dual-task experiment either in terms of stimulus modality (auditory instead of visual), response modality (turning a wheel and pressing pedals instead of left and right hand finger presses) or in both dimensions. Training reduced dual-task cost (but not the task-set cost) in the transfer tasks but only when the transfer task shared at least one dimensions (i.e., stimulus or response set) with the training task. Thus, it appears that transfer of dual-task training effects is possible, but is rather limited.

Overall, the reviewed studies indicate plasticity in multitasking whereby training in the laboratory can significantly reduce the various costs associated with multitasking on the exact trained tasks. Whether these benefits generalize to other new tasks as would be expected if the ability to multitask per se was improved remains highly contentious. The available evidence, rather, suggests that multitask training facilitates information extraction and motor selection as long as transfer tasks overlap along enough trained dimensions, be it in terms of stimulus or response properties or in terms of task structure and timings. It is in this context that we now turn to multitasking as it applies to real life applications.

Forms of media multitasking

The research reviewed above makes clear that extensive training with multitasking within laboratory conditions will help overcome some multitasking bottlenecks for the trained tasks, but lead to restricted transfer, if any, when considering other multitasking tasks. These results contrast with the ever-growing use of various forms of modern technology and media, which encourage or even require, extensive multitasking, and has led many of us to believe we are expert multitaskers.

For those growing up today, an enormous part of each day is spent consuming media. Recent surveys performed by the Kaiser Family foundation (Rideout, Foehr, & Roberts, 2010; Roberts, Foehr, & Rideout, 2005) suggest that media use occupies nearly 8 h of each and every day – more than any other activity, except perhaps for sleeping. Furthermore, multiple media streams are often consumed simultaneously.

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Thus, these 8 h of media consumption actually contain nearly 11 total hours of media content. These figures are up by around 20% from just 5 years ago. And while media use is often considered little more than a mindless diversion, there is an emerging scientific consensus that the regular use of many types of media has the ability to meaningfully impact users at many different levels, from bodily health to emotional regulation to basic aspects of attention and cognition (e.g., Staiano & Calvert, 2011). Because some of these impacts are overall positive, while others are overall negative, it seems urgent to establish what constitutes a “balanced media diet” for the developing human mind (Greenfield, 2009).

Much of the research in this domain though suffers from a number of clear issues. In particular, researchers often measure total “media usage” (i.e., the sum of all the hours spent on all forms of media) and attempt to link this number to either positive or negative outcomes. However, “media use” does not consist of a single experience. There are myriad forms of media, none of which are perfectly (or in many cases even close to) equivalent. Spending 10 h weekly watching documentaries about Alexander the Great is not the same as spending 10 h weekly shopping online. Nevertheless, completely disparate experiences such as streaming 5 h of reality shows, reading news articles for 5 h, or listening to 5 h of music, are all treated as if they are equivalent in most current studies of media usage because the same total number of hours of media are consumed in each case. This problem is exacerbated by the fact that there can be substantial differences in experience even within sub-types of media consumption. Ten hours per week of reading scientific journals online is likely not the same as 10 h per week of reading about celebrity gossip.

Furthermore, as mentioned earlier, multiple media streams are increasingly consumed in parallel (e.g., web browsing while watching television or listening to music while responding to emails), an activity that is known as *Media Multitasking* (Ophir, Nass, & Wagner, 2009). On average around 30% of media usage time is spent media multitasking. Media multitasking is typically assessed by self-report surveys from which one derives an index – the media multitasking index or MMI. This index weighs total media consumption by the percentage of time subjects utilize multiple forms of media simultaneously (i.e., a subject who consumes 80 total hours of media per week, but never uses multiple forms of media simultaneously, would have a lower MMI score than a subject who consumes 20 total hours of media per week, but always uses multiple forms of media simultaneously). It indicates on a one-dimensional continuous scale to what extent a participant consumes multiple streams of media when consuming media (Ophir et al., 2009). Figure 3 (left panel) illustrates the distribution of this score among recently surveyed young adults recruited through the University of Geneva population. As can be seen on that figure, there are large inter-individual differences in the extent of media multitasking. These individual differences offer the opportunity to run an “experiment of nature” wherein researchers explore the potential effects of media multitasking on brain and behavior as it is slowly becoming a staple of our society.

Moreover, the information extracted from the media consumption self-reports can be much richer than a single value. Indeed, a hierarchical cluster analysis performed on the self-reported media consumption clearly reveals patterns of consumption that have much more structure than just being sensitive to total amounts of media multitasking. For instance, there are clear preferences as to which media activities people tend to multitask between and which ones are almost never associated with each other. Games and music tend to co-occur quite often, but games and TV watching is seldom co-occurring. This is important information as playing video games might not have the same impact in terms of training multitasking abilities depending on the activities it is coupled with. In addition, this approach also reveals that there are qualitatively different categories of media multitaskers rather than a smooth continuum from low to high media multitaskers as has been studied so far. Thus, not all media are similarly combined, but rather certain media combinations are much more likely than others calling for more granular evaluations of media multitasking in future studies than what the MMI affords.

The study of the effects of new technologies on cognition is still in its infancy. To illustrate the importance of considering media at finer levels of description, we will contrast two media usages with apparently very different effects on dual-tasking and task-switching: media multitasking and action video game playing.

Media use and multitasking

Ophir et al. (2009) asked whether individuals who regularly engage in media multitasking exhibit different behaviors in a diverse set of laboratory tests of multitasking as compared with individuals

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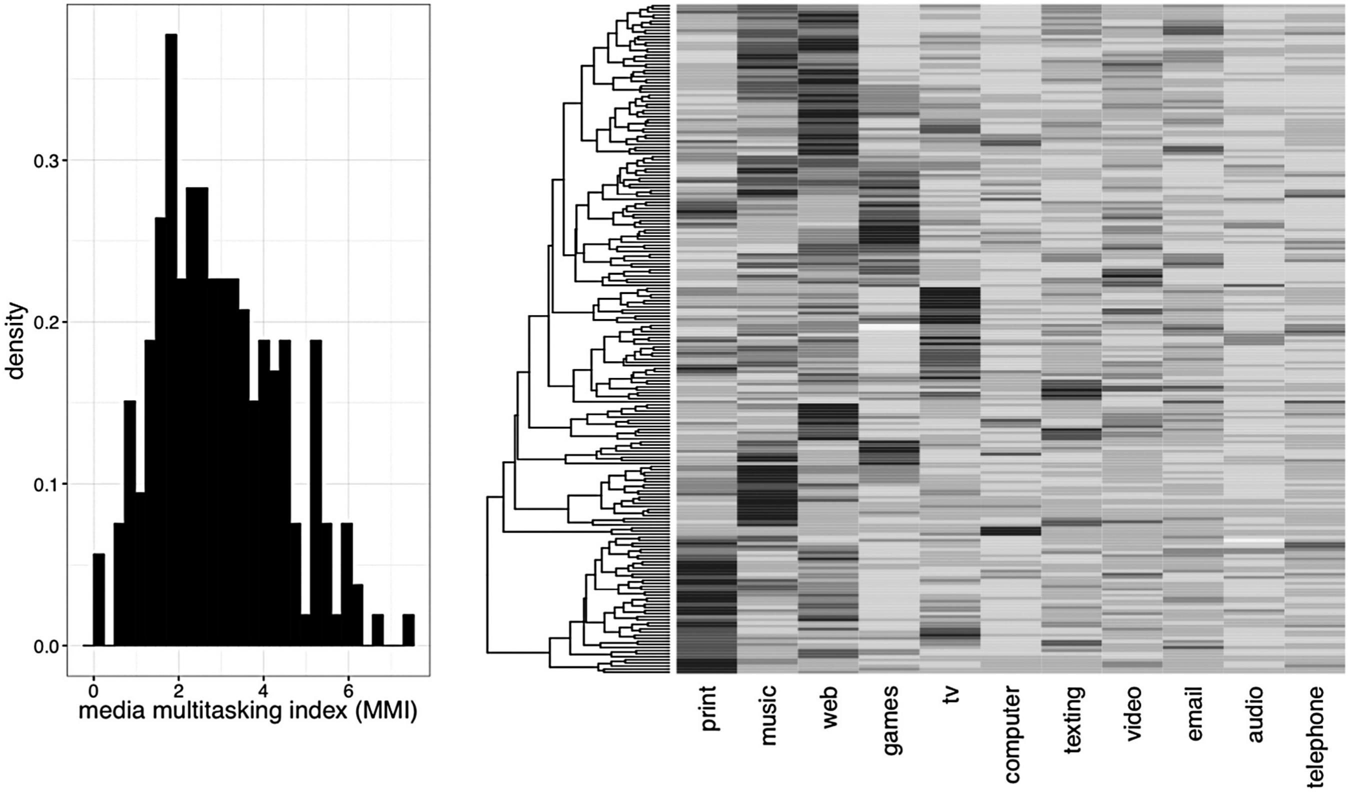

Fig. 3. Media multitasking among the student population in Geneva, Switzerland ($N = 218$). As can be seen from the histogram on the left panel, there are considerable differences across participants' self reported media multitasking, making this index (MMI) an interesting tool for research. This score, however, does not capture any of the structure inherent in media multitasking. The panel on the right is the result of a hierarchical cluster analysis performed on the same data that was used to compute the MMI score on the left panel. Each row of the matrix corresponds to a participant and each column to a media (e.g., listening to music, surfing the web; normalized such that the values in each row sum to one). Dark cells indicate high levels of consumption whereas light gray levels indicate rare media consumption. The vertical dendrogram clusters participants that are similar in terms of their multimedia consumption and suggests there are separate groups of media users.

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who do very little media multitasking. In their study, they first assessed the media multitasking habits of a large group of subjects using the MMI. From that large pool of subjects, the authors then selected those subjects who fell at the two extreme ends of the distribution (heavy media multitaskers: HMM; light media multitaskers: LMM). Next, both groups of subjects were compared on a battery of tasks designed to test multitasking ability, attentional selection and general executive function. One such task was a task switching experiment where the subjects were presented with stimuli comprised of a letter and a digit. In the letter task, the subjects were to classify the letter as vowel/consonant. In the digit task, the subjects were to classify the digit as even/odd. Which of the two tasks the subject was to perform on a given trial was determined by a task cue presented shortly before the stimuli appeared. As by definition HMM more frequently switch between tasks in their daily life (e.g., read a book, send text message, listen to a song) than LMM do, it was expected that HMM would be better at task-switching than LMM. Contrary to this prediction though, HMM actually performed worse than LMM in the task switching experiment (Ophir et al., 2009; Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013; but see Alzahabi & Becker, 2013; Minear, Brasher, McCurdy, Lewis, & Younggren, 2013 for failures to replicate). Not only were HMM subjects overall slower at responding to the stimuli on all trials, they also showed an increased task-switching cost (i.e., their RTs were slowed down to a greater extent than those of LMM when having to switch). Similar results were found in the other tests, which also required participants to filter out task-irrelevant information.

These results came as a surprise. One of the most robust results in the field of learning is that repeating an activity (i.e., training) leads to performance benefits on the trained and possibly similar activities; it certainly should not lead to performance *decrements*! Ironically, in another recent study, those subjects that were particularly poor in multitasking as measured in the laboratory tended to perceive themselves as expert multitaskers and also reported multitasking more frequently (Sanbonmatsu et al., 2013). Whether high media multitasking is profoundly detrimental to multitasking remains in need of replication though, as very few studies have been carried out so far, some with discrepant outcomes (see Alzahabi & Becker, 2013; Minear et al., 2013). Yet, it remains surprising that so much time engaged in multitasking does not lead to robust multitasking benefits[1].

It is interesting to contrast media multitasking with a different type of media exposure – playing *action video games*. This genre of game is characterized by a fast pace, a heavy load on divided attention and the nesting of goals and subgoals at many different time scales, among other factors. Action video games – in contrast to other forms of video games like life-simulation or puzzle games – have been shown to produce a variety of benefits in vision, attention, spatial cognition and decision-making (for a review, see Green & Bavelier, 2012). Furthermore, and quite unlike media multitasking, action gaming has generally been associated with positive effects[2] on both dual-tasking (Chiappe, Conger, Liao, Caldwell, & Vu, 2013; Dye & Bavelier, 2010; Green & Bavelier, 2006; Strobach, Frensch, & Schubert, 2012a; Wu & Spence, 2013; although see Donohue, James, Eslick, & Mitroff, 2012; Gaspar et al., 2013; Oei & Patterson, 2013) and task-switching (Andrews & Murphy, 2006; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Cain, Landau, & Shimamura, 2012; Colzato, van den Wildenberg, & Hommel, 2013; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Karle, Watter, & Shedden, 2010; Strobach et al., 2012a; although see Boot et al., 2008). We consider below separately the cases of dual-tasks and task switching.

Dual-tasking

Green and Bavelier (2006) trained adults for 30 h on either a first person shooter game or a puzzle game. Before and after this training, subjects underwent the Useful Field of View task, which mea-

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[1] Some authors argued that this apparent decrement in multitasking *performance* does not reflect a decrement in multitasking *ability*. Instead, media multitasking might lead to a change in cognitive control strategies with heavy media multitaskers focusing more on breath and light media multitaskers more on depth (e.g., Lin, 2009; Ophir et al., 2009).

[2] It is important to note that studies that had people play action video games in the laboratory distributed small training sessions (about 1 h per day, 5 days per week) across multiple weeks because this type of scheduling is thought to be most effective. Binging on these games may not only prevent the positive effects reported in the literature but also lead to adverse effect.

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sures subjects' abilities to locate a target, possibly among distractors, in the visual periphery. To this main task, the authors also added a challenging central shape identification task in some blocks (i.e., the task thus required some degree of multitasking). While both groups of subjects were hampered by the addition of the second task before training, the size of this cost was substantially reduced after training on action video game (but not on control video game). Hence, playing action video games led to an increased ability to perform two tasks simultaneously and suffer a lesser performance decrement. Although less studied in children, the few studies available suggest similar benefits in 7–17 years old classified as action video game players than in adult action video game players. For example, 11 year old action video players, like adult video game players, were observed to outperform not only children but also adults that did not play action video games when tested with the Useful Field of View task (Dye & Bavelier, 2010).

Using a more classic dual-tasking task Strobach et al. (2012a) have also shown benefits of action video game training on dual-tasking ability. The dual-task here consisted of a ternary auditory beep classification and a ternary visual stimulus classification. Both of these tasks were performed first in isolation, then in combination to determine the specific costs of dual-task performance. The results showed that action game training resulted in disproportionate reductions in RT in dual-task situations – particularly at short SOAs – which again is consistent with the idea that action video game training can improve the ability to multitask.

Finally, Chiappe et al. (2013) assessed the impact of action video games on the performance on the Multi-Attribute Task Battery (MATB). This test consisted of four tasks that subjects had to perform at the same time. Task one was a tracking task wherein subjects used a joystick to keep a target centered on the screen. Task two was a fuel management task wherein subjects had to ensure fuel levels remain as close as possible to some pre-determined level. Task three was a systems monitoring task, wherein various lights could become illuminated, which told the subject to perform a specific action. And lastly, task four was a communications task, which required subjects to make appropriate responses to auditory communications. The MATB simulates typical aircrew tasks and is a validated measure that correlates with real-world performance (Comstock & Arnegard, 1992). As was the case in previous research, individuals trained on an action video game showed significant improvements in their multitasking abilities, particularly in the speed at which they were able to respond to sudden onset communications or systems instructions, while individuals trained on a control non-action video game showed less or no benefits. This study therefore suggests that the multitasking benefits of action video game experience may "scale up" to real-life, complex, multitasking situations. Transfer from action video game play to real life dual tasking is not always found. For example, Gaspar et al. (2013) immersed participants in a virtual reality environment and tested their ability to safely cross the street while dual tasking or not. In the dual task condition, participants performed the street crossing under a concurrent working memory load. Participants classified as action video game players did not differ from their non-playing peers on their ability to cross the street safely in either condition suggesting little transfer in this case. Unfortunately, the authors also failed to replicate the effects that are typically observed when comparing these two groups on a battery of computerized tests making the lack of transfer difficult to interpret. To this day, very few studies have tested real-world transfer of action game play to dual tasking; this should be a rich area of investigation for future research.

Task-switching

Numerous studies have also reported enhanced task switching abilities both for individuals who regularly play action video games compared with non-action video game players (i.e., cross-sectional studies – Andrews & Murphy, 2006; Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010; Green et al., 2012; Karle et al., 2010; Strobach et al., 2012a; but see Gaspar et al., 2013) as well as a result of specific training (i.e., experimental studies – Colzato et al., 2013; Green et al., 2012; Strobach et al., 2012a; but see Boot et al., 2008). Andrews and Murphy (2006) had subjects switch between a digit and a letter classification task and observed a reduced task-switching cost for avid action gamer players as compared with non-action game players for short inter-trial intervals (150 ms) but not for longer ones. Boot et al. (2008) asked subjects to classify digits either as even/odd or as greater/smaller than 5. Subjects recruited as experienced action gamers showed a reduced task switching cost.

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And Green et al. (2012) compared avid action gamers and non-action gamers under four different task-switching experiments and observed reduced switch-costs for the action gamers irrespective of the motor effector used in these experiments (manual key presses versus vocal responses), of the nature of the task (perceptual vs. conceptual) and of the level at which the switch applies (switching tasks goals or switching stimulus response mappings). These authors also showed a causal relationship between action gaming and enhancements in task-switching by training non-gamers on action video games or control video games for 50 h and measuring their task-switching costs both before and after that training phase. The results showed again, significantly swifter task-switching following action video game training as compared with training on a non-action video game (with the same beneficial effect of action game training having also been found by Strobach et al., 2012a, 2012b, 2012c). Lastly, an exciting new study by Colzato et al. (2013) replicated and extended these results, showing that the benefits of action game training on task-switching behavior are partially mediated by genetic factors. Specifically, differences in a gene coding for an enzyme that promotes degradation of dopamine in the synaptic cleft predicted individual differences in the extent to which action game experience promoted benefits in task-switching.

But how exactly do these dual task and task-switching benefits come about? In two experiments, Karle et al. (2010) investigated whether the task-switching benefits associated with self-reported extensive action video game experience result from an enhancement in selective attention or from improved resistance to proactive interference. The first experiment was designed to minimize trial-to-trial interference. Subjects were presented with stimuli from two non-overlapping sets (ABC and 123) in response to which they pressed a specific key from a non-overlapping response set (three distinct fingers from the left and right hand). The "task" (digit vs. letter) could be either be validly cued or not; and this cue appeared at varying intervals prior to the stimulus – thus allowing for different levels of task preparation. Action gamers responded overall faster than non-action gamers. Moreover, they showed an additional task-switching cost reduction (i.e., a reduction in this cost that could not be accounted for by their overall increased response speed), but only when task-cues were presented long before the to-be-classified stimuli and in particular when the cues were informative – implying that avid action gamers are more efficient in preparing task-set shifting. Their second task-switching experiment was more challenging and involved both overlapping stimulus and response sets (stimuli {2,3,4,6,7,9} to be classified according to odd/even, <5/>5 or prime/multiple). In this setting avid action gamers did not show any additional reduction in task switching cost compared with non-action gamers. According to Karle et al. (2010), it may therefore be the case that action gamers do not have improved task-switching abilities by which they can more swiftly reconfigure task-sets, but rather may excel on task switching tasks through better attentional control.

Although the bulk of the literature on gaming thus far has focused not only on action games, but specifically on what are known as "first-person shooter" action games, recent research has shown that similar effects are seen in other game types as well. Wu and Spence (2013) report equal enhancements in dual-task performance for groups trained on either a violent action shooter game or a non-violent action driving video game as compared with a control group that trained on a non-action video game. Furthermore, both Glass, Maddox, and Love (2013) and Basak, Boot, Voss, and Kramer (2008) have shown that real-time strategy games (which also require substantial amounts of fast decisions) can also improve cognitive flexibility. Basak et al. (2008) for instance, trained older adults on such a game (Rise of Nations 2004) for almost 24 h, dispersed over the course of about 2 months. These participants were pre- and post-tested on a battery of cognitive tests – which included a task-switching paradigm – and compared with a no-training no-contact control group. Their results show that participants in the training group improved in the game itself but also outperformed the control group in tasks that measure reasoning, working-memory, visual-short term memory and, most important to our purposes, in task-switching. Similar learning effects have also been observed with younger adults (Glass et al., 2013). And finally, Anguera et al. (2013) had older adults play a custom-made video game containing both action and multitasking aspects for 12 total hours. The video game had two main components – driving a car in a virtual environment and responding as fast as possible to the onset of target stimuli. Subjects were assigned to one of three groups: (i) a multitasking group that trained on both tasks simultaneously, (ii) a single task group that trained on each task in isolation and (iii) a no contact group which did not have any form of training. Before and after this training, subjects took

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a battery of tests to assess to what extent such dual-task learning transfers to untrained tasks. The results showed that multitasking performance, as assessed in the multitasking version of the game, increased considerably for the group trained on that very same task, and that this benefit transferred to sustained attention and better working memory in the face of distraction and disruptions. However, only a trend for transfer was seen when considering novel dual-task experiments, reinforcing the view that transfer from multitasking training may be mediated through increased attentional flexibility, rather than a fundamental change toward more parallel processing.

Finally, less is known about the plasticity of task switching in children. While some studies document the developmental time course of task switching, few studies have addressed whether its associated costs may be alleviated through training and if so whether this plasticity may vary as development proceeds (for a review see, Karbach & Kray, 2009). While the impact of action video game play on children's performance on standard task-switching paradigms has not been documented yet, the Attentional Blink paradigm may be of interest. Participants in an Attentional Blink task are asked to select two pre-specified targets in a serial stream presented extremely rapidly. Processing of the second target is hindered by successful processing of the first target, an outcome proposed by some to reflect a similar processing bottleneck as the one that limits multitasking performance (e.g., Marti, Sigman, & Dehaene, 2012; Tombu et al., 2011). Interestingly, by age 7 action video game players performed as well as adult non action gamers, indicating a potent transfer from action video game play to blink performance at an extremely young age (Dye & Bavelier, 2010). Whether this result generalizes to the various costs associated with multitasking remains to be firmly established.

Conclusions

That playing certain types of video games improves both task-switching and dual-tasking could be considered – at a certain level of description – as surprising as the finding that media multitasking diminishes these abilities. After all action video game players are engaged in just one activity, which is playing that very game. Comparing action video game play with media multitasking thus leaves us with a paradox. Why does not media multitasking, which necessarily requires performing multiple tasks simultaneously as well as frequent task switching, lead to systematic improvements in multitasking? And why, on the other hand, do action video games improve multitasking (among other things) when in appearance they do not require the same degree of multitasking? Finally, how should we conceive of the rather far transfer noted after action game play given the limited evidence for transfer of multitasking in controlled laboratory training studies? While we do not yet have firm answers to these questions, it may be fruitful to consider models of human task performance, and the processes at play during multitasking.

The inability to simultaneously perform multiple tasks is typically attributed to hardware limitations of the brain, be it in terms of the limited number of task-sets that may be simultaneously represented in the prefrontal cortex (Koechlin & Hyafil, 2007) or processing bottlenecks (Welford 1952, 1980; for a review, see Pashler, 1997) or the idea that key aspects of processing, such as decision making or motor selection, have to be performed serially. In the task-switching literature, for example, it is assumed that subjects may prepare for upcoming task-switches by internally adjusting processing modules, like branching rails for the fluid transfer of trains in a railway system. Such adjustments are intrinsically serial and may be quite costly when they have to be made on the fly (i.e., at the time one is actually faced with stimuli – task-set reconfiguration theory – Rogers & Monsell, 1995). Similarly, some of the costs in task-switching have been attributed to task-set inertia (Allport et al., 1994) or the idea that switching between tasks requires the suppression of the task that is currently not to be performed. This suppression becomes detrimental if that task becomes relevant and the suppression is not lifted efficiently – again a drawback due to the serial nature of processing. In the dual-tasking literature, the same hardware limitations have been recognized.

Both in the task-switching and the dual-tasking literature, training may affect performance and ease the costs. One path for improvement consists in facilitating processes that are task-specific such as stimulus-response associations, or specific aspects of the task structures (e.g., switch every two trials). Once automatized, task components can be executed simultaneously under the control of

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executive functions that handle resources based on task priorities (see for example the adaptive executive control model – Meyer & Kieras, 1997, 1999; Meyer et al., 1995). In such models, reduced costs are expected on trained tasks, with little to no transfer to other multitasking activities. A different path for improvement consists of improving the efficiency of resource allocation and/or by building more accurate models of the tasks at hand on the fly (typically hierarchical representations of goals and subgoals). Action video games, but also other types of video games (e.g., Real Time Strategy games), might prove exceptionally efficient tools to enhance multitasking ability due to the fact that they require players to constantly re-evaluate their current task set in the context of a fast changing environment, thus putting a premium on cognitive flexibility and indeed the ability to swiftly re-evaluate goals and sub-goals as contingencies change. There are already some encouraging results linking general skills such as resource allocation and/or the ability to infer more accurate models of the world to multitasking. Dreisbach, Goschke, and Haider (2007) for instance have shown that the exact same action may or may not be subject to task-switching costs depending on whether subjects represent these actions as forming distinct tasks or instead as individual stimulus-response mappings (see also Weaver & Arrington, 2013), implying that improving participants' ability to accurately represent task contingencies might lead them to perform better in multitasking conditions.

More research is obviously needed, but the body of evidence reviewed here makes it clear that the use of different types of media can have dramatically different types of impact on multitasking. The outcome of such media use may be rather counter-intuitive with for example media multitasking being of little benefit to multitasking, even though the high media multitaskers themselves may be convinced otherwise. While controlled laboratory studies have struggled to establish transfer across multitasking paradigms, rich worlds such as those found in action video games appear much more potent in easing the various costs associated with multitasking. Whether such transfer can be entirely accounted for by enhanced attentional control abilities, or rather better inference of task contingencies that in turn facilitate learning and automatization remains largely unaddressed. As greater and greater number of younger and younger children engage with new media, understanding the impact of different media use on the developmental trajectory of multitasking as well as its underlying mechanisms seems therefore all the more pressing.

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References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and nonconscious information processing* (pp. 421–452). Cambridge, MA: MIT Press.

Alzahabi, R., & Becker, M. W. (2013). The association between media multitasking, task-switching, and dual-task performance. *Journal of Experimental Psychology. Human Perception and Performance*, doi:10.1037/a0031208.

Andrews, G., & Murphy, K. A. (2006). Does video game playing improve executive functioning?, 145–161.

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Faraji, F., Janowich, J., Kong, E., et al. (2013). Video game training enhances cognitive control in older adults. *Nature*, *501*(7465), 97–101. doi:10.1038/nature12486.

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging*, *23*(4), 765–777. doi:10.1037/a0013494.

Berryhill, M. E., & Hughes, H. C. (2009). On the minimization of task switch costs following long-term training. *Attention, Perception & Psychophysics*, *71*(3), 503–514. doi:10.3758/APP.71.3.503.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging*, *20*(4), 695–709. doi:10.1037/0882-7974.20.4.695.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2010). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research*, *34*(3), 188–219. doi:10.1080/03610730802070068.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129*(3), 387–398. doi:10.1016/j.actpsy.2008.09.005.

Buchweitz, A., Keller, T. A., Meyler, A., & Just, M. A. (2012). Brain activation for language dual-tasking: Listening to two people speak at the same time and a change in network timing. *Human Brain Mapping*, *33*(8), 1868–1882. doi:10.1002/hbm.21327.

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception & Psychophysics*, *74*(4), 641–647. doi:10.3758/s13414-012-0284-1.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology*, *37*(5), 715–730.

Chiappe, D., Conger, M., Liao, J., Caldwell, J. L., & Vu, K.-P. L. (2013). Improving multi-tasking ability through action videogames. *Applied Ergonomics*, *44*(2), 278–284. doi:10.1016/j.apergo.2012.08.002.

Colzato, L. S., van den Wildenberg, W. P. M., & Hommel, B. (2013). Cognitive control and the COMT Val(158)Met polymorphism: Genetic modulation of videogame training and transfer to task-switching efficiency. *Psychological Research*, doi:10.1007/s00426-013-0514-8.

Colzato, L. S., van Leeuwen, P. J. A., van den Wildenberg, W. P. M., & Hommel, B. (2010). DOOM'd to switch: Superior cognitive flexibility in players of first person shooter games. *Frontiers in Psychology*, *1*, 8. doi:10.3389/fpsyg.2010.00008.

Comstock, J. R., & Arnegard, R. J. (1992). *Multi-attribute task battery (NASA Tech. Memorandum 104174)*. Hampton, VA: NASA Langley Research Center.

Dibbets, P., & Jolles, J. (2006). The Switch Task for Children: Measuring mental flexibility in young children. *Cognitive Development*, *21*(1), 60–71. doi:10.1016/j.cogdev.2005.09.004.

Donohue, S. E., James, B., Eslick, A. N., & Mitroff, S. R. (2012). Cognitive pitfall! Videogame players are not immune to dual-task costs. *Attention, Perception & Psychophysics*, *74*(5), 803–809. doi:10.3758/s13414-012-0323-y.

Dreisbach, G., Goschke, T., & Haider, H. (2007). The role of task rules and stimulus-response mappings in the task switching paradigm. *Psychological Research*, *71*(4), 383–392. doi:10.1007/s00426-005-0041-3.

Dux, P. E., Tombu, M. N., Harrison, S., Rogers, B. P., Tong, F., & Marois, R. (2009). Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. *Neuron*, *63*(1), 127–138. doi:10.1016/j.neuron.2009.06.005.

Dye, M. W. G., & Bavelier, D. (2010). Differential development of visual attention skills in school-age children. *Vision Research*, *50*(4), 452–459. doi:10.1016/j.visres.2009.10.010.

Enriquez-Geppert, S., Huster, R. J., & Herrmann, C. S. (2013). Boosting brain functions: Improving executive functions with behavioral training, neurostimulation, and neurofeedback. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *88*(1), 1–16. doi:10.1016/j.ijpsycho.2013.02.001.

Gaspar, J. G., Neider, M. B., Crowell, J. A., Lutz, A., Kaczmarski, H., & Kramer, A. F. (2013). Are gamers better crossers: An examination of action video game experience and dual task effects in a simulated street crossing task. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, doi:10.1177/0018720813499930.

Glass, B. D., Maddox, W. T., & Love, B. C. (2013). Real-Time Strategy Game Training: Emergence of a Cognitive Flexibility Trait. *PLoS One*, *8*, e70350.

Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology. Human Perception and Performance*, *32*(6), 1465–1478. doi:10.1037/0096-1523.32.6.1465.

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. *Current Biology*, *22*(6), R197–R206. doi:10.1016/j.cub.2012.02.012.

Green, C. S., Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task-switching. *Computers in Human Behavior*, *28*(3), 984–994. doi:10.1016/j.chb.2011.12.020.

Greenfield, P. M. (2009). Technology and informal education: What is taught, what is learned. *Science*, *323*(5910), 69–71.

Hazeltine, E., Teague, D., & Ivry, R. B. (2002). Simultaneous dual-task performance reveals parallel response selection after practice. *Journal of Experimental Psychology. Human Perception and Performance*, *28*(3), 527–545. doi:10.1037//0096-1523.28.3.527.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*, *12*(6), 978–990. doi:10.1111/j.1467-7687.2009.00846.x.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica*, *134*(1), 70–78. doi:10.1016/j.actpsy.2009.12.007.

Koechlin, E., & Hyafil, A. (2007). Anterior prefrontal function and the limits of human decision-making. *Science (New York, N.Y.)*, *318*(5850), 594–598. doi:10.1126/science.1142995.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging*, *15*(1), 126–147.

Liepelt, R., Strobach, T., Frensch, P., & Schubert, T. (2011). Improved intertask coordination after extensive dual-task practice. *Quarterly Journal of Experimental Psychology (2006)*, *64*(7), 1251–1272. doi:10.1080/17470218.2010.543284.

Lin, L. (2009). Breadth-biased versus focused cognitive control in media multitasking behaviors. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(37), 15521–15522. doi:10.1073/pnas.0908642106.

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Frontiers in Human Neuroscience*, *6*(4), 129. doi:10.3389/fnhum.2012.00129.

Marti, S., Sigman, M., & Dehaene, S. (2012). A shared cortical bottleneck underlying Attentional Blink and Psychological Refractory Period. *Neuroimage*, *59*(3), 2883–2898. doi:10.1016/j.neuroimage.2011.09.063.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *22*(6), 1423–1442. doi:10.1037//0278-7393.22.6.1423.

Meyer, D. E., & Kieras, D. E. (1997). A computational theory of executive cognitive processes and multiple-task performance: part 2. Accounts of psychological refractory-period phenomena. *Psychological Review*, *10*(4), 749–791.

Meyer, D. E., & Kieras, D. E. (1999). Précis to a practical unified theory of cognition and action: Some lessons from EPIC computational models of human multiple-task performance. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 17–88). Cambridge, MA: MIT Press.

Meyer, D. E., Kieras, D. E., Lauber, E., Schumacher, E. H., Glass, J., Zurbriggen, N. E., et al. (1995). Adaptive executive control: flexible multiple-task performance without pervasive immutable response-selection bottlenecks. *Acta Psychologica*, *90*(1–3), 163–190.

Minear, M., Brasher, F., McCurdy, M., Lewis, J., & Younggren, A. (2013). Working memory, fluid intelligence, and impulsiveness in heavy media multitaskers. *Psychonomic Bulletin & Review*, *20*(6), 1274–1281. doi:10.3758/s13423-013-0456-6.

Minear, M., & Shah, P. (2008). Training and transfer effects in task switching. *Memory and Cognition*, *36*(8), 1470–1483. doi:10.3758/MC.336.8.1470.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134–140. doi:10.1016/S1364-6613(03)00028-7.
Nassi, J. J., & Callaway, E. M. (2009). Parallel processing strategies of the primate visual system. *Nature Reviews. Neuroscience*, *10*(5), 360–372. doi:10.1038/nrn2619.
Oei, A. C., & Patterson, M. D. (2013). Enhancing cognition with video games: A multiple game training study. *PLoS ONE*, *8*(3), e58546. doi:10.1371/journal.pone.0058546.
Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(37), 15583–15587. doi:10.1073/pnas.0903620106.
Pashler, H. (1990). Do response modality effects support multiprocessor models of divided attention? *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 826–840.
Pashler, H. (1997). *The psychology of attention*. Cambridge, MA: MIT Press.
Pashler, H. (2000). Task switching and multitask performance.
Pashler, H., Carrier, M., & Hoffman, J. E. (1993). Saccadic eye movements and dual-task interference. *Quarterly Journal of Experimental Psychology*, *46A*, 51–82.
Pereg, M., Shahar, N., & Meiran, N. (2013). Task switching training effects are mediated by working-memory management. *Intelligence*, *41*(5), 467–478. doi:10.1016/j.intell.2013.06.009.
Rideout, V. J., Foehr, U. G., & Roberts, D. F. (2010). *Generation M^2: Media in the Lives of 8-to 18-Year-Olds*. Henry J. Kaiser Family Foundation.
Roberts, D. F., Foehr, U. G., & Rideout, V. J. (2005). *Generation M: Media in the lives of 8–18 year-olds*. Henry J. Kaiser Family Foundation.
Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.
Sanbonmatsu, D. M., Strayer, D. L., Medeiros-Ward, N., & Watson, J. M. (2013). Who multi-tasks and why? Multi-tasking ability, perceived multi-tasking ability, impulsivity, and sensation seeking. *PLoS ONE*, *8*(1), e54402. doi:10.1371/journal.pone.0054402.
Schumacher, E. H., Seymour, T. L., Glass, J. M., Fencsik, D. E., Lauber, E. J., Kieras, D. E., et al. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck. *Psychological Science*, *12*(2), 101–108.
Staiano, A. E., & Calvert, S. L. (2011). Exergames for physical education courses: physical, social, and cognitive benefits. *Child Development Perspectives*, *5*(2), 93–98. doi:10.1111/j.1750-8606.2011.00162.x.
Strobach, T., Frensch, P. A., & Schubert, T. (2012a). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica*, *140*(1), 13–24. doi:10.1016/j.actpsy.2012.02.001.
Strobach, T., Frensch, P. A., Soutschek, A., & Schubert, T. (2012b). Investigation on the improvement and transfer of dual-task coordination skills. *Psychological Research*, *76*(6), 794–811. doi:10.1007/s00426-011-0381-0.
Strobach, T., Liepelt, R., Schubert, T., & Kiesel, A. (2012c). Task switching: Effects of practice on switch and mixing costs. *Psychological Research*, *76*(1), 74–83. doi:10.1007/s00426-011-0323-x.
Telford, C. W. (1931). The refractory phase of voluntary and associative responses. *Journal of Experimental Psychology*, *14*, 1–36.
Tombu, M. N., Asplund, C. L., Dux, P. E., Godwin, D., Martin, J. W., & Marois, R. (2011). A unified attentional bottleneck in the human brain. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(33), 13426–13431. doi:10.1073/pnas.1103583108.
Trafton, J. G., Altmann, E. M., Brock, D. P., & Mintz, F. E. (2003). Preparing to resume an interrupted task: Effects of prospective goal encoding and retrospective rehearsal. *International Journal of Human-Computer Studies*, *58*(5), 583–603. doi:10.1016/S1071-5819(03)00023-5.
Von Bastian, C. C., & Oberauer, K. (2013). Distinct transfer effects of training different facets of working memory capacity. *Journal of Memory and Language*, *69*(1), 36–58. doi:10.1016/j.jml.2013.02.002.
Weaver, S. M., & Arrington, C. M. (2013). The effect of hierarchical task representations on task selection in voluntary task switching. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *39*(4), 1128–1141. doi:10.1037/a0031677.
Welford, A. T. (1952). The “psychological refractory period” and the timing of high speed performance—A review and a theory. *British Journal of Psychology*, *43*, 2–19.
Welford, A. T. (1980). The single-channel hypothesis. In A. T. Welford (Ed.), *Reaction time* (pp. 215–252). San Diego, CA: Academic Press.
Wu, S., & Spence, I. (2013). Playing shooter and driving videogames improves top-down guidance in visual search. *Attention, Perception & Psychophysics*, *75*(4), 673–686. doi:10.3758/s13414-013-0440-2.
Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience*, *6*, 41. doi:10.3389/fnhum.2012.00041.

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