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# Technology consumption and cognitive control: Contrasting action video game experience with media multitasking

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## Abstract

Technology has the potential to impact cognition in many ways. Here we contrast two forms of technology usage: 1) media multitasking (i.e., the simultaneous consumption of multiple streams of media, such a texting while watching TV) and 2) playing action video games (a particular sub-type of video game). Previous work has outlined an association between high levels of media multitasking and specific deficits in handling distracting information, while playing action video games has been associated with enhanced attentional control. As these two factors are linked with reasonably opposing effects, failing to take them jointly into account may result in inappropriate conclusions as to the impact of technology use on attention. Across four experiments (AX-CPT, N-back, Task-switching and Filter task), testing different aspects of attention and cognition, we show that heavy media multitaskers perform worse than light media multitaskers. Contrary to previous reports though, the performance deficit was not specifically tied to distractors, but was instead more global in nature. Interestingly, participants with intermediate levels of media multitasking occasionally performed better than both light and heavy media multitaskers suggesting that the effects of increasing media multitasking are not monotonic. Action video game players, as expected, outperformed non-video game players on all tasks. However, surprisingly this was true only for participants with intermediate levels of media multitasking, suggesting that playing action video games does not protect against the deleterious effect of heavy media multitasking. Taken together this study shows that media consumption can have complex and counter-intuitive effects on attentional control.

### Keywords

Action video games; media multitasking; Task-switching; Filter task; N-back; AX-CPT

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## Introduction

Nearly every time a large portion of society begins to adopt a new form of technology, there is a concomitant increase in interest in the potential effects of that technology on the human body, brain, and/or behavior. For instance, over a period of approximately 20 years (starting in 1941), the percentage of American homes owning a television set went from 0% to more than 90% (Gentzkow & Shapiro, 2008). This trend resulted in a vast body of research investigating the effects of television viewing on everything from learning and scholastic performance (Greenstein, 1954), to the development of social relationships and social norms (Riley, Cantwell, & Ruttiger, 1949; Schramm, 1961), to basic visual and motor skills (Guba et al., 1964), to voting patterns (Glaser, 1965; Simon & Stern, 1955).

The forms of technology of most significant interest today include Internet access, cellphone possession, and computer/video game exposure. The amount of time the average American spends consuming multimedia today is substantial—in 2009, 8 to 18 year olds in the US consumed more than 7.5 hours of media *daily*. Moreover, this number is increasing rapidly —by more than 1h/day over the preceding 5 years (Rideout, Foehr, & Roberts, 2010; Roberts, Foehr, & Rideout, 2005). Although the literature on these newer forms of multimedia is only in its relative infancy, there are a few key lessons that have been gleaned from the broader literature. First, the effects of media on human cognition can depend on the medium even when the content is held constant. For example, 9-month-olds learn to discriminate Mandarin Chinese phonetic contrasts from live exposure to a human tutor, but not from exposure to a tutor presented on television (Kuhl, 2007; see also DeLoache et al., 2010). Second, the effects of media can depend on individual differences in the consumer. For example, the cognitive benefits gained via playing certain types of video games are larger in females than in males (Feng, Spence, & Pratt, 2007), and are larger in individuals with certain genetic traits than others (Colzato, van den Wildenberg, & Hommel, 2013b). Third, the effects of media can depend on specific forms of content within the medium. For example, 'violent' video games and 'heroic' video games are both 'types of video games' – however, playing violent video games has been linked with increases in anti-social behavior, while playing heroic video games has been linked in increases in pro-social behavior (Gentile et al., 2009). And finally, the effects of media can dependent on how a person engages with the medium (e.g., active vs. passive). For example, playing the exact same real-time strategy game may or may not lead to improved cognitive flexibility depending on whether the game is played in a challenging or non-challenging way (e.g., Glass, Maddox, & Love, 2013). It therefore follows that in order to make sensible claims about the impact of technology on cognition, it is necessary to focus on clearly defined forms of media. Following Cardoso-Leite, Green, & Bavelier (2014), we decided to contrast two groups of media users: action video game players and heavy media multitaskers.

## Impact of different technology use on cognition

### Action video game players (AVGP)

Action video games are fast-paced interactive systems that place a heavy load on divided attention, peripheral processing, information filtering, and motor control. There is also a large load placed upon decision-making via the nesting of goals and subgoals at multiple time scales. Action video games—in contrast to other types of games such as life-simulations—have been shown to produce a variety of benefits in vision, attention and decision-making (for a review, see Green & Bavelier, 2012; Latham, Patston, & Tippett, 2013; Spence & Feng, 2010). In the domain of attention, action video games have been shown to improve the top-down attentional system, which underlies abilities such as focusing attention on some elements at the expense of others (i.e., selective attention), maintaining attention over longer periods of time (i.e., sustained attention), and sharing attention in time, in space or across tasks (i.e., divided attention, for reviews see Hubert-Wallander, Green, & Bavelier, 2010; Green & Bavelier, 2012). Action video game players (AVGP)— typically defined as individuals who have played 5 hours or more of action video games per week for the last 6 months—have better spatial selective attention, as they can more accurately locate stimuli in space, either when the stimuli are presented in isolation (Buckley et al., 2010) or when the stimuli are presented alongside distractors (Feng et al., 2010; Green & Bavelier, 2003; 2006a; Spence et al., 2009; West et al., 2008). AVGP also show an increased ability to direct attention in time, as evidenced by a shorter interference window in backward masking (Li et al., 2010) and a reduced attentional blink (Cohen et al., 2007; Green & Bavelier, 2003). They can also visually track a greater number of targets (Boot et al., 2008; Cohen et al., 2007; Green & Bavelier, 2003, 2006b; Trick et al., 2005), which suggests increased attentional resources or an improved efficiency in attention allocation (Ma & Huang, 2009; Vul, Frank, Alvarez, & Tenenbaum, 2010; see also, Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Chisholm & Kingstone, 2012). However, not all aspects of perception and cognition appear to be enhanced in action video game players. For instance, bottom-up attention appears to be unaffected by action video game experience (Castel et al., 2005; Dye et al., 2009b; but see West et al. 2008). Importantly, long-term training studies, wherein individuals who do not naturally play action video games undergo training on either an action video game or a control video game for many hours (e.g., 50 hours spaced over the course of about 10 weeks), have confirmed that action video game play has a causal role in the observed effects (Bejjanki et al., 2014; Feng, Spence, & Pratt, 2007; Green, Pouget, & Bavelier, 2010; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Green & Bavelier, 2003; Oei & Patterson, 2013; Strobach, Frensch, & Schubert, 2012; Wu & Spence, 2013; Wu et al., 2012; for a review see Green & Bavelier, 2012; Bediou, Adams, Mayer, Green, & Bavelier, submitted).

## Media Multitasking

Media multitasking is the simultaneous consumption of multiple streams of media—for instance, reading a book while listening to music, texting while watching television, or viewing web videos while emailing (Ophir, Nass, & Wagner, 2009). It is important to note that extensive *media multitasking* is different than extensive *media use*. An individual may consume a large amount of different forms of media, but if they do not utilize the forms of media *concurrently*, they would not be considered a media multitasker. To study the potential impact of engaging in large amounts of media multitasking, Ophir et al. (2009) first devised a media multitasking questionnaire from which the authors computed an index (the media multitasking index; MMI) that reflects the extent to which a respondent self-reports media multitasking. Participants that were 1 standard deviation above the population average were termed Heavy Media Multitaskers (HMM) whereas those on the opposite end (i.e., 1 SD below the mean) were termed Light Media Multitaskers (LMM).

Intuitively, because HMM perform multiple tasks at the same time and switch more frequently between tasks or media than LMM, one might expect HMM to outperform LMM in multitasking. Indeed, practice typically leads to performance improvements. Contrary to this intuition, however, Ophir and colleagues reported that HMM were worse—not better—than LMM in a task-switching experiment. HMM were also worse in other tasks, like the Filter task (that requires participants to recall briefly presented visual elements while ignoring distractors), the N-back task (that requires participants to keep a series of recently presented items in working memory and update that list as new items appear) and the AXCP-task (which requires participants to respond differently to a target letter "X" depending on whether or not it was preceded by the letter "A"; *note: all of these tasks are presented in greater detail below). Furthermore, the performance decrements observed when contrasting HMM and LMM were not global in nature (i.e., with the HMM being generally slower/less accurate on all tasks and all conditions within tasks), but instead appeared to be specific to situations that involved distractors. For example, in the AXCP-task, HMM and LMM performed equally well in the distractor-absent condition. However, HMM were more negatively affected (slower response times) by the presence of distractors than LMM.

To account for these results the authors argued that media multitasking might have negative effects on cognitive control, thus leading to weaker resistance to distractors. Alternatively, because the study was purely cross-sectional in nature, it is also possible that those participants who are less resistant to distractors or who privilege breadth over depth with regard to cognitive control might more frequently engage in media multitasking.

Recent studies have brought some support for this final possibility. Ralph, Thomson, Seli, Carriere, & Smilek, (2014) for instance, observed a negative impact of media multitasking in some but not other measures of sustained attention, unlike what might be expected if high media multitaskers are generally less resistant to distractors. Meanwhile, Cain & Mitroff (2011) used the additional singleton task to test the idea of breadth-biased attention. In this task, participants are presented with an array of shapes (squares and circles) and asked to report which symbol is presented in the unique target shape (circle) while ignoring the remaining non-target shapes (squares). In half of the trials, all the shapes are colored green whereas in the remaining half of the trials, one of the shapes is colored red (the additional singleton). Participants were informed that there were two experimental conditions. In the "sometimes" condition the color singleton could be the target whereas in the "never" condition this was never the case. The difference in performance across these two conditions reflects the ability to take into account instructions or prior knowledge when spatially distributing attention. HMM, as opposed to LMM, did not modulate their responses between these two tasks suggesting that they maintained a broader attentional scope despite the explicit task instructions.

Lui & Wong (2012) went a step further and reasoned that there might be situations in which a broader attentional scope may in fact be advantageous. These authors used the pip-and-pop paradigm, where participants search for a vertical or horizontal line (target) among an array of both red and green distractor lines with multiple orientations. The color of the lines changed periodically within a trial, with target and distractor lines changing their colors at different frequencies (the orientation of the lines was kept constant within each trial). In some conditions a tone was presented in synchrony with the flickering of the target line; participants were not explicitly informed about the meaning of the tones. The results showed that target detection performance increased in the presence of the tones and this benefit correlated positively with the MMI score. The authors concluded that HMM—perhaps because of their breadth-biased attentional processes—are better able to integrate multisensory information.

Finally, a recent study used Voxel-Based Morphometry and reported that participants with higher levels of media multitasking had lesser gray matter density in the anterior cingulate cortex compared to individuals with lower levels of media multitasking (Loh & Kanai, 2014).

Although these results are suggestive, the available literature remains somewhat unsettled. Minear, Brasher, McCurdy, Lewis, & Younggren (2013) for example, compared HMM and LMM in two task-switching experiments but found no significant difference between these two groups of participants, while Alzahabi & Becker (2013) found that HMM actually performed better at task-switching than LMM, not worse as reported by Ophir and colleagues. Thus, due to the inconsistent results that have been observed, there is a definite need for additional replications in the domain.

## Comparing action video game players to media multitaskers

Media multitasking and playing action video games are two common forms of technology usage; as such they are likely to co-occur in the same participants. Yet, little is known about their joint impact or interaction. Media multitaskers and action video game players have, though, been independently evaluated using the same experimental paradigms across different studies. For example, HMM have not been seen to differ from LMM on the Attentional Network Test (ANT; Minear et al., 2013)—which measures three components of attention (alerting, orienting and executive control)—or in terms of dual task performance (Alzahabi & Becker, 2013), whereas AVGP differ from NVGP both on the ANT (Dye, Green, & Bavelier, 2009; but see Wilms, Petersen, & Vangkilde, 2013) and in terms of dual-tasking (Strobach, Frensch, & Schubert, 2012). HMM appear to be more impulsive and sensation seeking than LMM (Minear et al., 2013; Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013) and to score lower on fluid intelligence tests (Minear et al., 2013). AVGP on the other hand have been shown to be no more impulsive than NVGP (Dye, Green, & Bavelier, 2009) and do not differ from NVGP on measures of fluid intelligence (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013). Finally, some abilities seem to be unchanged by both media multitasking and action video game play, such as the ability to abort an imminent motor response as measured with the Stop signal task (Ophir et al., 2009; Colzato, van den Wildenberg, Zmigrod, et al., 2013).

So far, only one study has investigated both gaming and media multitasking. The additional singleton experiment by Cain & Mitroff (2011), described earlier, reported that HMM did not take into account information about the task structure. These authors classified the same set of participants into AVGP and NVGP based on their self-reported gaming experience. While both gaming groups' performance was modulated by task structure, there was no difference between these two groups. Unfortunately, this study did not consider that media multitasking and gaming experience might interact. For example, action game play could serve as a protective mechanism against the negative effects seen with extensive media multitasking, or conversely, the negative effects of media multitasking could overwhelm the positive benefits of action video game play. One of the aims of the present study is to evaluate the potential interactions between these two types of technology experiences and thus gain a fuller picture of their effects.

The primary focus of this study is to contrast the effects of these two types of media consumption on tasks measuring attentional or cognitive control. To this end, we utilized the exact four tasks as were used by Ophir et al. (2009). Below we review, for each of the four tasks utilized in the current study, the existing literature for both action video gaming and media multitasking.

## AX-Continuous Performance Task

The AX-Continuous Performance Task (AX-CPT, see Figure 1) measures proactive cognitive control—as opposed to reactive control that is required, for example, in the Stroop task. In the AX-CPT participants have to first encode a stimulus (the cue) that signifies a context and allows them to prepare a response to a second stimulus (the probe).

Ophir and colleagues compared HMM and LMM on two versions of the AX-CPT: the distractor-absent condition and the distractor-present condition. In the distractor-present condition, additional irrelevant and clearly identifiable stimuli were presented between the cue and the probe. Ophir and colleagues results showed that HMM and LMM did not differ in the distractor-absent condition, but HMM were slower than LMM to respond in the distractor-present condition. This pattern led these authors to conclude that HMM were more affected by distracting information than LMM.

The AX-CPT has not been used to contrast AVGP and NVGP. Some studies however, suggest that AVGP might outperform NVGP in this type of cognitive control task. Dye, Green, & Bavelier (2009) assessed performance of AVGP and NVGP on the Test of Variables of Attention (TOVA). The TOVA is in essence a Go/NoGo task, wherein participants press a button whenever a target shape appears in one location, and withhold a response when the target appears in a different location. Dye, Green, and Bavelier (2009) found that AVGP responded more quickly than NVGP with no difference in accuracy, that is, the faster responses were not the result of a speed-accuracy tradeoff. Bailey, West, & Anderson (2010) used different subsets of trials on the Stroop task to extract indices of proactive and reactive cognitive control in AVGP and NVGP. In this set up, video game experience was not found to modulate reactive cognitive control. Proactive control, as measured by reaction time analyses, also did not differ as a function of video game experience, except for a tendency for lesser influence of the previous trial in more experienced gamers, which the authors interpreted as deficient maintenance of proactive control with more video game experience. More recently, McDermott, Bavelier, & Green (2014) using a "recent probes" proactive interference task found different speed-accuracy trade-offs between AVGP and NVGP, with AVGP being faster but less accurate, but no genuine difference in proactive interference. It remains to be tested if these results can be replicated when using a more direct measure of proactive control (AX-CPT) and controlling for media multitasking.

## N-back Task

In the N-back task, participants are shown a sequence of letter stimuli and have to decide for each of them whether it matched the stimulus presented N items ago (see Figure 2). Thus, to perform the task well participants must remember the N most recently presented items and update that list as new items are presented. The N-back task taps the process of "updating" — one of the three major functions of cognitive control (Miyake et al., 2000; the remaining components being shifting/flexibility and inhibition).

Ophir and colleagues (2009) compared HMM and LMM on 2-back and 3-back versions of the N-back task. Performance was assessed only in terms of accuracy, not reaction time. The results showed that HMM and LMM differed only in the 3-back condition where HMM had approximately the same hit rate as LMM, but made substantially more false alarms. Furthermore, this increased false alarm rate appeared to build up during the course of the experiment, as if HMM had increasing difficulty in filtering out previously encountered, but now irrelevant items.

In the AVGP/NVGP literature, Boot, Kramer, Simons, Fabiani, & Gratton (2008) used a spatial version of the 2-back task in two experiments. In the first experiment, they observed that self-reported AVGP tended to be faster, but not more accurate than NVGP. In the second experiment, NVGPs trained on either an action video game or a control game. The results showed that all participants improved in this task but there were no significant differences between the two groups.

More recently, Colzato, van den Wildenberg, Zmigrod, & Hommel (2013) compared AVGP and NVGP in 1-back and 2-back conditions—similar to those used by Ophir et al. (2009). Performance was assessed using both d′ and response times on correct trials. Their results show that in both of these conditions AVGP were faster and more accurate than NVGP. Specifically, AVGP had both higher hit rates and lower false alarm rates than NVGP, which is compatible with the hypothesis of improved cognitive control (rather than a specific improvement in distractor filtering). Finally, McDermott et al. (2014) measured both accuracy and response time for AVGP and NVGP in a spatial N-back task where N varied from 1 to 7. AVGP were overall faster than NVGP while keeping the same level of accuracy. These group differences were particularly salient when task difficulty was increased.

## Task-switching

Task-switching experiments require participants to keep active multiple task-sets and flexibly switch among task-sets across trials. In a typical task-switching experiment, participants are presented with a sequence of stimuli on which they have to perform one of two tasks depending on a previously presented cue (see Figure 3 for an example). The reduction in performance after a task switch is termed the task-switch cost. Ophir et al. reported that HMM had a significantly larger switch cost than LMM, suggesting that HMM are less able to filter out irrelevant task-sets.

Task-switching has been repeatedly investigated in AVGP (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, Frensch, & Schubert, 2012; although see Boot et al., 2008). Most of these studies reported enhanced task-switching abilities. This is true both for studies that selected individuals based on their self-reported action video game experience (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, Frensch, & Schubert, 2012; but see Gaspar et al., 2013) and for studies that had participants train on action video games (i.e., training studies—Colzato et al., 2013; Green et al., 2012; Strobach, Frensch, & Schubert, 2012; but see Boot et al., 2008). For example, Andrews & Murphy (2006), using a number and letter discrimination task, observed a reduced task-switching cost for AVGP relative to NVGP. This was true for short inter-trial intervals (150ms) but not for longer ones (600ms and 1200ms). Boot et al. (2008) required participants to classify numbers into either greater/ smaller than 5 or into even/odd. AVGP showed a reduced task-switching cost (although this was not seen in a training experiment). More recently, Green et al. (2012) contrasted AVGP and NVGP in four different task-switching experiments which varied in terms of response mode (vocal vs. manual), nature of the task (perceptual vs. conceptual) and in terms of the level at which the switches were applied (switching among goals or stimulus response mappings). They also trained participants on either an action video game or a control game for 50h. In all these conditions, AVGP showed reduced switch costs relative to NVGP. Overall, the vast majority of this literature suggests that action video game play improves cognitive flexibility.

### Filter Task

In the Filter task, participants are successively presented with two arrays of oriented lines that are colored red or blue (see Figure 4). On half of the trials, one of the red lines from the first display changes orientation in the second display. Participants are asked to report whether there was an orientation change in any of the red lines and ignore the blue lines. By varying the number of targets (red lines) and distractors (blue lines) in the display, this task assesses both visual short-term memory capacity and resistance to distractors. Ophir and colleagues (2009) measured performance in 10 different combinations of target-number/ distractor-number, but because their focus was on the effect of distractors, they reported data only from the 4 conditions that kept target number constant at 2 and varied distractor number. Their results showed that for LMM, performance did not vary with the number of distractors. However, for HMM, performance decreased when the number of distractors was high, suggesting that HMM might be specifically impaired in filtering out task-irrelevant information.

Some studies suggest that AVGP have better visual short-term visual memory (e.g., Appelbaum, Cain, Darling, & Mitroff, 2013) and are better at filtering out distractors (e.g., Mishra, Zinni, Bavelier, & Hillyard, 2011) than NVGP. More recently, Oei & Patterson (2013) investigated the impact of 20h of action video game training on the Filter task. They measured the same 10 target/distractor-number conditions as Ophir and colleagues but reported only the “2-targets 6-distractors” (maximal number of distractors) and the “8-targets 0-distractors” conditions (maximal number of targets condition). Playing action video games, in comparison to other forms of video games, improved performance in both of these conditions suggesting that action video game experience improves both visual capacity and distractor suppression (see also, Oei & Patterson, 2015).

## Methods

### Recruitment procedure

Participants were students recruited at the University of Rochester and the University of Wisconsin using a mixture of procedures. At the University of Wisconsin, students filled out a battery of questionnaires that included the media multitasking and video game experience questionnaires as part of a general screening procedure to enroll in psychology experiments (and were recruited based upon their responses to these questionnaires). In addition, flyers were distributed at both Universities to overtly and specifically recruit students with or without extensive action video gaming experience.

### Participants

Out of the 68 students that were initially enrolled in the study, 60 completed all the experiments and questionnaires (the partial data from the 8 incomplete participants were excluded from further analysis). From these, 35 were recruited and tested at the University of Rochester and 25 at the University of Wisconsin.

Participants filled in the same media multitasking questionnaire as in Ophir et al. (2009) and the same video game usage questionnaire as that used in the Bavelier lab (see Appendix). In the media multitasking questionnaire, participants are presented a list of media (e.g., TV, print) and asked to report how much time they spend on each medium and to what extent they simultaneously consume each of the media combinations (e.g., TV and print at the same time). In the video game usage questionnaire, participants are asked to report their weekly consumption of video games separately for a set of game genres (e.g., action games, role playing games). In the case of the media multitasking questionnaire, participants were classified as heavy media multitaskers (HMM) and light media multitaskers (LMM) using the same boundary values as Ophir et al. (i.e., media multitasking index <2.86: LMM; >5.90: HMM). All participants falling in-between these two extremes were termed Intermediate Media Multitasking (IMM). For gaming, we used the same criterion as previously used in our work (Hubert-Wallander, Green, Sugarman, & Bavelier, 2011), in that those who played first person shooter or other action games for more than 5 hours per week (and at most 3 hours of Turn-based, role playing or music games) were classified as AVGP; those who played less than 1 hour of first-person shooters, action or sports games and real time strategy games were classified as NVGP. Figure 5 reports the sample sizes across media multitasking and gaming groups.

Participants were on average 20.68 (sem: 0.43) years old and mostly males (52/60); the 8 females were all NVGP, distributed in media multitasking groups as follows: 0 HMM, 4 IMM and 4 LMM. All participants gave written consent and received either $10/hour or course credit for their participation.

## Apparatus

Participants were seated at an approximate distance of 57 cm from the screen. All measurements were made on the same Dell Optiplex computer running E-Prime 2.0 software, with stimuli presented on a 19″ Dell TFT monitor.

## Procedure

All participants completed three questionnaires: the Adult ADHD Self-Report Scale (ASRS-V1.1, 6 items, Kessler et al., 2005), the Cognitive Failure Questionnaire (CFQ; 25 items; Broadbent, Cooper, FitzGerald, & Parkes, 1982) and the Work and Family Orientation Questionnaire (WOFO, 19 items, 3 subscales: work, mastery and competitiveness; Helmreich & Spence, 1978).

The four experiments presented in this study (i.e., AX-CPT, N-back, Filter task, and Task switching) were identical to that of Ophir et al. (2009) and administered over two sessions. Half of the participants completed the N-back and Filter task in their first session and the AX-CPT and Task-switching tasks during the second session. This order was reversed for the remaining participants. Individual task procedures are described below.

**AX-Continuous Performance Task (AXCPT)—**Figure 1 illustrates the time course of a typical trial in the distractor-absent and distractor-present conditions of the AX-CPT. Participants were exposed to a sequence of colored letters. Participants were instructed to press the “Yes” key only in cases where the current letter was a red “X” AND the previous red letter (regardless of any intervening white letters—see below) was an “A”. In all other cases, participants were to press the “No” key. There were two experimental conditions that were run in succession: the distractor-absent and the distractor-present conditions. The difference between these two conditions was that in the distractor-absent condition, all letters that appeared were red (with approximately 5 seconds between the presentations—see Figure 1). Conversely, in the distractor-present condition, three different white colored distractor letters were presented within the 5 second period between red letter presentations. Distractors were presented for 300 ms and separated by 1 second intervals. Participants were to press the “No” key in response to each of these distractor stimuli.

All participants first completed the distractor-absent condition and then the distractor-present condition. Each of these conditions contained 5 blocks of 30 trials—21 trials were of the type “AX”, 3 trials had a cue “A” but a non-”X” probe (generically termed “AY” trial type), 3 trials had an “X” probe but a non-“A” cue (“BX” trial type) and finally 3 trials had neither an “A” as a cue nor an “X” as a probe (“BY” trials). The complete experiment lasted about 30 minutes.

**N-back—**Figure 2 illustrates the time course of a typical trial in the 2-back and 3-back conditions. Participants were presented with sequences of letters (selected from the set: B C D F G H J K L M N P Q R S T V W Y Z). Letters were presented for 500 ms and interleaved with 3 seconds periods of a blank screen during which participants were to press one of two keyboard keys to indicate if the just-presented letter was the same as the letter presented 2 letters (in the 2-back condition) or 3 letters (in the 3-back condition) earlier.

All participants first completed the 2-back condition before moving on to the 3-back condition. For each of these conditions, participants started with a practice block of 20 trials before completing 3 blocks of 30 trials of the N-back task. One third of the trials in each of these blocks required a "same as N-back" response.

**Task-Switching—**Figure 3 illustrates a typical trial in the task-switching experiment. In this experiment, participants were presented with a stimulus composed of both a letter (from the set a, e, i, k, n, p, u, s) and a number (from the numbers 2 to 9; e.g., "e7") and asked to perform either a letter discrimination task ("vowel vs. consonant") or a number discrimination task ("odd vs. even") by pressing one of two keys. The same two keys were used for both tasks (left button for odd/vowel and the right button for even/consonant). A task cue ("NUMBER" vs. "LETTER") was displayed for 200 ms at the beginning of each trial and indicated which task to perform on the stimulus presented 226 ms later. The inter-trial interval was 950 ms.

Participants first performed three practice blocks (both tasks in isolation, and then a shortened version of the full task). Each of these blocks contained 30 trials. After the practice blocks, participants performed four blocks of the task-switching experiment. Each of these blocks contained 80 trials, 40% of which were randomly interleaved switch trials.

**Filter Task—**Figure 4 illustrates the spatial layout and time course of a typical trial in the filter task. Participants were asked to fixate a central cross that appeared at the beginning of each trial on a gray background. Two hundred ms after this onset, an array of randomly oriented, evenly distributed, non-overlapping red and blue lines was displayed for 100 ms. The participants' task was to encode the orientation of the red target lines. The blue lines were task-irrelevant and therefore called "distractors". A second array, displayed for 2000 ms, was presented 900 ms after the offset of the first display. Participants report whether or not one of the red target lines changed orientation (±45°) across these two arrays. An orientation change occurred on 50% of the trials. The number of targets and distractors varied from trial to trial. There could be 2, 4, 6 or 8 targets and 0, 2, 4, or 6 distractors with the additional constraint that the total number of elements in an array could not exceed 8 (making up a total of 10 target-distractor conditions). Participants first performed 20 practice trials (2 trials per condition) before completing a unique block of 200 trials (10 trials per condition).

## Data analysis

**Software Package—**Data were analyzed using R (version 3.0.1).

**MMI scores—**The media multitasking questionnaire (Ophir et al., 2009) assesses both the total amount of media use (across 12 distinct forms of media) as well as the joint usage of all pairs of media. We then compute a Media Multitasking Index which reflects the mean amount of simultaneously used media weighted by the total use of each form of media (see supplementary methods for further details). Ophir and colleagues observed that MMI measured on 262 university students produced an approximately Gaussian distribution with a mean of 4.38 and a standard deviation of 1.52. Participants that were 1 SD above or below the mean were classified as heavy (HMM) and light media multitaskers (LMM), respectively. Note that the remaining participants were not included in their study. Unlike Ophir et al., we included these participants as a third group of media multitaskers that we call the intermediate media multitaskers (IMM).

In the present study we measured MMI on 60 participants some of whom were overtly recruited for being AVGP or NVGP. Figure 5 illustrates the distribution of MMI as a function of gaming group. MMI appeared again approximately normally distributed, with a mean of 3.98 and a standard deviation of 1.99. Action video game players had higher scores than non-video game players (4.45 vs. 3.62), but this difference was not statistically significant (two-sided t-test: t(58)=1.63, p=0.109).

To classify our participants into HMM, LMM and IMM we used the same numeric values obtained by Ophir and colleagues (as opposed to using +/− 1SD from our own sample). We did so for a number of reasons. First, their sample matches more closely the distribution of MMI scores in the general population because they used a larger sample of participants from a homogenous population (as compared to our sample that is dramatically over-represented by AVGP as compared to their numbers in the general population). Second, we wanted to be able to compare and contrast our results directly with theirs. Finally, because in our sample action video game players tended to have larger MMI scores than non-action video game players, using a cutoff of 1SD below the mean would lead to a very small sample size of AVGP among the LMM (there would however be no effect on the composition of the HMM group).

**Accuracy—**Trials without any response or with aberrant reaction times (RTs so short that they could not be based on processing the display (less than 120 ms), or so long that participants were not doing our tasks (greater than 5 seconds) were excluded from further accuracy analyses (on average 0.6% of the data: AXCPT 1.81%; N-back 0.41%; TS 0.11%, Filter task 0.15%). Accuracy was assessed using percentage of correct responses in all but the Filter task. Following previous studies, performance in the Filter task was assessed using the index of visual capacity $K = S(H - F)$ where $S$ is the number of targets in the display, $H$ the hit rate, and $F$ the false alarm rate (Marois & Ivanoff, 2005; Vogel, McCollough, & Machizawa, 2005). In addition, performance in the Filter task was evaluated using an alternative model (Ma, Husain, & Bays, 2014; van den Berg, Shin, Chou, George, & Ma, 2012); in this case accuracy was assessed in terms of number of hits and false alarms.

**Response Speed—**Response speed was assessed on correct trials only. As reaction time distributions are known to be skewed, RTs were treated for outliers by first log transforming RTs, removing as outliers all trials where the log(RT) were 2SD beyond the mean of their respective condition for each task and participant, before transforming back to RTs. This procedure excluded 4.5% of the data across tasks and groups. The percentage of trials removed across tasks (AXCPT and N-back 4.6%; TS 4.5%, Filter task 4.2%) and across groups (LMM: 4.34%; IMM: 4.53% HMM: 4.54%; AVGP: 4.35%; NVGP: 4.59%) were comparable. Analyses were then carried out on the median RTs computed for each condition and each participant. In the task-switching experiment, as is customary, all trials that immediately followed an error trial were excluded from the median RT computation. We note that analyses carried out on the median RT, without applying the outlier RT trimming procedure described above, lead to virtually identical results. However, because the p-values were overall more significant without outlier removal, we chose to report the results from the more conservative approach with outlier removal.

**Combined RT/Accuracy Analyses—**In order to assess group differences in terms of both speed and accuracy we computed inverse efficiency scores that combine measures of response speed and accuracy in a unique variable (i.e., by dividing response speed by accuracy rate), a method often used in the developmental or aging literature when groups with different baseline RTs have to be compared (see for example Akhtar & Enns, 1989; McDermott et al., 2014). Inverse efficiency scores were then submitted to statistical analysis for all tasks, except for the Filter task where response speed is not emphasized and the typical measure of interest is K.

**Data analyses plan—**For each of the tasks, the omnibus analysis of variance with between-group factors of media multitasking group (3 levels: HMM, IMM, LMM) and of gaming group (2 levels: AVGP, NVGP) is first presented. Next, because previously published studies on media multi-tasking contrast only LMM and HMM, we present an ANOVA that includes only HMM and LMM with media multitasking group (2 levels: HMM, LMM) and gaming group (2 levels: AVGP, NVGP). Then, because the bulk of the action videogame literature does not select for either high or low media multi-taskers and thus the IMM group is likely to be most similar to previously published studies contrasting AVGP to NVGP, an ANOVA focused only on IMM with gaming group (2 levels: AVGP, NVGP) is presented. Because the number of AVGP and NVGP within the HMM and LMM groups are limited it was not possible to reliably assess the effect of video game experience within each of these two groups. As an alternative we decided to collapse these two groups to contrast the effect of gaming among these more “extreme” media multitaskers with those observed within the IMM. Finally, when contrasting two conditions or groups we used the Welch’s t-test, which doesn’t assume the samples to have equal variance.

## Results

### Questionnaires

Scores on the Adult ADHD Self-Report Scale (ASRS), the Cognitive Failure Questionnaire (CFQ) and the Work and Family Orientation Questionnaire (WOFO) did not differ across gaming and media multitasking groups (ANOVA; all $p>0.19$) with the exception of the mastery subscale of the WOFO questionnaire. High scores on this scale reflect a strong “preference for difficult, challenging tasks and for meeting internally prescribed standards of performance excellence". We observed a significant difference in WOFO-mastery across media multitasking levels (F(2,54)=5.78, p=5.3e-3) and a significant media multitasking x gaming group interaction (F(2,54)=3.44, p=0.04). Mastery scores were higher for HMM (3.65±0.1; p<0.02) than for both intermediate (IMM: 3.25±0.07; p=1.6e-3) and low media multitaskers (LMM: 3.37±0.11; p=0.06); these last two groups were not different from each other (p=0.35). The gaming by media multitasking interaction is more difficult to interpret: among the LMM group, mastery scores did not differ between AVGP and NVGP (p=0.75); among the IMM group, AVGP had lower mastery scores than NVGP (p=0.02) while among the HMM the opposite tended to be true (p=0.07).

**AX-CPT—**The average speed and accuracy for each group and each condition of the experiment are displayed in Table 1.

Overall performance was assessed using inverse efficiency scores (Figure 6). The 2×3×2 omnibus ANOVA on inverse efficiency scores with the factors "condition" (i.e., distractor-present & distractor-absent), "media multitasking" (i.e., HMM, IMM & LMM) and "gaming" (i.e., AVGP & NVGP) revealed a main effect of condition (F(1,108)=11.73, p=8.7e-4), a main effect of media multitasking (F(2,108)=4.01, p=0.02) and no significant effect of gaming (F(1,108)=0.94, p=0.34). Condition did not interact with gaming group and/or media multitasking group (all ps>0.25). The gaming by media multitasking group interaction was significant (F(2,108)=3.83, p=0.02) suggesting different impact of video game group as a function of media multitasking group. Given the low Ns in the extreme media multitasking cells (HMM and LMM), we regrouped these two into an extreme MM group and carried 2×2×2 ANOVA with the factors "condition" (i.e., distractor-present & distractor-absent), "media multitasking" (i.e., extreme MM & IMM) and "gaming" (i.e., AVGP & NVGP). The results confirm a main effect of condition (F(1,112)=8.53, p<5e-3) and a significant gaming group by media multitasking interaction (F(1,112)=8.44, p<5e-3). There was no significant effect of gaming (F(1,112)=3.07, p=0.08) and no effect of media multitasking (IMM vs. extreme MM: F(1,112)=1.32, p=0.25; all other ps>0.14).

The 2×2×2 ANOVA focused on media multitasking impact and contrasting HMM and LMM revealed a main effect of condition (F(1,56)=15, p=2.8e-4), a main effect of media multitasking (F(1,56)=9.04, p=3.9e-3) due to worse performance in HMM and no significant main effect of gaming group (F(1,56)=0.4, p=0.5). None of the other effects were significant (interactions with condition p's>0.2; interaction between gaming and media multitasking group p=0.99). Thus, unlike what was reported by Ophir et al., condition and media multitasking group did not interact.

Finally, the 2×2 ANOVA with condition and gaming group including only IMM individuals yielded a main effect of gaming group (F(2,25)=8.16, p=6e-3). There was no significant main effect of condition and no significant gaming group by condition interaction (p>0.37).

**AX-CPT: Discussion:** As in previous work, overall performance in this proactive cognitive control task was best in the distractor condition as compared to the non-distractor condition. Indeed, it has been reported that the presence of differently colored distractors between prime and target tends to facilitate processing, possibly by maintaining the engagement of participants over time as they wait for the next target. A main effect of media multitasking group indicates differences in performance as a function of media multitasking, and a media by gaming group interaction suggested different impact of gaming as a function of media multitasking group.

A closer look at the impact of media multitasking group confirmed worse performance in HMM as compared to LMM. Although this effect is in the same direction as that reported previously by Ophir et al. (2009), in that study, HMM differed from LMM only when distractors were added to the task. In the present study we did not observe this type of specific impairment of the HMM group relative to the LMM group in the presence of distractors. Instead we noted that HMM performed overall worse than LMM, with IMM falling numerically in-between the two groups (see Table 1).

Finally, the effects of AVGP on proactive control depended on the media multitasking group. It was only in the IMM group that action video game players outperformed non-action video game players. They did so both in terms of accuracy and response speed (see Table 1), excluding different speed accuracy tradeoffs between AVGP and NVGP as a possible explanation. Importantly, gaming group was not a differentiating variable when considering the extreme MM groups, whether IMM and HMM, as confirmed by the significant interactions between gaming status and MM status.

**N-back: Results—**The average speed and accuracy for each group and each condition of the experiment are displayed in Table 2.

Overall performance was assessed using inverse efficiency scores (Figure 7). The 2×3×2 omnibus ANOVA on inverse efficiency scores with the factors “condition” (i.e., 2-back & 3-back), “media multitasking” (i.e., HMM, IMM & LMM) and “gaming” (i.e., AVGP & NVGP) revealed a main effect of condition ($F(1,108)=5.77$, $p=0.02$). There was no significant main effect of gaming group ($F(1,108)=0.31$, $p=0.58$) and a marginal effect of media multitasking group ($F(2,108)=2.7$, $p=0.07$). Condition did not interact with gaming and/or media multitasking (all ps>0.5). There was however a significant gaming by media multitasking group interaction ($F(2,108)=4.05$, $p=0.02$) again indicating a different impact of action video game play as a function of media multitasking. To further understand this effect, a 2(2-back & 3-back) × 2(extreme MM & IMM) × 2(AVGP & NVGP) ANOVA grouping participants from both HMM and LMM as an extreme MM group was carried out. This analysis showed a main effect of condition ($F(1,112)=6.3$, $p<0.02$) and a significant gaming group by media multitasking interaction ($F(1,112)=7.2$, $p<9e-3$). There was no main effect of gaming group ($F(1,112)=1.26$, $p=0.26$) but there was a significant effect of media mulitasking ($F(1,112)=4$, $p<0.05$) suggesting that in this task IMM performed overall better than the combined HMM and LMM groups. No other effects were signficant (ps>0.6).

The 2×2×2 ANOVA contrasting HMM and LMM on inverse efficiency scores revealed only a marginal effect of condition ($F(1,56)=2.69$, $p=0.11$; all other ps>0.32). There was no significant difference when contrasting HMM and LMM ($F(1,56)=0.78$, $p=0.38$). Because Ophir et al. reported increased false alarms in HMM relative to LMM, but only in the 3 back condition, we ran generalized mixed effects models on the false alarms rates and computed likelihood ratio tests to compare models with and without media multitasking group. There was no significant difference between HMM and LMM in terms of overall false alarm rates ("condition" vs. "condition" + "media multitasking group": $\chi^2(1)=1.02$, $p=0.31$) and there was also no evidence for an interaction between media multitasking group and condition ("condition" + "media multitasking group" vs. "condition" x "media multitasking group" : $\chi^2(1)=0.93$, $p=0.33$).

Finally, the 2×2 ANOVA restricted to IMM with condition and gaming group as factors showed a marginally significant effect of condition ($F(1,52)=3.84$, $p=0.06$) and of gaming group ($F(1,52)=12.9$, $p=7e-4$) with no significant interaction ($p>0.8$). Numerically, AVGP were both more accurate and faster than NVGP (see Table 2).

**N-back: Discussion:** Poorer performance was found on 3-back trials than 2-back trials as expected. The main effect of media multitasking group was only marginally significant, driven by greater efficiency in IMM than both HMM and LMM (faster responses at equivalent accuracy – see Table 2). Within the IMM group, the action video game players exhibited significantly better performance as compared to non gamers, replicating and extending previous work on action video games. In contrast, action video game play did not have any effect when considering HMM and LMM participants.

Finally, although numerically HMM tended to be less efficient than LMM (less accurate and slower), no significant differences were observed between HMM and LMM and unlike Ophir and colleagues, HMM were not specifically impaired in the 3-back condition.

Interestingly, the effects of AVGP on N-back performance depended on the media multitasking group. It was only in the IMM group that action video game players outperformed non-action video game players. Gaming group was not a differentiating variable when considering the extreme MM groups, whether IMM and HMM, as confirmed by the significant interactions between gaming status and MM status.

**Task Switching: Results—**The average speed and accuracy for each group and each condition of the experiment are displayed in Table 3.

Overall performance was assessed using inverse efficiency scores (Figure 8). The 2×3×2 omnibus ANOVA on inverse efficiency scores with the factors "trial type" (2 levels, task-repeat and task-switch trials), "media multitasking" (3 levels) and "gaming" (2 levels) revealed only a significant effect of trial type ($F(1,108)=16.5$, $p=9e-5$) due to greater efficiency on task-repeat as compared to task-switch trials. None of the other effects were significant (all ps >0.12). As before a 2×2×2 ANOVA grouping participants from both HMM and LMM as an extreme MM group was carried out. The results showed a main effect of condition ($F(1,112)=17$, $p=7e-5$) and a significant effect of gaming group ($F(1,112)=4.4$, $p<0.04$), with AVGP being overall more efficient than NVGP (809±32 vs. 910±40). No other effects were significant (ps>0.1).

The 2×2×2 ANOVA on inverse efficiency scores comparing LMM and HMM revealed again a main effect of trial type ($F(1, 56)=9$, $p=4e-3$). None of the other effects were significant (ps>0.2), except for a marginal interaction between gaming and media multitasking group

($F(1,56)=2.93$, $p=0.09$) most likely reflecting a trend for greater AVGP efficiency in LMM but worse in HMM.

The 2×2 ANOVA restricted to IMM participants showed a main effect of trial type ($F(1,52)=7.53$, $p=8e-3$) and of gaming group ($F(1,52)=5.83$, $p=0.02$) with no interaction ($p>0.7$). The AVGP appeared numerically both more accurate and faster than NVGP (see Table 3).

**Task Switching: Discussion:** As expected, performance was poorer on task-switch as compared to task-repeat trials, no significant effects of media multi-tasking were observed, and overall AVGP tended to show better performance than NVGP.

Several previous studies have compared the ability of HMM and LMM to flexibly switch between tasks. Ophir et al. reported that HMM were less flexible than LMM. Subsequent studies, however, either observed no difference between these two groups (Minear, Brasher, McCurdy, Lewis, & Younggren, 2013) or a difference in the opposite direction (Alzahabi & Becker, 2013). In the present study we observed no reliable difference across these two media multitasking groups. One possible explanation for these discrepancies may reside in an interaction effect between media multitasking, video game play and trial-type (i.e., task-switch vs. task-repeat trials). For illustrative purposes only, if we consider the non video game players within the HMM and LMM groups, we see a pattern similar to Alzahabi & Becker, (2013, i.e., smaller switch-costs for HMM) whereas the action video game players within those same groups present a pattern similar to Ophir et al. (i.e., larger switch-costs for HMM). Clearly, our data lacks the power to test such a claim and we leave it to future studies with increased sample sizes to resolve this issue.

A large number of studies have investigated whether action video game play is associated with an improved task-switching ability and most observed this to be the case both in 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, Frensch, & Schubert, 2012; but see Gaspar et al., 2013) as well as in experimental studies (i.e., training – Colzato et al., 2013; Green et al., 2012; Strobach, Frensch, & Schubert, 2012; but see Boot et al., 2008). In the present study we observed that AVGP were indeed faster than NVGP, especially when considering IMM participants. However, although switch costs were numerically smaller in AVGP than NVGP—and by an amount that was similar to that previously observed in the literature—the variance was such that the reduction in switch cost proper was not statistically significant.

Finally, the interaction between MM status and gaming status was less clear for this measure than the previous two measures, although numerically a trend for worse AVGP performance in the HMM group was noted.

**Filter Task: Results—**Analyses were carried out on the index of visual capacity $K$ (Figure 9). As target and distractor numbers are not independent but rather negatively correlated, the analysis was performed with target number as the variable of interest, collapsing across distractor numbers. We note that K is expected to increase as target numbers increase, as K is by definition limited by target number.

The 4×3×2 omnibus ANOVA on the K index with the factors "target number" (4 levels, 2, 4, 6 or 8 targets), "media multitasking" (3 levels) and "gaming" (2 levels) revealed main effects of target number ($F(3,216)=3.87$, $p=0.01$), of media multitasking ($F(2,216)=4.3$, $p=0.01$) and a significant gaming group by media multitasking interaction ($F(2,216)=5.8$, $p=3e\text{-}3$; all other $ps>0.16$). As before, we ran the same ANOVA after grouping participants from both the HMM and LMM as an extreme group to better characterize the interaction between gaming status and media multitasking. This 4×2×2 omnibus ANOVA showed a main effect of gaming ($F(1,224)=7.1$, $p<0.01$), a main effect of media multitasking (IMM vs. extreme MM; $F(1,224)=6.4$, $p<0.02$)—with IMM performing better than the extreme MM (K: 2.1±0.12 vs. 1.8±0.10) —and a significant gaming group by media multitasking interaction ($F(1,224)=12$, $p=6e\text{-}4$). Apart from the main effect of the number of targets ($F(3,224)=6$, $p=6e\text{-}4$), no other effects were significant ($ps>0.14$).

When contrasting HMM and LMM in a 4×2×2 ANOVA, no significant effect was found (all $ps>.13$). Yet, as Ophir et al. (2009) reported a rather specific effect of HMM whereby those individuals showed worse performance than LMM as distractors increased when target number was held at 2, we ran the equivalent analysis. For each participant we regressed K on the number of distractors in the 2 targets condition. We then contrasted the estimated slopes and intercepts across "media multitasking" (LMM/HMM), and "gaming" (AVGP/NVGP) groups. Numerically, HMM were more affected by the number of distractors than LMM (HMM: −0.027±0.02; LMM: −0.018±0.01) and had lower intercepts (HMM: 1.43±0.11; LMM: 1.59±0.05) but these differences were not statistically reliable (t-tests on intercept or slope, all $ps>0.22$). The equivalent analysis on AVGP and NVGP also showed no significant difference ($ps>0.16$) except when focusing on the IMM group where numerically AVGP had higher intercepts than NVGP (1.73±0.04 vs. 1.52±0.09) and smaller distractor effects (−0.018±0.02 vs. −0.035±0.02). The effect on intercept was significant ($t(19)=2.1$, $p=0.05$) but the distractor effect was not ($t(25.1)=0.5741$, $p=0.57$).

The 4×2 ANOVA restricted to IMM with target number and gaming as factors revealed main effects of gaming group ($F(1,104)=19.2$, $p=3e\text{-}5$), and of target number ($F(3, 104)=6.4$, $p=5e\text{-}4$) as well as a significant gaming group by target number interaction ($F(3, 104)=4.4$, $p=5e\text{-}3$), suggesting different effects of gaming group as a function of media and target number. Following Oei & Patterson (2013, 2015) who compared AVGP and NVGP visual capacity in this same task, we ran analyses on just the "2-targets 6-distractors" condition and just the "8-targets 0-distractors" condition as they did. Within the IMM group, AVGP did outperform NVGP on the "2-targets 6-distractors" condition (K AVGP: 1.650±0.118; NVGP: 1.346±0.113; one-sided t-test: $t(25)=1.83$, $p=0.04$) and on the "8-targets 0-distractors condition" (AVGP: 3.852±0.436; NVGP: 1.685±0.413; $t(24.9)=3.6$, $p=7e\text{-}4$), confirming enhanced visual memory in AVGP. The equivalent analysis on HMM and LMM showed no significant difference on the "8-targets 0-distractor condition" ($t(26.7)=1.15$, $p=0.13$) but there was a trend for LMM performing better in the "2-targets 6-distractors condition" (K LMM: 1.56±0.09; HMM: 1.30±0.13; one-sided $t(20.6)=1.6$, $p=0.06$).

Although it is conventional to use capacity K to characterize individual's visual working memory, it has recently been pointed out that using of this measure implies a commitment to the underlying slot model of working memory limitations, in which a fixed number of items is stored perfectly and any others are forgotten completely (Ma, Husain, & Bays, 2014; van den Berg, Shin, Chou, George, & Ma, 2012; for a review on the slot model, see Cowan, 2001; Fukuda, Awh, & Vogel, 2010). This account contrasts with the so-called noise-based or resource models of visual memory (Wilken and Ma 2004; Bays and Husain 2008; Van den Berg 2012; Ma, Husain & Bays 2014), in which performance declines with set size solely due to an increase of noise per items as set size increases. To make sure that our conclusions are not dependent on model assumptions we reanalyzed the data under the variable-precision model of visual short-term memory (van den Berg et al., 2012). Figure 10 shows the hits (solid symbols) and false alarm rates (empty symbols) for each the media multitasking (panels) and gaming group (color) as a function of the number of targets. Symbols are group averages and lines represent the models best fit of the within group pooled data.

To assess group differences quantitatively we fit the pooled data within each subgroup (e.g., only data from the AVGP within the IMM group) or across groups (e.g., combining data across all IMM subjects irrespective of their gaming group) and computed nested likelihood ratio tests to determine if the increased number of parameters required to fit each subgroup separately (e.g., AVGP and NVGPs within IMMs) yielded an improvement in the fits controlling for those extra parameters. As in the previous analyses, we first looked at media multitasking related group differences. There was a significant difference between HMM and LMM (D=19, df=3, p=3e-4, AIC difference=13) and HMM and IMM (D=22, df=3, p=1e-4, AIC difference=16) but there was no reliable difference between IMM and LMM (D=3.8, df=3, p=0.28, AIC difference=−2.2). Numerically, HMM had the lowest average performance (d′=1.2) followed by LMM (d′=1.5) and IMM (d′=1.6). Next we looked at gaming related group differences. As in the previous analyses, there was a clear difference between AVGP and NVGP within the IMM group (D=53, df=3, p=1.7e-13; AIC difference: 47.1); there was no significant difference between AVGP and NVGP within the LMM group (D=2.9, df=3, p=0.41; AIC difference: −3.1) and a small difference within the HMM group (D=9.4, p=0.02, AIC difference: 3.4). Numerically, AVGP outperformed NVGP within IMM group (AVGP d′=1.8; NVGP d′=1.3), but not among LMM (AVGP d′=1.5; NVGP d′=1.5) or HMM (AVGP d′=1.1; NVGP d′=1.3).

**Filter Task: Discussion:** As expected, capacity in this visual memory task increased as the number of targets to be remembered was increased. With regard to media effects, an interaction between media multitasking group and gaming group was seen, suggesting again a different impact of gaming group as a function of media multitasking group. Indeed, when considering IMM only, AVGP showed greater visual capacity than NVGP reflecting enhanced visual memory abilities. This effect seems mostly due to enhanced hits, rather than differences in false alarms (Figure 10). Thus overall we replicate previous work suggesting AVGP have a greater ability at encoding targets in memory (Oei and Patterson, 2013; Green and Bavelier, 2006). A main effect of media multi-tasking was observed, with HMM performing worse than IMM and LMM. Intermediate media multitaskers (IMM) showed a numerical tendency for better performance as measured by K or d′. However, this seems mostly driven by AVGP in that sub-population. When contrasting HMM and LMM, we found no reliable differences in terms of distractor effects and modest differences in terms of visual capacity. This stands in contrast to Ophir et al.'s (2009) report that HMM, contrary to LMM, were affected by the number of distractors presented in the display but did not differ in their ability to encode targets.

## General Discussion

The goal of the current study was to investigate the impact of diverse forms of media consumption on cognitive control functions. Previous studies have reported that people who consume a large number of forms of media at the same time—known as heavy media multitaskers (HMM)—experience an increased and specific difficulty in handling distracting information relative to people who media multitask less intensively. A different line of research has investigated the effects of action video game play on cognition and has generally reported cognitive benefits. These two groups of participants are therefore interesting candidates for the study of the impact of media on cognition. In addition, gaming and media multitasking are not mutually exclusive factors. In fact, because they appear to lead to opposite effects, failing to control for one while studying the other may lead to improper conclusions about one or both. In the present study we measured cognitive performance on four different tasks requiring cognitive control on the same set of participants for which we recorded their self-reported media multitasking activity and action video game experience. Although our results demonstrate that it is indeed important to take both of these factors into account, one should keep in mind that this study is purely correlational and thus is agnostic about whether the causal relationship between these forms of media consumption and cognitive performance. Numerous training studies have shown that playing action video games may cause cognitive benefits but no study has yet attempted to manipulate the media multitasking habits of randomly selected participants and to assess their cognitive consequences.

In the present study, participants' performance was measured in tasks that tap proactive cognitive control (the AX-continuous performance task), working memory (N-back task), cognitive flexibility (task-switching task) and visual short-term memory (the Filter task) respectively. For each of these tasks we asked what differences in cognitive ability are associated with media multitasking, with action video game play and to what extent these two factors interact.

### Media Multitasking Effects

The same four tasks were used by Ophir and colleagues (2009) who documented HMM to be specifically impaired in the presence of distractors (as compared to LMM). The present results do not exactly replicate their findings. In our data there was not a specific impairment for HMM in conditions containing distractors. Instead, the HMM in our data set appeared to be overall less efficient than LMM, in that they were either slower, made more errors, or were both slower and made more errors. This result was significant in the AX-CPT and the Filter Task.

Interestingly, most previous studies focused only on HMM and LMM, ignoring participants with intermediate levels of media multitasking (IMM), presumably on the assumption that the dependent variable of interest should be a monotonic function of media multitasking. In other words, IMM performance was expected to lie somewhere in between HMM and LMM. This assumption is contradicted by our data. In the AXCPT task, IMM did indeed perform better than HMM and worse than LMM, but in the N-back and the Filter task IMM performed best. Although this pattern may lead one to conclude that the relationship between performance and media multitasking follows a U-shaped curve with intermediate levels of media multitasking being associated with enhanced cognitive control, the inclusion of action video game status sheds a rather different light.

## Action video game effects

Research on the effects of action video games has repeatedly shown that AVGP outperform NVGP on a number of cognitive dimensions with occasionally studies reporting an absence of such group differences. Based on that literature one might expect AVGP to outperform NVGP in all four tasks used in this study. Yet, the omnibus ANOVA failed to document a main effect of gaming for each of the four tasks. Rather, our results show that AVGP outperformed NVGP in all four tasks, but only when those participants had an intermediate level of media multitasking (IMM). Thus, the effects of action video games as described in the literature may depend on a variety of individual difference factors including media multitasking experience (see also individual differences in genetic composition–Colzato, van den Wildenberg, & Hommel, 2013). While this study replicates previous reports of attentional and cognitive benefits in action game players, it only does so in the IMM group, with the main effect of action game play vanishing when considering the whole sample. This pattern of results has interesting implications for various criticisms raised about the field. For instance, some researchers have argued that the reason why AVGP outperform NVGP in cognitive tasks is that AVGP, but not NVGP, might believe that they have above average cognitive abilities and that this belief is what actually drives the observed cognitive benefits (Boot, Simons, Stothart, & Stutts, 2013; Boot, Blakely, & Simons, 2011). Although we did not ask our participants about their expectations, our results nonetheless indicate that this hypothesis is unlikely. Indeed, across our four experiments AVGP outperformed NVGP only within the group of intermediate levels of media multitaskers, showing that being an AVGP is not sufficient for observing the effect. It is also worth mentioning that HMM, who have been documented to be quite self-confident in their cognitive abilities (Sanbonmatsu et al., 2013) and who showed the highest mastery scores as measured by the WOFO in the present study, did not show better performance, but instead showed, if anything, worse performance. Overall this pattern of results is inconsistent with the idea that the effects of media on cognitive performance can be accounted by ‘expectation effects’.

## Media-multitasking by action gaming interactions

When considering the relative impact of media multi-tasking and action gaming, omnibus ANOVAs indicate significant interactions between gaming and media multitasking status in 3 of the 4 tasks presented (AX-CPT, N-back and Filter tasks). Such interactions highlight the importance of being aware of the media multitasking status of participants when considering the impact of other experiential factors, such as video game experience, on performance.

Experiments that sample AVGP and NVGP from the higher or lower ranges of media multitaskers will have difficulties in observing group differences (Cain & Mitroff, 2011). Among the three media multitasking groups, HMM performed overall quite poorly. And within the extreme MM groups (HMM & LMM) we saw no effect of playing action video games. Thus, playing action video games appears only beneficial in the intermediate media multi-tasking group, suggesting its potential benefit may be of no protective value to HMM. It is important to note though that this latter suggestion comes with a variety of critical caveats–in particular that 1) there is as yet no conclusive evidence showing the relationship between heavy media multitasking and poor attentional performance is casual (as all of the research in the domain thus far has been correlational in nature) and 2) that the number of participants in the relevant cells (e.g., AVGP + HMM) is small.

Substantiating these suggestive interaction effects will require the collection of much larger sample sizes to reach adequate levels of statistical power. The typical recruitment procedure utilized in the field (and in the current manuscript) is ill-adapted to this aim given the scarcity of these extreme populations. Indeed, we currently estimate that AVGP and NVGP each represent less than 10% of the student population on US campuses given our selection criteria (with the situation being worse given the goal of perfectly matching for sex). Similarly, LMM and HMM, by definition, each represent approximately 16% of the student population on US campuses. Because action gaming and media multitasking behavior are not strongly correlated, the intersection of these extremes is quite rare (i.e., 1–2% of the population). For such rare populations, recruitment may be best achieved by implementing online versions of these tasks and recruiting participants via crowdsourcing platforms (e.g., Shapiro, Chandler, & Mueller, 2013). In addition to the increase in certainty that larger Ns would provide regarding the observed effects, significantly larger sample sizes would also allow for more sophisticated statistical tools such as factor analysis, confirmatory factor analysis, and structural equation modeling, to be employed. These in turn could provide much needed clarity regarding the sometimes counter-intuitive effects of media consumption on attentional control.

## Conclusions

In sum, these results highlight the complex relationship between technology use and cognitive control. We recognize that the number of participants within each of our 6 categories of technology use is small and thus the details of some of our results are in need of confirmation. However, the finding of an action video game advantage in IMM, but not when considering all media multitaskers, is recurrent across tasks. This raises the issue for future research to understand who may or may not benefit from action video game play (see also, Cardoso-Leite & Bavelier, 2014). This is a particularly relevant question as this genre of game play is being considered for practical applications either in health or education (Franceschini et al., 2013; Li, Ngo, Nguyen, & Levi, 2011). In the case of HMM, although we did not replicate the specific decrement of performance in the presence of distractors as documented by Ophir et al. we did though observe worse performance in these participants on several of our tasks. Whether these effects are due to technology use per se or another common cause remains unknown. In an effort to control for attention problems, the Adult ADHD Self-Report Scale was given to all participants. However, HMM did not differ from the other groups on that scale suggesting that their high media multitasking habits cannot easily be attributed to higher distractibility or lack of attention. More generally, our findings call for more studies on how media multitasking and action video game play may interact. While one could argue that the benefits of playing action video games are outweighed by the hindrance of high media-multitasking, the lack of a video game effect in LMM indicates other factors are at play. As we strive to understand technology use impact on behavior, these will be important issues to address in the future.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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# Appendix

## Video Game Playing Questionnaire – PAST YEAR

For each category of games, please rate:

1. Your estimated EXPERTISE in that category (1 = lowest, 7 = highest) – even if no experience, how do you think you would perform, compared to the general public?
2. Your average HOURS PER WEEK in that category for the past 12 months. Ex: If you play 1.5 hrs/week, mark "1+ to 3"

**FIRST PERSON SHOOTERS** (Halo, Call of Duty, Gears of War, GTA, Half-Life, Unreal etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**ACTION/ACTION-SPORTS GAMES** (God of War, Mario Kart, Burnout, Madden, FIFA, etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**REAL TIME STRATEGY** (Warcraft, Starcraft, Command & Conquer, Age of Empires, Total War, etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**TURN-BASED STRATEGY/PUZZLE** (Civilization, Sims, Puzzle Quest, Bejewled, Solitaire, etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**RPG/FANTASY** (World of Warcraft, Final Fantasy, Fable, Oblivion, etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**MUSIC GAMES** (Guitar Hero, Dance Dance Revolution, Rock Band, etc)

Expertise: **1 2 3 4 5 6 7** Hours per week: **Never** **0+ to 1** **1+ to 3** **3+ to 5** **5+ to 10** **10+**
Games played most over the past year:

**OTHER** (games that don't fit into any other category, phone games, browser games, etc.)

____________ Hours per week: ________

____________ Hours per week: ________

## Video Game Playing Questionnaire – BEFORE THE PAST YEAR

For each category of games, please write:

1. Your average HOURS/WEEK when you played that category most
2. The games you played and how old you were when you played them most

**FIRST PERSON SHOOTERS** (Halo, Call of Duty, Gears of War, GTA, Half-Life, Unreal etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**ACTION/ACTION-SPORTS GAMES** (God of War, Mario Kart, Burnout, Madden, FIFA, etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**REAL TIME STRATEGY** (Warcraft, Starcraft, Command & Conquer, Age of Empires, Total War, etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**TURN-BASED STRATEGY/PUZZLE** (Civilization, Sims, Puzzle Quest, Bejewled, Solitaire, etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**RPG/FANTASY** (World of Warcraft, Final Fantasy, Fable, Oblivion, etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**MUSIC GAMES** (Guitar Hero, Dance Dance Revolution, Rock Band, etc)

Hours per week: Never 0+ to 1 1+ to 3 3+ to 5 5+ to 10 10+

Games played most and age when played:

**OTHER** (games that don't fit into any other category, phone games, browser games, etc.)

_______________ Hours per week: ________

_______________ Hours per week: ________

## MMI

Report the total number of hours per week you spend using each
of the following media:

Print media ____

TV ____

computer-based video ____

music ____

nonmusic audio ____

video/computer games ____

telephone/mobile phone voice calls ____

instant messaging ____

email ____

web surfing ____

other computer-based applications ____

For each type of media, indicate how often you simultaneously engage in each of the other types of media.

0 = "Never"
1 = "A little of the time"
2 = "Some of the time"
3 = "Most of the time"

| | TV | computer-based video | music | nonmusic audio | video/computer games | telephone/mobile phone voice calls | instant messaging | email | web surfing | other computer-based applications | text messaging |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Print media | | | | | | | | | | | |
| TV | | | | | | | | | | | |
| computer-based video | | | | | | | | | | | |
| music | | | | | | | | | | | |
| nonmusic audio | | | | | | | | | | | |
| video/computer games | | | | | | | | | | | |
| telephone/mobile phone voice calls | | | | | | | | | | | |
| instant messaging | | | | | | | | | | | |
| email | | | | | | | | | | | |
| web surfing | | | | | | | | | | | |
| other computer-based applications | | | | | | | | | | | |

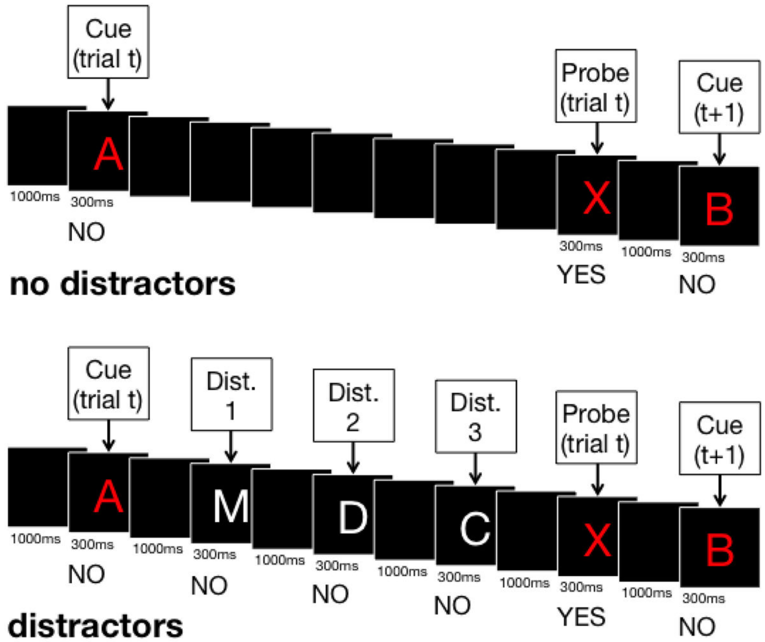


**Figure 1.**

AX-Continuous Performance Task. Participants are presented with sequences of red letters, and are required to press a specific key (the “YES” key) if and only if the letter presented is a red “X” AND the previous red letter was an “A”. In all other situations (e.g., the letter that is presented is not a red “X”, or the letter is a red “X” but the previous red letter was not an “A” ), participants are to press a different key (the “NO” key). There were two experimental conditions: the “no distractors” condition (top panel) and the “distractors” condition (bottom panel). The latter differed from the former by the presentation of three white letters—the distractors—sandwiched between red letters. Participants were to press the “NO” key in response to each of these distractor elements.

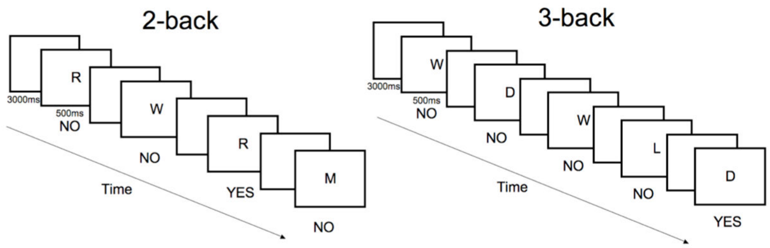


**Figure 2. N-back task**

Participants face a constant stream of letters presented for 500 ms and separated by 3000 ms of a blank screen. For each new letter, participants report via key presses (“YES” and “NO” keys) whether it was the same as the letter presented N steps back. The left and right panels illustrate a sequence of such trials (a) in the 2-back and (b) the 3-back conditions respectively.

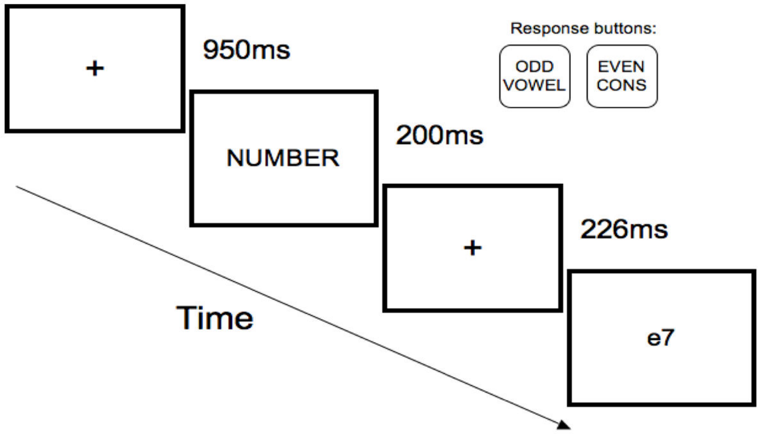


**Figure 3. Task-switching**

At the beginning of each trial, participants are presented a task-cue indicating whether participants should perform a NUMBER ("odd vs. even", as in the example depicted above) or a LETTER discrimination task ("vowel vs. consonant") on the subsequently presented stimulus that comprises both a letter and a number (e.g., "e7").

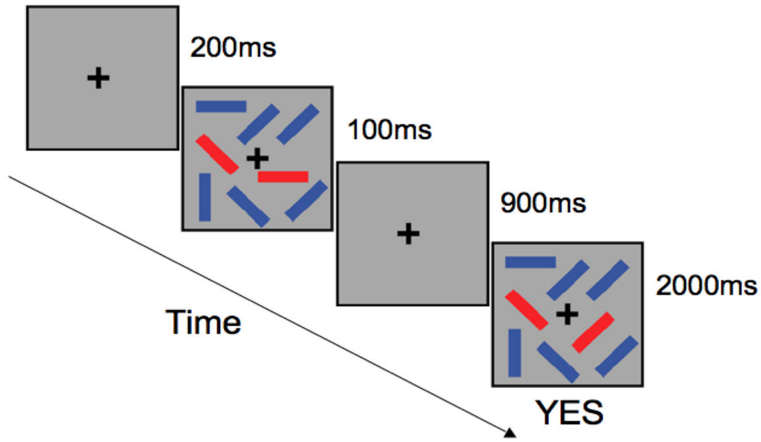


**Figure 4. Filter task**

Participants fixate the central cross during the complete trial. Two images, separated by a blank screen are presented in succession and depict an array of randomly oriented red (target) and blue (distractor) lines. From the first to the second exposure these images are either exactly identical ("same" response) or one (and only one) of the targets changes its orientation ("different" response). The number of targets and distractors varies across trials.

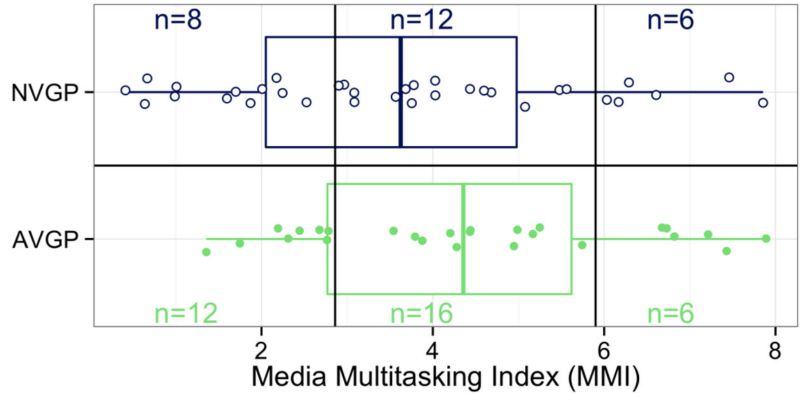


**Figure 5.**
Distribution of the Media Multimedia Index (MMI) among the action video game players (AVGP, blue) and non-video game players (NVGP, green). Vertical solid lines represent the criterion values to be considered either light (LMM) or heavy (HMM) media-multitaskers (with individuals in between categorized as intermediate media-multitaskers – IMM). These values are identical to those used by Ophir et al. (2009) based upon their large sample of college students.

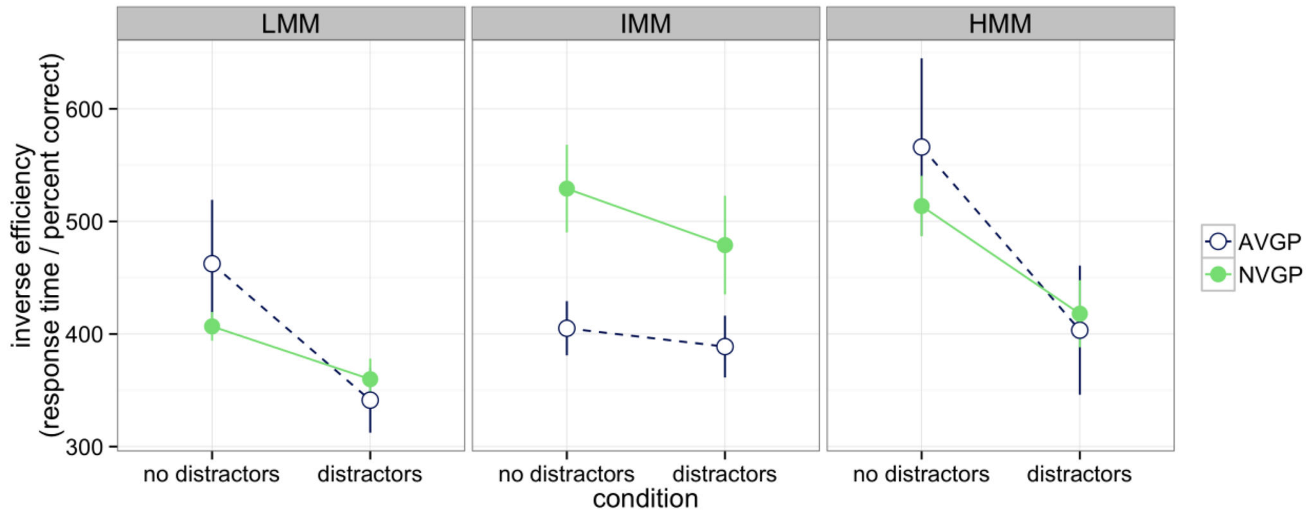


**Figure 6. AX-CPT: Mean inverse efficiency as a function of group and condition**

Overall performance illustrated in terms of inverse efficiency. Note that a smaller inverse efficiency score means better performance. The left, middle and right column of panels represent the data from participants classified as light (LMM), intermediate (IMM) and heavy (HMM) media multitaskers. Data from AVGP and NVGP are displayed in blue and green respectively. Performance decreased with increasing levels of media multitasking. AVGP outperformed NVGP but only among the IMM group. Error bars are 1 sem.

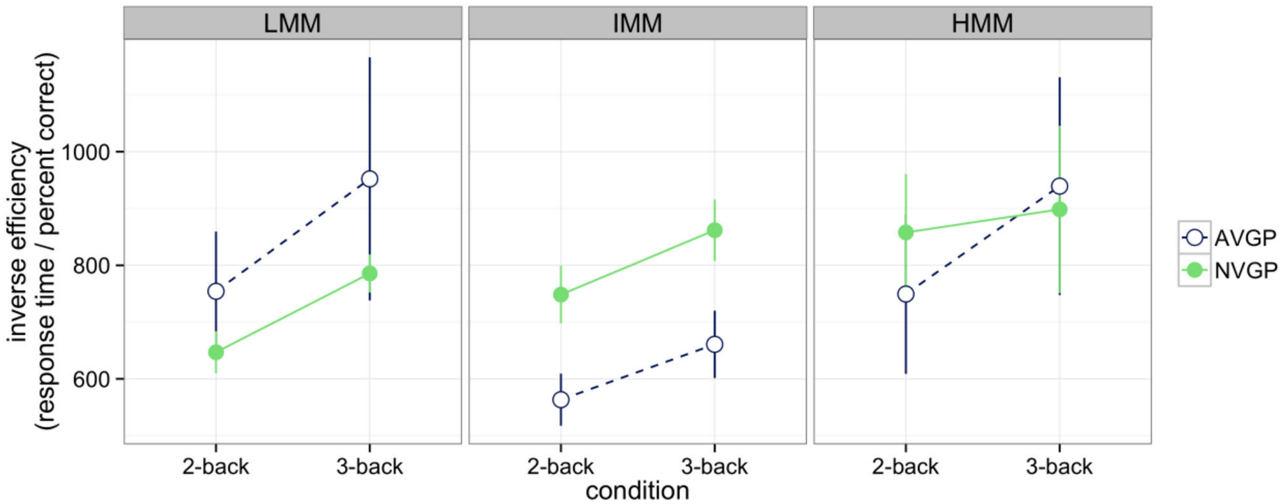


**Figure 7. N-back: Mean inverse efficiency as a function of group and condition**

Overall performance assessed with inverse efficiency. The left, middle and right columns represent data from the light media multitaskers (LMM), intermediate media multitaskers (IMM) and heavy media multitaskers (HMM). Data from the action video game players (AVGP) and non video game players (NVGP) are displayed in blue and green, respectively. Data points are group averages and error bars are 1 sem.

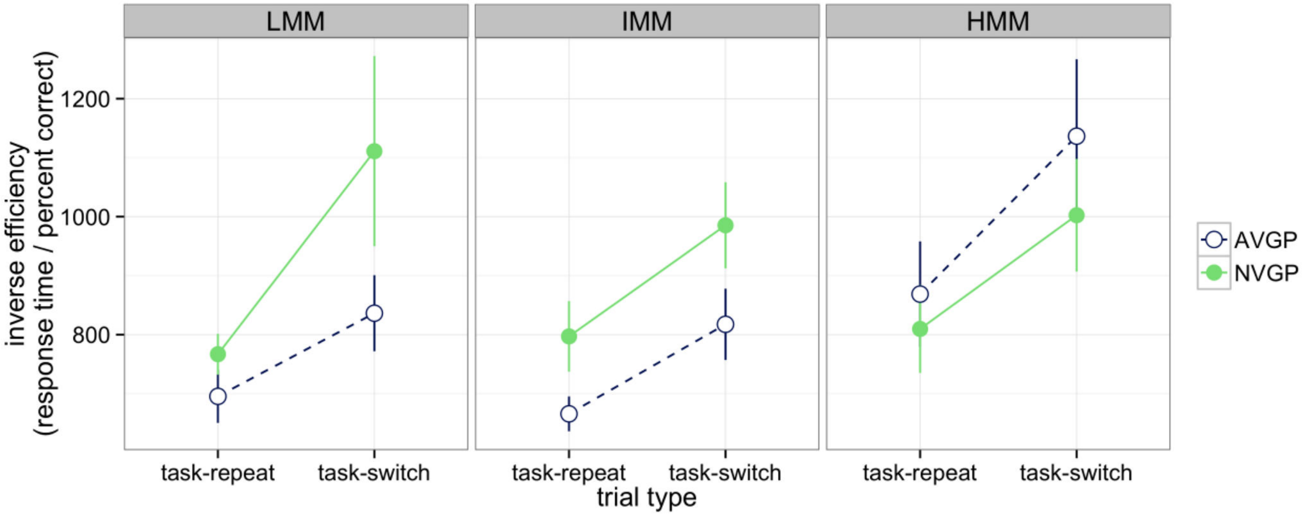


**Figure 8. Task-switching: Mean inverse efficiency as a function of group and trial type (i.e., task-repeat and task-switch trials)**

Overall performance assessed with inverse efficiency. The left, middle and right columns of panels show the group averages for the LMM, IMM and HMM groups respectively. Data from the action video gamers (AVGP) are depicted in blue; that from the non-video gamers (NVGP) are shown in green. Error bars are 1 sem.

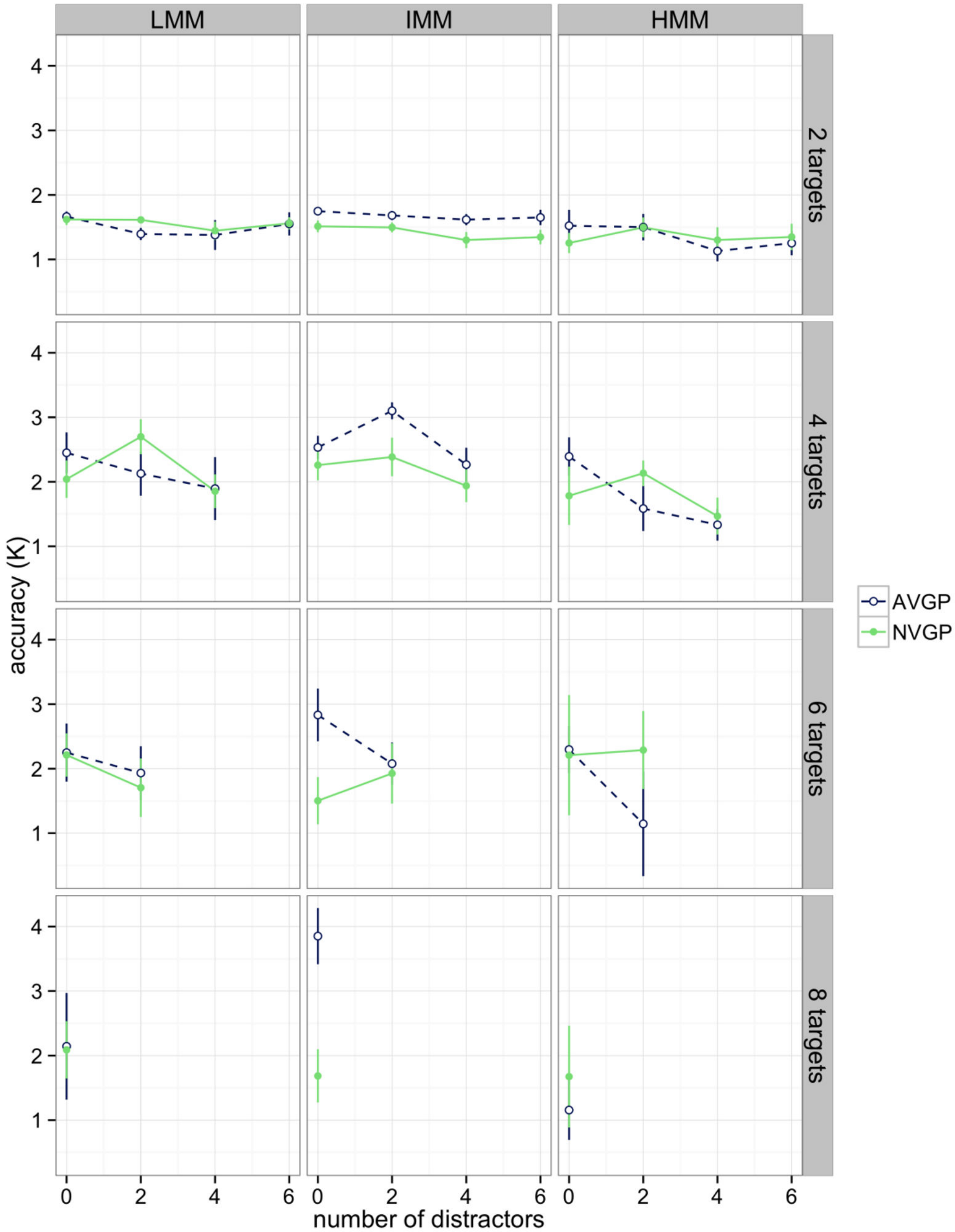


**Figure 9. Filter Task: Mean visual capacity (K) as a function of group and condition**

K is plotted as a function of the number of distractors (x-axis), the number of targets (rows of panels), the media multitasking group (i.e., LMM, IMM and HMM, columns of panels) and the gaming group (i.e., AVGP and NVGP, colour). Error bars are 1 sem.

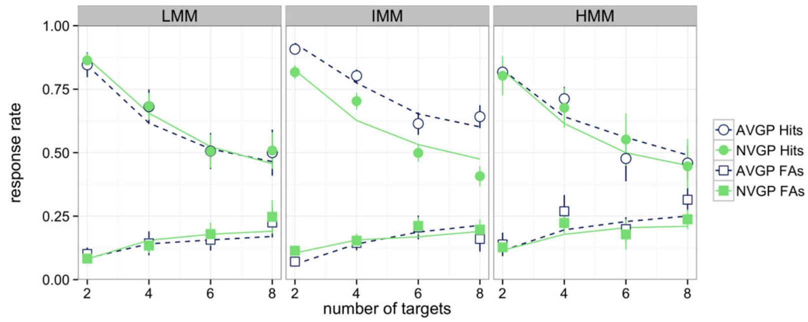


**Figure 10. Filter Task: data and model fits of the hit and false alarm rates**

Hit and False Alarm rates are plotted (circles and square symbols, respectively) as a function of the number of targets (x-axis), the media multitasking group (i.e., LMM, IMM and HMM, columns of panels) and the gaming group (i.e., AVGP empty symbols and NVGP filled symbols). Points are group averages and error bars are 1 sem. Lines illustrate the model fits.

## Table 1

Mean ± 1sem response times and accuracy across groups and conditions in the AX-CP task.

| | | no distractors | | distractors | |
|---|---|---|---|---|---|
| **media multitasking** | **gaming** | **accuracy** | **speed** | **accuracy** | **speed** |
| LMM | AVGP | 0.96±0.01 | 443±54 | 0.90±0.03 | 302±17 |
| LMM | NVGP | 0.96±0.01 | 388±12 | 0.89±0.02 | 318±11 |
| IMM | AVGP | 0.95±0.01 | 387±25 | 0.90±0.01 | 350±26 |
| IMM | NVGP | 0.94±0.01 | 497±35 | 0.81±0.03 | 367±19 |
| HMM | AVGP | 0.90±0.02 | 505±61 | 0.82±0.03 | 325±35 |
| HMM | NVGP | 0.89±0.05 | 457±33 | 0.85±0.03 | 353±17 |

## Table 2

Mean ± 1sem response times and accuracy across groups and conditions in the N-back task.

| | | 2-back | | 3-back | |
|---|---|---|---|---|---|
| **media multitasking** | **gaming** | **accuracy** | **speed** | **accuracy** | **speed** |
| LMM | AVGP | 0.97±0.01 | 729±102 | 0.91±0.02 | 850±174 |
| LMM | NVGP | 0.95±0.02 | 611±35 | 0.91±0.01 | 717±33 |
| IMM | AVGP | 0.97±0.01 | 547±45 | 0.94±0.01 | 622±57 |
| IMM | NVGP | 0.95±0.01 | 709±46 | 0.88±0.02 | 746±39 |
| HMM | AVGP | 0.90±0.03 | 662±115 | 0.82±0.06 | 739±142 |
| HMM | NVGP | 0.95±0.03 | 820±113 | 0.85±0.04 | 764±130 |

**Table 3**

Mean ± 1sem response times and accuracy across groups and conditions in the task—switching task.

| | | task-repeat | | task-switch | |
|---|---|---|---|---|---|
| **media multitasking** | **gaming** | **accuracy** | **speed** | **accuracy** | **speed** |
| LMM | AVGP | 0.96±0.01 | 668±44 | 0.96±0.01 | 802±63 |
| LMM | NVGP | 0.96±0.01 | 737±31 | 0.92±0.02 | 986±111 |
| IMM | AVGP | 0.96±0.01 | 638±25 | 0.94±0.01 | 763±51 |
| IMM | NVGP | 0.95±0.02 | 748±53 | 0.91±0.02 | 884±62 |
| HMM | AVGP | 0.98±0.01 | 845±82 | 0.95±0.01 | 1080±122 |
| HMM | NVGP | 0.92±0.04 | 732±47 | 0.90±0.04 | 893±70 |