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Effects of media multitasking and video gaming on cognitive functions and their neural bases in adolescents and young adults

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Abstract

The increasing use of digital technology among adolescents and young adults has led to concerns about possible detrimental effects on cognitive and brain functions. Indeed, as reviewed here, according to behavioral and brain-imaging studies, excessive media multitasking (i.e., using different digital media in parallel) may lead to enhanced distractibility and problems in maintaining attention. However, frequent video gaming may be beneficial for the development of working memory, task switching, and attention skills. All these cognitive skills depend on the executive cognitive functions. Still scant but gradually cumulating brain-imaging results suggest that the negative effects of frequent media multitasking and the positive effects of frequent video gaming on cognitive skills in adolescents and young adults are mediated by effects on the frontal lobes, implicated in executive cognitive functions and still developing even through early adulthood.

Key reference terms: media multitasking, video gaming, executive functions, adolescence, early adulthood

Introduction

The use of digital technology, especially the use of smartphones and the time spent in social and recreation media and video gaming, has increased tremendously among adolescents and young adults (Anderson & Jingling, 2018; Ofcom, 2018; Smith et al., 2018). This has led to concerns about the effects of excessive digital technology use on the cognitive and brain functions of younger generations of "digital natives" (Prensky, 2001) growing up in the modern society filled with information and communication technology (e.g., Greenfield, 2015; Spitzer, 2014). For example, it has been proposed that frequent interruptions, surfing between web sites, and "shallow" information processing common to Internet use may produce "grass-hopper minds" (Carr, 2010). The effects of excessive digital technology use in the younger age groups might be long-lasting, as their brains are still developing even through early adulthood (e.g., Blakemore & Choudhury, 2006; Casey et al., 2000; Giedd et al., 1999; Gogtay et al., 2004; Huttenlocher, 1979; Huttenlocher & Dabholkar, 1998; Moisala et al., 2018; Rothbart & Posner, 2015). This development is paralleled by improved executive cognitive functions, which are crucial, for example, in situations demanding working memory, task switching or attention skills, and suppression of distractors (see, e.g., Chan et al., 2008; Diamond, 2013).

Digital technology use encompasses a wide variety of different activities, ranging from recreational activities, such as video gaming, to information retrieval and interaction in social media. The present review focuses on the effects of two of the most common forms of modern-day digital technology use in young people, namely, media multitasking and video gaming, on cognitive functions and their neural bases (Carrier et al., 2015; Fomby et al., 2015; Perrin, 2018; Zhang et al., 2015). More specifically, we review here how these activities affect cognitive functions and the brain in adolescence and early adulthood. Our review builds on related review articles (Firth et al., 2019; Kühn et al., 2019; Uncapher & Wagner, 2018) by including even more recent brain-imaging studies. To find these studies, we used the search terms *multitasking*/*gaming* and *brain*/*MRI* (MRI refers to magnetic resonance imaging, the most common brain-imaging method) at https://scholar.google.com and then ensured that the studied participants were healthy adolescents or young adults. For example, we excluded studies on individuals with signs of a gaming disorder (for a review of those, see Choi et al., 2021), except for one study (Zhou et al., 2019) that also reports separate results on the effects of gaming in participants with no such problems. In addition, we review findings from research without brain imaging on associations of media multitasking or gaming with cognitive functions. Since these results have been thoroughly covered in previous reviews (e.g., Chopin et al., 2019; Connolly et al., 2012; May & Elder, 2018; Powers et al., 2013; van der Schuur et al., 2015), we selectively examine only the ones that are needed to give sufficient background for understanding the more systematically reviewed brain-imaging studies. In the following, we focus first on media multitasking, cognition, and the brain, and then on video gaming, cognition, and the brain.

Media multitasking and cognition

Media multitasking refers to the use of different forms of digital media in parallel, for example, chatting on a smartphone and watching video content simultaneously. Some studies on young adults have suggested that media multitasking might, in fact, entrain cognitive skills. For example, in a study of 92 young adults, Alzahabi and Becker (2013) reported that higher levels of daily media multitasking are associated with better performance in a test demanding switching between a number-classification (odd vs. even) task and a letter-classification (consonant vs. vowel) task. Moreover, Yap and Lim (2013) observed in 66 young adults that frequent multitasking predicts faster target detection in a task demanding division of visual attention between two spatial locations. In turn, Lui and Wong (2012) reported that in a sample of 63 young adults, heavy media multitaskers performed faster and more accurately than light media multitaskers in a search task where finding a visual target object was facilitated by integration of auditory cue stimuli.

However, there are markedly more findings suggesting negative effects of media multitasking on cognitive functions (for reviews, see Firth et al., 2019; May & Elder, 2018; Uncapher & Wagner, 2018; van der Schuur et al., 2015). For example, Uncapher et al. (2016) found in 143 young adults that higher levels of daily multitasking are associated with poorer performance in a visual working memory task. Madore et al. (2020) observed in 80 young adults that the amount of media multitasking correlates negatively with performance accuracy in a visual long-term memory task. Moreover, according to the results of Ophir et al. (2009), who studied 262 young adults, more frequent media multitasking is associated with higher distractibility in a task requiring attention to red target objects while ignoring blue distractor objects, and slower task performance when switching between letter classification and number classification tasks.

The detrimental effects of frequent media multitasking have also been brought up by studies with both younger and older adults as participants. Sanbonmatsu et al. (2013) observed in a group of 310 18–44-year-olds that higher amounts of multitasking were associated with worse performance in a dual-tasking test. In the applied Operation Span test, the participant is to simultaneously solve mathematical problems and maintain a set of numbers in working memory. In turn, Shin et al. (2018) found in a study with 144 18–48-year-olds that those participants who multitasked more frequently were slower and showed more omission errors in a go/no-go task. The authors interpreted this finding as suggesting higher inattention among frequent multitaskers.

There are at least three studies that suggest negative associations between media multitasking and cognitive performance in adolescents. In longitudinal studies including over 2000 11–16-year-olds, Baumgartner et al. (2018) found that the self-reported amount of media multitasking was associated with enhanced attention problems estimated by the participants on five-point scales (e.g., “I am easily distracted,” “I have difficulty sustaining attention”). Cain et al. (2016) observed in a smaller group of 73 12–16-year-olds that higher levels of daily media multitasking were associated with worse performance in visuo-linguistic working memory tasks, as well as worse academic achievement. Off-task media multitasking while studying might also be expected to result in worse learning outcomes (May & Elder, 2018). Nevertheless, a recent three-wave longitudinal study by van der Schuur et al. (2020) in over 1000 11–15-year-olds found no relationship between such “academic-media multitasking” and long-term academic achievement. However, an eight-item questionnaire filled out by the participants did reveal an association of academic-media multitasking with subsequent increased attention problems at school and home.

Media multitasking and the brain

According to our literature search (see also the recent reviews by Firth et al., 2019; Uncapher & Wagner, 2018), there are only three studies reporting associations of frequent media multitasking and brain structure or function in adolescents or young adults. These studies are reviewed in the following.

In the study by Loh and Kanai (2014), structural magnetic resonance imaging (sMRI) in 75 young adults suggested that frequent media multitasking is associated with lower gray matter volume in the anterior cingulate cortex, a frontal lobe structure implicated in executive cognitive control. Moreover, functional magnetic resonance imaging (fMRI) in the same participants during a “resting state" revealed a negative correlation between the frequency of the participants' multitasking and the functional connectivity of the anterior cingulate cortex to the precuneus, a parietal brain area implicated in various cognitive functions, including orienting of attention, mental imagery, and memory retrieval (Cavanna & Trimble, 2006). Thus, based on these results, excessive multitasking may have a negative impact on brain structures and functions involved in cognitive skills.

Moisala et al. (2016) studied 149 13–24-year-olds who also filled out a questionnaire on their daily media multitasking habits. During fMRI, the participants performed comprehension tasks involving written or spoken sentences in either a distracted or non-distracted condition. The distractors during the reading task were spoken sentences or instrumental music, and the distractors during the listening task were written sentences seen by the participants on a computer screen. Higher media multitasking scores were associated with less accuracy in the comprehension task in conditions with distractors than in conditions without them. The presence of distractors was also associated with right-hemisphere dorsolateral and dorsomedial prefrontal activity, which was higher the more frequently the participants multitasked in their daily life (Figure 1). This finding may indicate increased need among frequent multitaskers to recruit brain areas involved in attentional control and suppression of processing the distractors.

[Figure 1 about here]

In a recent study, Kobayashi et al. (2020) reported fMRI results from 103 young adults which indicated that the number of functional connections (quantified as a degree centrality value) within the dorsal attention network during an auditory discrimination ("oddball") task correlates positively with the frequency of participants' media multitasking. The dorsal attention network is a network of fronto-parietal cortical areas involved in various tasks demanding attention. In addition, Kobayashi et al. found that the decrease in the number of these connections from a resting state to the auditory discrimination condition was smaller in more frequently multitasking participants. However, there was no significant correlation between media multitasking frequency and task performance (reaction time) measures. Therefore, it is difficult to judge the relation of this finding to frequently and infrequently multitasking participants' attention skills. However, in light of the results of Moisala et al. (2016) reviewed above, this finding might be associated with an increased need among frequent multitaskers for executive control in attention-demanding situations.

Video gaming and cognition

Numerous studies have indicated that frequent action video gaming is associated with enhanced cognitive skills, and also among adolescents and young adults (for a systematic review, see Connolly et al., 2012; for a meta-analysis, see Powers et al., 2013). For example, studies of young adults (with gamer and non-gamer group sizes varying from 8 to 26) have shown that action video gamers perform better than non-gamers in various visual tasks demanding selective attention (Boot et al., 2008; Green and Bavelier, 2003), working memory (Boot et al., 2008; Colzato et al., 2013; McDermott et al., 2014), or tracking of multiple objects, that is, dividing attention between different moving objects (Boot et al., 2008; Green and Bavelier, 2006). In addition, young adult gamers have been found to be better than non-gamers (group sizes varying from 10 to 30) at switching between two visual tasks (Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010; Green et al., 2012; Karle et al., 2010). While these studies comparing gamers and non-gamers cannot prove a causal relationship between video gaming and cognitive skills, there are also studies indicating such causality. In these studies, training non-gaming young adults in action video games was found to enhance visual attention skills (Green and Bavelier, 2003; 9 participants in the action game training group), as well as audio-visual dual-tasking and visual task-switching skills (Strobach et al., 2012; 10 participants in the action game training group).

In addition to action games, playing other types of games may also enhance cognitive skills. In the study by Oei and Patterson (2013), each of five participant groups of non-gaming young adults (14–16 participants in each group) played one game for four weeks (one hour per day five days a week). The games included an action game, a visuo-spatial memory game, a visual matching game, a hidden object game, and an agent-based life simulation game. Behavioral tasks were performed by the participants before and after video game training. Action gaming was found to eliminate a visual attentional blink effect, improve tracking of multiple visual objects and filtering out of distractors, and increase verbal working memory span. Playing a visual matching game, in turn, improved visual search performance as well as visuo-spatial and verbal working memory, while playing a hidden object game improved visual search performance and visuo-spatial working memory.

Video gaming and the brain

According to our literature search (see also the recent reviews by Firth et al., 2019; Kühn et al., 2019), there are only seven studies on the association of video gaming and brain structure or function in healthy individuals. All these studies (reviewed below) had adolescents or young adults as participants.

Kühn and Gallinat (2014) studied 64 young adults with sMRI and found a significant positive association between the lifetime amount of video gaming and the volume of hippocampus and the gray matter volume in the adjacent entorhinal cortex. They proposed that these effects might be due to frequent navigation in video games, since the hippocampus and entorhinal cortex have been shown to have a crucial role in spatial navigation. They also observed a positive association between the amount of video gaming and gray matter volume in the visual cortex, which might be due to training of visual attention during video gaming.

Moreover, Kühn et al. (2014a) studied 48 young adults with sMRI and found that a two-month period of training (30 min or more per day) on *Super Mario 64* resulted in a significant increase in gray matter volume in the hippocampus and dorsolateral prefrontal cortex of the right hemisphere, as well as in the cerebellum. *Super Mario 64* is a video game where the player controls Mario, the character, through different courses. Kühn et al. proposed that the hippocampal effect was due to training of spatial navigation, the cerebellar effect due to training of motor performance (since the cerebellum has an important role in coordination of movements), and the prefrontal effect due to training of strategic planning and working memory (since the prefrontal cortex is involved in these functions).

However, the effect of video gaming on the right dorsolateral prefrontal cortex observed by Kühn et al. (2014a) might be specific to the type of video game trained in. In another study of 152 14-year-olds, Kühn et al. (2014b) found that the amount of self-reported video gaming in any type of game correlates positively with cortical thickness in two prefrontal areas of the left hemisphere, namely, the dorsolateral prefrontal cortex and the frontal eye field. They proposed that the finding in the dorsolateral prefrontal cortex is related to executive control and the strategic planning essential for successful gaming. The finding in the frontal eye field, in turn, would be related to visuo-motor integration, programming and execution of eye movements, and allocation of visuo-spatial attention during video gaming.

In another sMRI study, Zhou et al. (2019) assigned 78 gaming-naïve young adult participants randomly to a training group playing *World of Warcraft* for six weeks (at least one hour per day) or to a non-gaming control group. *World of Warcraft* is a multiplayer online role-playing game. The sMRI results suggested that during the training period, the gray matter volume decreased in the left-hemisphere lateral orbitofrontal cortex, implicated in the emotional evaluation of rewards and previous choices, and in the control of emotions. However, decreased volumes in the lateral orbitofrontal gray matter were also observed in another group of 41 participants with a long history of excessive *World of Warcraft* gaming, regarded as a sign of gaming addiction. In this excessive gaming group, the gray matter loss correlated positively with the estimated severity of addiction. Therefore, the gray matter loss in the training group might have been a sign of developing gaming addiction.

Likewise, an earlier sMRI study of Kühn et al. (2011) including 154 14-year-olds suggested altered reward processing in frequent video game players. In that study, participants playing video games more frequently were found to have higher gray matter volumes in the striatum of the left hemisphere than those who played video games less frequently. This difference was suggested to reflect altered reward processing in the frequent gamers, as the striatum is a dopamine-driven subcortical structure belonging to the brain's reward network. This finding was supported by fMRI results during the so-called Monetary Incentive Delay task, a reaction time task used to study brain activity associated with reward anticipation and reward feedback. Feedback of loss, compared with feedback of no loss, was observed to elicit higher striatal activity in more frequently video gaming participants.

Moisala et al. (2017) studied brain activity with fMRI in 167 13–24-year-olds while the participants performed "*n*-back" tasks with vowels that were either spoken or written, with the sensory modality in the vowel stream switching between audition and vision at random intervals. In the 1-back and 2-back tasks, the participants were to indicate, by pressing one of two buttons, whether or not the presented vowel was the same as the vowel one or two trials before, respectively. In a 0-back control task, the participants were asked to simply press one button for spoken and another button for written vowels. Overall, the participants' performance accuracy gradually decreased and reaction times increased with augmented working-memory load from the 0-back task to the 1-back task, and further, to the 2-back task. Moreover, higher amounts of daily video gaming (with a wide variety of games included) were associated with smaller decreases in performance speed and accuracy when moving from the 1-back task to the 2-back task. fMRI results showed that the 1-back and 2-back tasks, in comparison with the 0-back task, activated a network of frontal and parietal brain areas (Fig. 2), similarly to previous n-back studies involving only one sensory modality (e.g., Nee et al., 2013; Wang et al., 2019). In both cerebral hemispheres, an area in the middle frontal gyrus belonging to this network showed a higher activity increase from the 1-back task to the 2-back task the higher the amount of a participant's daily gaming. This suggested that frequent gaming resulted in more efficient recruitment of the prefrontal executive functions demanded by the 2-back task. Unexpectedly, the activity increase in the in the middle frontal gyri was smaller from the 0-back task to the 1-back task the higher the amount of the participant's daily gaming. Apparently, frequently gaming participants were more trained to perform the cognitive operations needed in the 1-back task, demanding shifts of focused attention between the auditory and visual modalities but not yet markedly demanding working memory. Therefore, when performing the 1-back task, the more frequently gaming participants were presumably less dependent on prefrontal cognitive-control functions than the less frequently gaming participants.

[Figure 2 about here]

The finding by Moisala et al. (2016) that prefrontal activity was increased less in the 1-back task (in relation to the 0-back task) in more frequently gaming participants is paralleled by the previous fMRI results of Bavelier et al. (2012). They compared the brain activity and performance of young adults frequently playing action games and those not playing action games, 12 in each group, in a task demanding selective attention to visual target objects in the presence of moving distractors. Their results showed that the moving distractors elicited less activity in the motion-sensitive areas of the visual cortex of the gamers, compared to the non-gamers, suggesting more efficient attention-related filtering of distractors among the gamers. Moreover, they observed activity increase with increasing attention demands in a distributed fronto-parietal network. This network included frontal areas in the superior frontal sulcus, supplementary motor area, and dorsal anterior cingulate gyrus of both hemispheres, and in the frontal pole, the middle frontal gyrus and inferior frontal gyrus/insula of the right hemisphere. The parietal portion of the network included areas in the cuneus/precuneus in both hemispheres and in the inferior parietal sulcus in the right hemisphere. Smaller activity increase in this network in the gamers than in the non-gamers with increasing attention demands suggested that the gamers allocated their attentional resources more automatically than the non-gamers, whose performance was more dependent on the fronto-parietal network, presumably involved in controlling attention in a top-down manner.

In their fMRI study, Richlan et al. (2018) compared task performance and related brain activity in a visuo-spatial task and in a letter-detection task between action video gamers and non-gamers, with 14 in each group. Contrary to many of the studies reviewed above, they did not find differences between the groups in visuo-spatial task performance or related brain activity. Moreover, there was no group difference in the performance of the letter-detection task (demanding detection of a designated target letter in words presented serially on a computer screen). However, during this task, in relation to a baseline task (a simple reaction time task) or the visuo-spatial task, they observed significantly higher activity increases in the gamers than in the non-gamers in several fronto-parietal cortical regions. These areas were located in the superior frontal sulcus, inferior frontal gyrus, and middle paracingulate cortex of the left hemisphere and in the posterior parietal cortex of each hemisphere. The authors proposed that this finding indicated higher neural engagement in the gamers than in the non-gamers during the letter detection task. Due to this finding, they also speculated that this task might have been more demanding for the gamers than for the non-gamers, although there was no difference in task performance between the two groups.

Concluding remarks

As reviewed above, numerous studies of adolescents and young adults have found negative associations between frequent media multitasking and cognitive skills (for reviews, see Firth et al., 2019; May & Elder, 2018; Uncapher & Wagner, 2018; van der Schuur et al., 2015). These findings include poorer performance of more frequently multitasking participants in experimental conditions demanding working memory, focused attention and filtering of distractors, dual-tasking, or task switching (Cain et al., 2016; Moisala et al., 2016; Ophir et al., 2009; Sanbonmatsu et al., 2013; Shin et al., 2018; Uncapher et al., 2016). All these cognitive skills depend on executive cognitive functions (see, e.g., Chan et al., 2008; Diamond, 2013). Therefore, it is likely that frequent media multitasking especially affects the executive functions. Although the aforementioned studies on media multitasking and cognitive skills cannot indicate the direction of causality, self-reports collected in longitudinal studies of adolescents suggest that frequent media multitasking results in enhanced attention problems (Baumgartner et al., 2018; van der Schuur et al., 2020), perhaps reflecting more general problems in the executive functions.

The frontal lobes have been implicated in the executive functions (e.g., Miyake et al., 2000; Stuss and Alexander, 2000). Therefore, the effects of frequent media multitasking on executive functions in adolescents and young adults might be associated with effects on the frontal lobes still developing through early adulthood (e.g., Blakemore & Choudhury, 2006; Casey et al., 2000). According to our literature search, there are only three published studies on associations of media multitasking frequency and the brain in adolescents or young adults. Nevertheless, they all suggest that frequent multitasking affects frontal structures or functions in adolescents and young adults: Loh and Kanai (2014) reported an association of frequent multitasking with lower gray matter volume in the anterior cingulate cortex and lower functional connectivity between the anterior cingulate cortex and the parietal precuneus; Moisala et al. (2016) reported higher right dorsolateral and dorsomedial prefrontal activity in more frequently multitasking participants during distracted linguistic performance, which might indicate increased effort in controlling attention and suppressing distractors; and Kobayashi et al. (2020) reported higher functional connectivity within the fronto-parietal dorsal attention network during an auditory discrimination task among more frequently multitasking participants, a finding that might also indicate enhanced effort in controlling attention.

In contrast, frequent action video gaming appears to have beneficial effects on cognitive skills related to the executive functions. As reviewed above, young adult action video gamers are better than non-gamers at tasks demanding visual attention, visual working memory, tracking of multiple visual objects, or switching between two visual tasks (Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010, 2013; Green and Bavelier, 2003, 2006; Green et al., 2012; Karle et al., 2010; McDermott et al., 2014; see also Chopin et al., 2019; Connolly et al., 2012; Powers et al., 2013). While these studies do not prove a causal relationship between video gaming and visuo-cognitive skills, there are also studies indicating such causality. In three studies, training young adult non-gamers in action video games improved visual attention, visual task switching, and multiple object tracking (Green and Bavelier, 2003; Oei and Patterson 2013; Strobach et al., 2012). The benefits of action gaming were not limited to the visual modality, as training in action video games also improved audio-visual dual-tasking and verbal working memory (Oei and Patterson, 2013; Strobach et al., 2012). Moreover, training in other game genres also improves cognitive skills: training in a visual matching game or hidden object game resulted in improved visual search performance and visuo-spatial working memory, and training in a hidden object game improved verbal working memory (Oei and Patterson, 2013).

The effects of different types of gaming on verbal working memory might explain the better performance of more frequently gaming participants in the *n*-back task on written and spoken vowels applied by Moisala et al. (2017), who studied adolescent and young adult participants. They observed in the middle frontal gyrus of both hemispheres a higher activity increase from the 1-back task to the 2-back task (i.e., from a less-demanding to a more-demanding working memory task) in more frequently gaming participants. Improved recruitment of brain areas involved in executive cognitive control might also explain the higher activity in several frontal and parietal brain areas in young adult participants more frequently involved in action gaming, as observed by Richlan et al. (2018) in the letter detection task. These findings might be related to the results of Kühn et al. (2014a, 2014b), which show that training in *Super Mario 64* among young adults and higher amounts of video gaming in 14-year-olds result in increased gray matter volume or cortical thickness in the dorsolateral prefrontal cortex of the right and left hemispheres, respectively. Moreover, Moisala et al. (2017) also observed that in the 1-back task compared to the 0-back task, the activity enhancement in the left and right middle frontal gyrus was in the more frequently gaming participants. This suggests that the more frequently gaming participants were less dependent on the prefrontal executive functions when performing the 1-back task than the less frequently gaming participants. This is in line with the results from the visual attention experiment of Bavelier et al. (2012) with young adult participants. They observed a lower level of activity enhancement with enhanced attentional demands among action gamers than among non-gamers in the fronto-parietal network, which is presumably involved in top-down control of attention.

Thus, like the detrimental effects of frequent media multitasking, the positive effects of frequent video gaming appear to be mediated by effects on frontal executive functions and structures. However, frequent video gaming appears to also affect other brain areas, as there are results from adolescents and young adults indicating that video gaming enhances the total or gray matter volume of the hippocampus (Kühn and Gallinat, 2014; Kühn et al., 2014a), presumably due to training in navigation during gaming. In addition, gaming seems to enhance the gray matter volume in the visual cortex and cerebellum (Kühn and Gallinat, 1984), presumably due to concomitant training in visual attention and motor coordination, respectively. Moreover, two brain-imaging studies suggest that video gaming also affects fronto-striatal reward-processing in adolescence and young adulthood (Kühn et al., 2011; Zhou et al., 2019).

In conclusion, there is cumulating evidence that frequent media multitasking may deteriorate attention and working memory skills, at least in adolescents and young adults, whereas frequent video gaming may be beneficial for these skills. Since these skills depend on executive functions, it is probable that the negative effects of frequent media multitasking and the positive effects of frequent video gaming on these skills are mediated by effects on the prefrontal executive brain functions, as also suggested by the brain-imaging studies reviewed here. However, the results from studies comparing, for example, frequent multitaskers with less frequently multitasking participants or video gamers with non-gamers cannot rule out the possibility, for instance, that more distractible individuals are more prone to multitasking or that individuals with better working memory, task switching, and attention skills are more prone to video gaming. Therefore, in addition to these cross-sectional studies, there is a need for longitudinal brain-imaging studies on media multitasking, video gaming, and cognitive skills. Such studies would add to the longitudinal studies in adolescents suggesting causal effects of media multitasking on self-reported attention skills (Baumgartner et al., 2018; van der Schuur, 2020) and to the studies in young adults indicating causal effects of video game training on cognitive skills or the brain (Green and Bavelier, 2003; Kühn et al., 2014a; Oei and Patterson 2013; Strobach et al., 2012).

Finally, since video gaming is beneficial for various cognitive skills, increased use of educational games at school would be recommendable. This is also supported by a meta-analysis showing that digital learning games enhance learning in children and adolescents (Clark et al., 2016). However, more systematic research is needed on what kind of educational games should be used to enhance both learning in the studied subject and development of cognitive skills (Mayer, 2019). More frequent educational gaming might be beneficial also for the development of the executive functions needed in suppressing distraction caused by digital technology in learning situations and other attention-demanding conditions.

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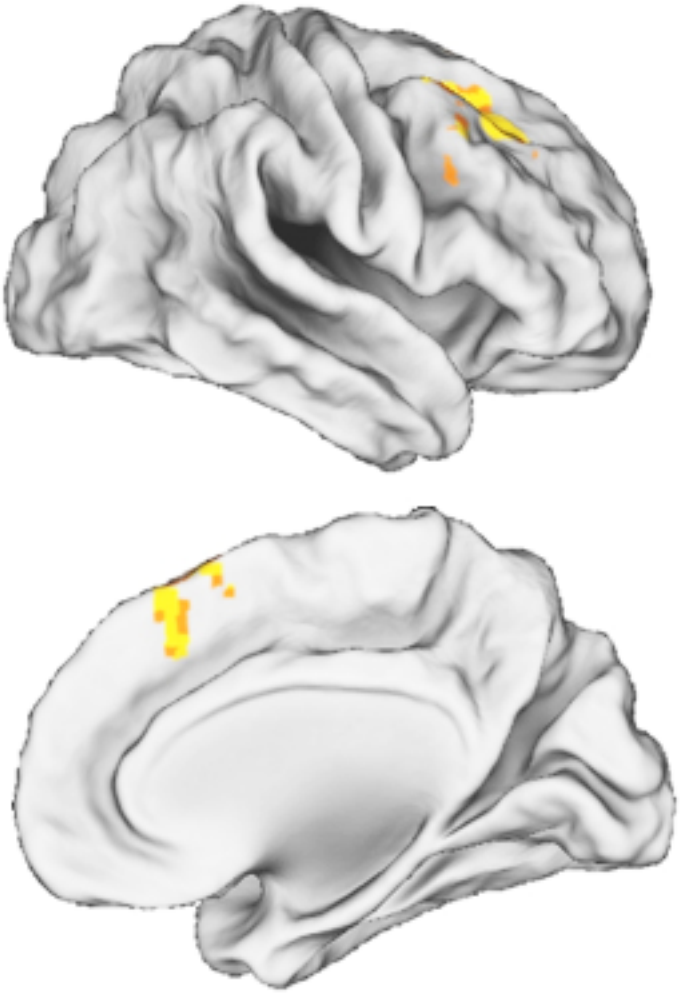

Figure 1. The colored dorsolateral and dorsomedial prefrontal cortical regions in the right hemisphere (top: lateral view; bottom: medial view) showed a significant positive association between the self-reported amount of media multitasking in everyday life and brain activity measured with fMRI during classification of written sentences as congruent or incongruent in the presence of distracting speech or music or during similar classification of spoken sentences in the presence of distracting written text. Data from 147 13–24-year-olds (Moisala et al. 2016).

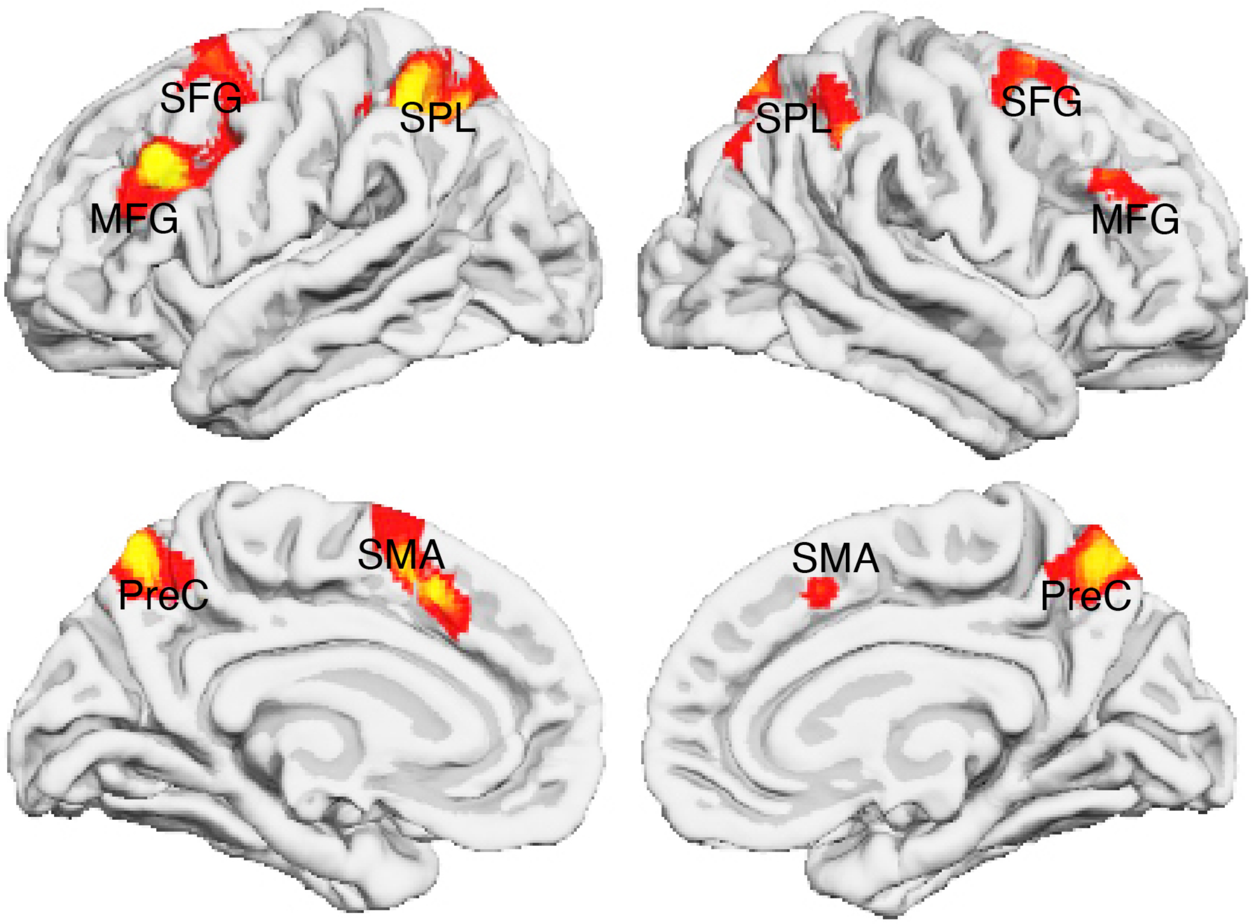

Figure 2. The colored prefrontal and parietal cortical regions showed significantly stronger activity during 1-back and 2-back working-memory tasks involving spoken and written vowels than in a 0-back control task. Top: Lateral views of the left and right hemisphere. Bottom: The respective medial views. fMRI data from 167 13–24-year-olds (Moisala et al. 2017). MFG: middle frontal gyrus, SFG: superior frontal gyrus, SPL: superior parietal lobule, PreC: precuneus, SMA: supplementary motor area.