CHAPTER 8

The Impact of Digital Media on Executive Planning and Performance in Children, Adolescents, and Emerging Adults

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Individuals in the United States have access to an unprecedented number of digital screens. National reports estimate that the average household has four digital screens and that consumers use them an average of 60 hours per week (Nielsen, 2014). For example, children between the ages of 2 and 11 are reported to watch more than 22 hours of television and play three hours of video games weekly, while adolescents between the ages of 12 and 17 watch more than 19 hours of television and play more than four hours of video games weekly (Nielsen, 2016). In addition, 24% of adolescents are online "almost constantly" (Pew Research Center, 2015). Questions regarding how this constant and extensive screen use might affect the development of cognitive functions such as executive functioning (EF) remain unanswered, which has been shown to mature throughout childhood and adolescence (see Best, Miller, & Jones, 2009).

EF refers to a specific set of cognitive functions that is related yet distinct from other cognitive functions such as intelligence (e.g., Arffa, 2007). EF broadly pertains to those aspects of cognition that require focused concentration, ignoring extraneous stimuli, and planning complex sequences of actions to achieve a goal. Given that various forms of screen media require these aspects (e.g., planning the shortest route to a goal in a video game, task switching in social media from consuming content to creating it), the ubiquity of screens and the reported frequency of their use, pose interesting questions in terms of their influence on the development of EF.

We review in the following, the impact of three different forms of screen media—video games, mobile technology, and social networking sites (also

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known as social media)—on the development of EF in children and adolescents and special needs populations. Here, digital screen media is characterized as including any device that produces digitized images in applications used at an individual or small group level. We conceptualized EF from a clinical neuropsychological standpoint based on a modified framework initially articulated by Lezak, Howieson, Bigler, and Tranel (2012), whereby EF comprises: (1) attention, or the ability to focus on a stimulus without losing concentration; (2) working memory, or the ability to retain elements of a stimulus in a memory store while manipulating them in some novel way; (3) set shifting, or the ability to switch from one task to a different task without significant errors occurring in either task; (4) inhibition, or the ability to respond correctly to a target stimulus while preventing responses to distractor stimuli that are similar; (5) fluency, defined as correctly generating responses that fit into a predefined category (e.g., retrieving the names of as many vegetables as possible in a given amount of time); (6) planning/problem solving, or the ability to organize information about the rules or requirements of a task in order to facilitate its completion as efficiently as possible; and (7) metacognition, which refers to the ability to identify patterns of thinking, reasoning, and problem solving that one or the other uses, and to deduce logical rules about these patterns.

THE IMPACT OF SCREEN MEDIA ON EF

Video Games

Video games have been categorized into three broad and overlapping categories: "edugames," whereby the goal is to educate the player about some topic or skill; "commercial off-the-shelf games," which include all games that are sold commercially either online or in physical stores; and "exergames" that allow an individual to control the game using some type of gross motor movement (e.g., jumping) (Jiménez, Pulina, & Lanfranchi, 2015). A broad range of game genres are found in each category including puzzle games, wherein the goal is to solve logic problems, role playing, and strategy games that require planning and resource management, and action games that require quick reflexes in the navigation of the game space.

Given that the overwhelming majority of games require sustained attention, planning, monitoring, inhibition, and set shifting, it follows that EF may differ among individuals who avidly play video games and those who do not. However, there is a distinct lack of longitudinal experimental designs to provide clear evidence for or against this hypothesis. Instead, most research designs have been cross-sectional in nature.

Powers, Brooks, Aldrich, Palladino, and Alfieri (2013) conducted two meta-analyses that investigated the impact of commercially available video games in relation to information processing skills, including EF—with one meta-analysis focusing on the results of quasi-experiments, comparing individuals who avidly play video games with less-experienced players, and one focusing on true experiments, involving training with a commercially available game. The authors defined EF as including measures of inhibition, task-shifting, intelligence, working memory, as well as EF test batteries. The meta-analysis of quasi-experiments examining the effects on EF comprised 110 statistical comparisons involving 4395 participants in 22 studies. These cross-sectional studies included control groups of inexperienced video game players, players with little skill in playing video games, and players who played video games that differed from more action-oriented games (e.g., shooter games). The results demonstrated a small but statistically significant effect size of $d=0.44$ for a composite EF variable. Dividing the composite EF variable into its constituent parts revealed statistically significant small to medium effects sizes for all subcategories ranging from $d=0.29$ (inhibition) to $d=0.67$ (task-switching and dual/multitasking). However, only one study, by Li and Atkins (2004), was classified as examining the relationship between video games and EF in youth, and the authors found no relationship between the presence of computer games at home, and intelligence in a sample of 122 rural preschoolers.

A study by Dye, Green, and Bavelier (2009) was included in the first meta-analysis by Powers et al. (2013), but was classified as a visual processing task rather than as an EF task. However, Dye and colleagues considered their dependent variable to be a measure of EF, so we include it in this review. This study investigated the impact of playing predominantly action-oriented video games compared with other video game types such as puzzle-based and strategy games on attention in a cross-sectional study of 131 participants ranging from age 7 to age 22. The authors assessed attention using the Child Attention Network Task (ANT-C), a reaction-time task that requires a participant to identify correctly the direction in which a target stimulus (e.g., a fish) is pointing. Across trials, distractors (i.e., other fish identical to the target) appear on both sides of the target and either point in the same direction (congruent) or the opposite direction (incongruent) as the target. Incongruent trials presumably assess inhibitory responding, as one must ignore the contradictory stimuli and focus on the target. Dye and colleagues found that action game players outperformed players of other video games in terms of reaction time across all age groups without sacrificing accuracy.

They also found that reaction time increased with age. Thus, as the authors noted, action video game players appeared to process information more quickly than their nonaction game playing peers.

The second meta-analysis of experimental studies conducted by Powers et al. (2013) provided less support for the hypothesis that playing video games improves EF. These studies included either pretest/posttest within-groups designs or random assignment of naïve participants to video game training and control conditions. In studies that included a control group, typically participants with minimal exposure to video games would be randomly assigned to play a video game or engage in another comparable task. Aggregating 89 statistical comparisons from 13 experimental studies involving a total of 3721 participants, Powers et al. found a statistically significant but marginal effect size of $d=0.16$ across all studies. However, when deconstructing EF into its constituent domains, only inhibition was statistically significant, albeit with a small effect size of $d=0.39$. Notably, only two of the experimental studies included youth samples (defined as ranging in age from 3 to 17).

One study, by Staiano, Abraham, and Calvert (2012), examined whether competition in video games might affect EF. African-American teenagers of low socioeconomic status ($N=54$) were randomly assigned to a competitive exergame, cooperative exergame, or no-game control group. Both exergame groups played the same video game, but the competitive group sought to win the game while playing with a peer, while the cooperative group sought to achieve the highest total score with their peer. EF was measured with task-switching and fluency tasks before and after a 10-week exergame training regimen. Results revealed that the competitive exergame group outperformed the other two groups in EF. The other study, by Miller and Kapel (1985) used a within-groups pretest/posttest design with 95 middle schoolers completing both pre- and posttest measurements. Students played puzzle and strategy computer games for 50 min per day for 15 days. The authors examined the sequential thinking and visuospatial processing of the students. They found that participants' spatial abilities improved over time, but that their sequential reasoning did not.

Note that studies examining effects of proprietary (custom-made) as opposed to commercially available video games were not included in the Powers et al. (2013) meta-analyses. Such studies also show mixed results of the impact of video games on EF in children and adolescents. In one of the few studies using preschool participants, Thorell, Lindqvist, Bergman Nutley, Bohlin, and Klingberg (2009) investigated whether playing video games could enhance the working memory and inhibitory response ability of preschoolers. The researchers assigned a sample of 65 toddlers into one of the four groups: one that was trained to improve their EF using a proprietary video game developed by the authors that targeted working memory, another group that played a proprietary video game targeting inhibition, an active control group that played a commercially available game chosen because it did not tax either working memory or inhibition, and a passive control group that received no intervention. All groups received a pretest and posttest battery consisting of eight EF instruments measuring inhibition, interference control, spatial and verbal working memory, auditory and visual attention, problem solving, and processing speed. The authors found that training improved the working memory capacity of toddlers in the working memory group relative to the control groups only; training did not improve the inhibition of toddlers in any group. Thus, at least the working memory of toddlers showed improvement through training.

Goldin et al. (2014) examined whether repeatedly playing video games could improve the EF of 6- and 7-year-old Argentinian children of low socioeconomic status and result in improved academic performance in language and mathematics. Children were assigned to either an experimental or control group that played games in class for 15 min from 1 to 3 times per week for 10 weeks. The experimental group played each of three proprietary computer games that targeted either working memory, planning, or inhibition in an individual. The control group played computer games matched to the experimental group's games for motor input but requiring minimal use of EF to advance in the game. Findings showed that video game training improved children's inhibitory control and attention, but not their planning. These improved skills resulted in improved academic grades in math and literacy at the end of the third quarter of the school year as assessed by teachers who were blind to the study.

Similarly, Mackey, Hill, Stone, and Bunge (2011) investigated whether extensive cognitive training (i.e., playing video games for 1 h twice per week for 8 weeks) using commercially available video games would improve different cognitive domains (working memory, processing speed, or fluid reasoning) among children from low socioeconomic backgrounds between the ages of 7 and 10. Children were trained using either a video game that rewarded fast processing speed or one that rewarded fluid reasoning skills. Children exposed to video games that rewarded faster cognitive processing (i.e., speed training) improved on tasks of processing speed and children exposed to games that rewarded reasoning ability improved on measures of cognitive reasoning.

Studies also show that EF does not necessarily improve with exposure to video games. For instance, Best (2012) assessed whether video game playing and sedentary habits influenced inhibitory responding using a within-subjects design. Thirty-three US children between the ages of 6 and 10 participated in four groups that varied in cognitive engagement and physical activity. Low physical activity sessions were either high in cognitive engagement (the child played a video game) or low (the child watched a video on healthy living habits). Sessions high in physical activity also varied between high cognitive engagement, whereby children played an exergame that required reacting to random stimuli to progress, or low cognitive engagement whereby children played an exergame that required them to run in place. Children's inhibition and attention were measured using the ANT-C (described previously). Neither video games nor engagement significantly predicted EF processes, although participants in the high physical activity condition did show improved attention compared with those in the low physical activity condition. Syväoja, Tammelin, Ahonen, Kankaanpää, and Kantomaa (2014) also found that self-reported frequency of playing video games in a sample of Finnish fifth and sixth graders predicted worse performance on measures of spatial working memory and set shifting.

Extraneous variables may explain such discrepant results. The relationship among sleep, attention, and video games illustrates this possibility. Wolfe et al. (2014) examined whether playing video games might lead to EF deficits in adolescents and examined the role of sleep as a potential mediating variable. A sample of 21 adolescents participated in a sleep study in which they could play video games before going to bed. The authors found that the amount of time spent playing video games correlated highly negatively with sleep duration and with sustained attention the following day, but was uncorrelated with working memory.

Hartanto, Toh, and Yang (2016) illustrated another such possibility. The authors examined the impact of the age of onset of intensive video game playing on EF performance. A sample of 134 undergraduate students reported the age at which they had begun playing video games intensively. Intensive playing was characterized as the self-reported number of hours per week that an individual engaged in playing video games and the age at which the individual began actively playing video games. The authors assigned the participants into three groups based on their experience: nonvideo game players (individuals who had rarely or never played video games prior to the study), early video game players (participants who actively played video games starting before age 12), and late video game players (participants who actively played video games starting after age 12). Findings demonstrated that an earlier age of onset, but not hours played per week, predicted improved EF performance.

Taken together, it appears that video games at least modestly improve the EF of children and adolescents. Furthermore, no studies found that playing video games was pernicious to EF. However, it is clear that longitudinal studies are needed to understand the development of EF among children and adolescents further and the relationship of that development to video game play.

Video Games and Special Needs Populations

Given that video games may potentially improve EF, it is notable that there remains little research examining whether video game play improves EF among individuals with special needs. One of the few studies was conducted by Grynszpan, Martin, and Nadel (2007), who developed two educational video games to determine whether an educational game could be used to ameliorate specific EF deficits in autism and ADHD (such as response inhibition and planning). One game was a network planning game designed to train and evaluate visuospatial planning. This game required participants to determine the most efficient path between nodes. The other was a text-based game designed to assess language comprehension of subtleties of speech such as irony, sarcasm, or metaphors. The authors used an experimental cross-treatment design using ten children with autism and 10 matched controls. They found that the text-based game helped improve language comprehension, but the network planning game did not improve the planning ability.

Dovis, Van der Oord, Wiers, and Prins (2015) examined whether playing a game that engaged children in three EF domains (visuospatial working memory, inhibition, and task-switching) improved these domains compared with playing versions of the same game that engaged children in one or none of the tasks. The authors used *Braingame Brian*, which requires participants to help the inventor Brian create new objects by having children "design" blueprints (visuospatial working memory), forge new materials (inhibition), or sort objects according to changing rules (task-switching). Children played the game for 25 sessions over the course of 5 weeks. The researchers examined 89 children between the ages of 8 and 12 diagnosed with ADHD. Participants were assigned to one of three conditions: a full-active condition where the difficulty for each task increased as the child progressed, a partially active condition where the difficulty increased for only the inhibition and task-switching tasks, and a placebo condition where the difficulty never increased for any of the tasks. Participants in the full-active condition demonstrated the most improvement on measures of inhibition and working memory (both auditory and visuospatial) that remained 3 months after completion of the study. However, these gains did not translate to ADHD symptoms or problem behavior reduction according to self-report, teacher-rating, or parent-rating scales.

Commercially available video games also have been found to improve the EF functioning in special needs populations. Anderson-Hanley, Tureck, and Schneiderman (2011) examined the impact of exergaming on the EF (i.e., inhibition, auditory working memory, and task-switching) of adolescents with autism. Using two popular commercial exergames (*Dance, Dance Revolution* and *Dragon Chase*), they found that these games reduced the repetitive behaviors of autism and improved performance in working memory and inhibition compared with that of a control group.

Findings also show that there may be potential risks for children with special needs who play video games. For example, Gentile, Swing, Lim, and Khoo (2012) investigated the relationship between video games and self-reported deficits in EF among children with ADHD using a 3-year longitudinal correlational design. Among a sample of 3034 children and adolescents, the researchers found that the amount of video game exposure was predictive of self-reported inhibitory and attentional control problems, even when controlling for potential moderating variables such as age, gender, race, and socioeconomic status.

Overall, there is a dearth of controlled studies that investigate the effect of video games on special needs populations. As with video games and EF in general, more studies are needed to understand better how video games differentially affect the functioning of each subpopulation (such as ADHD, ASD, or learning disorders).

Mobile Technology

Mobile technology includes portable electronic devices (i.e., computers) that use a liquid crystal display to project digital images and are manipulated by touching the screen using a stylus, or by entry of characters from a digital keypad. Typically, mobile devices include tablets (e.g., iPad, LeapPad, Android tablets), smartphones, and laptop computers. Research regarding mobile devices and EF is still relatively new and focuses on whether mobile devices can be used to measure children's EF or how EF moderates children's learning via mobile technology.

For example, Howard and Okely (2015) adapted a go/no go task for use on an iPad and a desktop computer to understand how variations in the task affected preschoolers' inhibitory responding. In these tasks, 60 participants completed six trials of the go/no go task, wherein participants try to react to a target stimulus as quickly as possible by pressing a key or without pressing the key during the presentation of nontarget stimuli. Each task varied in its stimulus presentation time, whether it was animated or static, and whether it required a touchscreen (tablet) or button press (desktop computer). The authors found that using longer spaces between trials (greater than 1000 ms) and using the touchscreen of the iPad resulted in the best discrimination between children on the go/no-go task.

Marshall, Bouquet, Thomas, and Shipley (2010) examined a novel form of motor inhibition in young children. The authors predicted that social learning of a gross motor response (drawing an "S" shape in the air) would occur after having observed another human model the gesture. Marshall et al. (2010) conducted two studies among 4- and 5-year-olds. In each study, participants were told to draw a sinusoidal shape with either a vertical orientation or a horizontal orientation on a digital tablet. As they completed the task, the screen of the device showed a video of an adult drawing the same shape in the air. On some of the trials, the adult drew in a direction that was either congruent or incongruent with what the child was instructed to do. In the latter case, the child needed to inhibit what they saw the adult do. Results demonstrated that children experienced difficulty drawing in the correct direction during the incongruent trials. In a follow-up study, the authors varied the age of the model (between 4.5 and 36 years of age) shown drawing the shape on the screen across types of trials between a similarly aged child and an adult. The results indicated that more interference effects occurred during trials with adult models, suggesting that measurement of EF in young children may vary depending on the age of the model used.

Other researchers have examined whether mobile devices enhance learning. McEwan and Dubé (2015) explored whether tablet computers improved children's learning of mathematical content, using EF as a moderator variable. The authors used eye-tracking technology to collect information on where exactly the 30 Canadian second-graders looked on a screen as they played four educational mathematics games. The authors classified the games as either simple or complex. Simple games only focused on one type of mathematics content (e.g., number line estimation, probability), had one learning mechanic, and had many static visuals. Complex games involved multiple types of mathematics content (e.g., counting, magnitude comparison, and number identification), had multiple learning mechanics, and displayed many animated visuals. McEwan and Dubé found that all tablet games enhanced learning of mathematics. Furthermore, they found that a composite EF variable consisting of auditory working memory and response inhibition moderated how a child interacted with a particular game. Children with lower EF scores focused on the content that related directly to the mathematics topic presented in the program (i.e., number identification) when the presentation was simple, while children with high EF scores adjusted to the complexity of the program.

One question that arises when using tablets as teaching tools for use among child participants is whether they may provide too much extraneous stimulus for any meaningful learning to occur. Axelsson, Andersson, and Gulz (2016) examined whether preschoolers could inhibit attending to distracting stimuli (e.g., a glitch on the screen, irrelevant animated stimuli in the background) and benefit from a learning-by-teaching program (LBT). LBT allows the child to tutor a peer or, in this case, a digital "peer" that uses an algorithm to appear to "learn" from the child. A sample of 36 5-year-olds were pretested on their attention and inhibitory ability using go/no go and anti-saccade tasks. The authors found that children were able to inhibit attending to the distracting stimuli during the tasks. Axelsson et al. concluded that LBT software on tablet computers would likely benefit all children, even if their EF was not yet fully developed.

Buckner and Kim (2012) used mobile devices innovatively to measure the EF of children living in areas with few resources such as war-torn countries and refugee camps. The authors recruited a sample of 185 Palestinian children from either rural or urban backgrounds and who had either high or low risk exposure to traumatic events due to war. They used electronic applications of the Wisconsin Card Sort Test and Tower of London EF tasks, both of which assess planning and problem solving. Buckner and Kim found that children living in high-risk areas performed poorly on both EF measures than children from low-risk areas, and that children from rural areas performed poorly on these EF measures than children from urban areas.

Collectively, these results suggest that mobile devices generally enhance the learning of typically developing children. The next logical question is whether mobile devices can assist the learning of children with developmental delays or disabilities. In one of the few studies examining this population, Arthanat, Curtin, and Knotak (2013) conducted a pilot case study of four children with developmental delays (autism spectrum disorder with some children also diagnosed with intellectual disability). The authors examined whether using mobile technology would improve learning for these children compared with that of a desktop computer. Arthanat and colleagues found no difference in the learning of three of the four children based on the device used. Furthermore, all four children displayed attentional issues regardless of the type of technology used. Although clearly more evidence is needed, it appears that simply using mobile technology without further scaffolding may provide little benefit to learners with developmental disabilities.

Social Media

Social media can be described as an interactive electronic interface that facilitates the communication among individuals via creating, sharing, or exchanging information in virtual communities or networks. In terms of number of users, three of the most popular social networking sites in the United States are Facebook, Youtube, and Twitter (eBizMBA, 2016). Facebook enables an individual to create a personalized biographic site and post personal information, connect with friends, and share content such as news and events. Youtube is a video-sharing platform whereby people can watch others' videos or create their own channel. Twitter is most often used for reading, posting, updating, or sharing brief messages (140 characters or less), although recently those limits have been expanded.

According to two studies that examined the relationship between social media and EF, engagement of social media appears to affect the attention and working memory domains. Rosen, Carrier, and Cheever (2013) examined multitasking between studying and engaging in social media among 263 students aged 12–23. Participants who preferred to switch between multiple tasks exhibited a shortened attention span during the study period. Alloway, Horton, Alloway, and Dawson (2013) studied the length of engagement and type of engagement with Facebook and Youtube on cognitive skills among 103 adolescents. The results demonstrated that individuals who had used Facebook for more than 1 year scored better on working memory than individuals who had used it for less time. The authors also investigated whether particular activities (e.g., checking a friend's status updates) were predictive of working memory performance, but found no significant differences. Alloway and colleagues also examined whether type of engagement with social media significantly affected the working memory. Based on the quality of social media interaction, students were assigned to one of two groups: active use (e.g., posting an update or comment, uploading a video, or playing a game) and passive use (e.g., watching a video, looking at a friend's page). However, the authors found no differences in EF between social media interaction types.

These findings suggest that more social media use can increase working memory while multitasking between activities including social media can decrease attention. However, given the dearth of literature on these topics, further research focusing on social media and its impact on EF in children, adolescents, and those with special needs is needed.

CONCLUDING THOUGHTS

A number of broad themes can be gleaned from perusing the literature examining the impact of digital screen media on EF. The first is that not enough research has been done regarding the potential benefits of digital screen media on EF in children and adolescents. A second theme is that concern about the pernicious effects of digital media on the development of EF in children and adolescents has little evidence to support it. Third, currently no longitudinal studies exist that would clarify the effects of digital screen media on EF.

Based on these themes, we recommend that future research use more longitudinal methods to understand better how EF develops over time in children and adolescents. Research using longitudinal designs, although expensive, would have the added benefit of permitting comparison between generational cohorts. Thus, we could conceivably compare how EF in children and adolescents may be affected by early exposure to social media versus those who matured alongside video games. Another recommendation is that more unique measures for each latent EF factor could be used to more accurately and validly measure each facet of EF in applications that involve latent variable modeling. This is because using more than one measure per domain would reduce measurement error while permitting comparison across different administrative methods (such as pen-and-paper versus kinetic). Finally, we recommend that more investigative work be performed on populations with special needs to understand better whether digital media exacerbates or ameliorates clinical issues in children and adolescents.

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