CHAPTER 6

Young Minds on Video Games

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Video games are one of the most heavily used forms of entertainment in the modern world. According to the most recent estimates, 155 million adults in the United States play video games (ESA, 2015). Furthermore, and counter to many common stereotypes, gaming is an activity that cuts across nearly all demographic categories, with females making up 44% of gamers, and 27% of gamers being older than 50 (ESA, 2015). Of all the demographic categories though, children, teens, and young adults are the group that has seen the most dramatic rise in video game play. In fact, video game play has become so ubiquitous within these groups that some surveys have found that up to 90% of teens play video games, with 8–18-year-old boys playing an average of 16 h per week, and girls playing an average of 9 h per week (see Gentile, 2009).

As is the case with any new technology that reaches such levels of use, questions naturally arise as to the possible consequences, especially among younger individuals. The fear that video games will lead to serious harm with regard to attention spans, cognitive abilities, and/or academic performance are similar to the fears society once raised toward television, movies, radio, and the phonograph. While none of these previous technologies led to the downfall of society (although this is not to say that they are totally benign—e.g., Gentzkow & Shapiro, 2008), the interactive and rewarding nature of video games makes this newest massively popular technology potentially more capable of altering the human brain (Gentile & Gentile, 2008). As such, the literature on the effects of video games is vast, and spans myriad disparate areas of psychology—from clinical (e.g., addiction—Gentile, 2009), to social (e.g., aggressive or pro-social behavior—Anderson & Bushman, 2001), to educational (e.g., the development of games to augment or replace classroom instruction—Charsky, 2010), to the main interest of this chapter, cognitive psychology.

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NOT ALL GAMES ARE CREATED EQUAL

Before we begin our discussion of the cognitive impact of certain types of video games, it is critical to note that the label "video games" covers an incredibly broad range of quite dissimilar experiences. Games can vary enormously along tens or even hundreds of distinct dimensions. For example, some games involve extremely simple graphics (e.g., the game *Tetris* has only seven distinct shapes, with each shape constructed by four joined squares). Other games involve the creation of vast and detailed worlds (e.g., the game *Rise of the Tomb Raider,* where the level of graphical detail extends all the way down to the avatar's hair, which floats in water and clumps when wet). Some games are purely solitary experiences (i.e., engage only single player at a time), while others involve interacting with a myriad of other individuals in real-time experiences (e.g., *World of Warcraft*). Even within the broad group of games that involve interacting with other human players, some are purely cooperative (e.g., *Portal 2*, where two players must work together to solve puzzles), some are purely competitive (e.g., *StarCraft*, where two players compete over limited space and resources), and others involve mixtures of cooperative and competitive play (e.g., team-based competitive games such as *League of Legends*). All told, this wide-spread variation in game content, mechanics and dynamics, means that simply knowing that an individual has, for instance, played "two hours of video games," provides extremely little information regarding what that individual has actually experienced. Given that it is the actual experiences that drive changes in behavior, the enormous differences that exist across video games strongly suggest that not all games will affect behavior equally. As discussed next, there is one particular type of game that appears to drive changes in cognitive function to a greater degree than others.

VIDEO GAME RESEARCH

Action Video Games

The main video game genre of interest within the domain of cognitive psychology is what is known as the "action" video game genre. The distinguishing characteristics of action games include quickly moving target objects that must be tracked within a complex field of distracting objects; the need to frequently and efficiently switch between a diffuse attentional state, in which one monitors the broad environment, and a highly focused attentional state, where one locks in on a target and suppresses nontarget information; high cognitive and motor load, in that multiple objects must be tracked and often acted upon in quick succession, and multiple goals and or rules that constrain in-game behavior must be constantly updated and maintained (Spence & Feng, 2010). In practice, the games that are most commonly classified as "action" games are what are known as first-person shooter games (i.e., where the player looks through his/her avatar's eyes) and third-person shooter games (i.e., where the player looks at the back of his/her avatar).

METHODS

Correlational Methods

Research on the relationship between cognitive abilities and action video games has in general taken one of two different forms. The most commonly employed study design has been the correlational, or cross-sectional, design. Here researchers have taken advantage of the natural variation in different individuals' game playing habits (in particular the fact that some individuals play a great deal of action games, while other individuals play almost no action games). In these experiments, individuals who already avidly engage with action games (referred to as "Action Video Game Players" or AVGPs) are invited into the lab to undergo a series of diverse cognitive measures. These individuals are typically identified either through large-scale surveys administered to students in introductory psychology courses, or through recruitment posters or online advertisements that explicitly seek heavy action gamers. AVGP performance on the cognitive or perceptual tasks of interest is then compared against that of a group of individuals who rarely or never play action games (referred to as "Nonaction Video Game Players" or NVGPs). This methodology offers an easy and effective means of collecting data in adult populations, and it is quite viable given the large degree of natural variation in gaming habits across individuals. However, whereas the gaming habits of adults tend to be limited by their time and interests, the gaming habits of youth tend to be limited by their parents. In particular, given the violent content of many of the most popular action games (although not all—see Spence & Feng, 2010), some parents do not allow their children to play such games. This prohibition then limits the extent to which studies utilizing this type of video game can be conducted with children. As such, the number of correlational studies examining the impact of action video games in adults substantially outnumbers the number of correlational studies examining the impact of action video games in children and youth (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013).

Intervention/Experimental Methods

While correlational studies are certainly informative, they do not show how action video game play *causes* changes in cognitive or perceptual abilities. Indeed, AVGPs might be more likely to engage in some other activity than NVGPs, and this other activity may be the cause of their improved cognitive abilities. Similarly, individuals with innately superior cognitive abilities may be more drawn toward playing action games. Thus, to go beyond simple correlation, researchers typically perform an intervention study (i.e., a true experiment). In these studies, researchers first recruit individuals who have minimal video game experience. Next, pretest measures are taken of the participants' cognitive and/or perceptual abilities of interest. Importantly, these pretests measures do not remotely resemble video games (meaning that if improved performance is seen after video game training, it cannot be attributed to superficial/task specific improvements as discussed next). After pretesting, half of the participants are then trained on an action video game and half are trained on a nonaction video game (i.e., the control group). Importantly, the nonaction video game is carefully selected to be just as engaging and entertaining as the action game being used, to rule out subtle confounds, such as the possibility that engaging activities alone are sufficient to produce cognitive improvements. Total training durations have varied across the literature, but have typically been in the range of 10–50 h (with shorter durations used when performance on the tasks of interest is known to be more malleable—such as the case with visual search—and longer durations used when performance on the tasks of interest is more difficult to change via experience as is the case of contrast sensitivity). Importantly, researchers of quality studies in this domain have been sure to distribute training across time, rather than massing it together, as findings suggest that such distribution is essential for optimal learning of any skill (Baddeley & Longman, 1978). Finally, at least 24-h after the final training session (to ensure that any transient changes in the participants' internal state that could be induced by playing their respective video games have had time to dissipate), participants are posttested on the same measures of interest they were tested on prior to training. The final critical measure is whether the group trained on the action game improved more from pretest to posttest on the measure(s) of interest than the control group; see Green, Strobach, and Schubert (2014) for a more in-depth review on current issues in video game training research methodology.

Overall, intervention studies in this domain are far less common than correlational studies (Powers et al., 2013). While in adults this difference in prevalence is largely attributable to the considerable cost and difficulty associated with intervention studies, many additional issues are at play when considering younger populations. In particular, as noted above, action video games tend to contain violent content. Given that previous research suggests that exposure to such content may produce small, but, nonetheless, statistically reliable increases in aggressive tendencies, and that children may be particularly susceptible to such effects (Anderson et al., 2010), it would not be ethical to train individuals younger than 18 years old on most action video games (although see below for some solutions to this problem employed by researchers to date).

BRIEF REVIEW OF THE PERCEPTUAL AND COGNITIVE EFFECTS OF ACTION VIDEO GAMES IN ADULTS

Perception

A large portion of the work on action video games has examined the effects of such games on perceptual skills, in particular visual perception. One such study conducted by Li, Polat, Makous, and Bavelier (2009) examined the impact of action video games on low-level visual abilities—specifically contrast sensitivity (i.e., the ability to detect small changes in luminance across the visual field). These experimenters first conducted a correlational study (of the type previously described), comparing contrast sensitivity in AVGPs and NVGPs. Expert action gamers showed significantly superior contrast sensitivity. Then, to establish a causal relationship, the researchers performed a 50-h intervention study. Half of the participants were trained on an action game (*Unreal Tournament 2004* or *Call of Duty*), while the other half were trained on a nonaction game (*The Sims 2*). No improvements were observed in the control group. However, the action-game trained group showed significant improvements in their contrast sensitivity at posttest relative to their pretest scores. This finding is notable because contrast sensitivity is of great importance for many visual tasks (e.g., driving, reading), and has proven difficult to train (Sowden, Rose, & Davies, 2002).

Beyond contrast sensitivity, a number of other studies have similarly shown positive associations between action gaming and improved perceptual skills. For example, correlational studies have shown that AVGPs have superior peripheral vision (Buckley, Codina, Bhardwaj, & Pascalis, 2010), and an enhanced ability to process moving stimuli (Hutchinson & Stocks, 2013). Donohue, Woldorff, and Mitroff (2010) also showed that when AVGPs were presented with rapidly alternating visual and auditory stimuli, they demonstrated a superior ability to distinguish the correct temporal order of those stimuli, which is indicative of enhanced multisensory integration.

An Aside: Why Action Games Are Interesting—Transfer of Learning Is Rare

While one may not initially be surprised that training on a perceptually demanding task (like an action video game) results in improvements in perceptual skills (like contrast sensitivity), it is important to note that transfer of this nature is the exception, rather than the rule, within the domains of perception and cognition. Indeed, while humans are capable of improving at most perceptual and cognitive tasks, it is typically the case that such improvements are task specific and inflexible, and do not generalize to other, even very similar tasks (Fahle, 2005). A classic example of this phenomenon is the work of Fiorentini and Berardi (1980), who trained subjects to discriminate between two different types of visual patterns. Participants became very good at performing this discrimination, but then when the parameters of the task were changed in seemingly minor ways (i.e., the orientation of the patterns or the distance of the participants from the patterns), performance dropped back down to initial levels. Overall, this type of task-specific learning tends to be the most common result of perceptual and cognitive training. Because of this tendency toward learning specificity, the results of action game training are of particular note (i.e., improvements on tasks that share no clear surface features with the games).

Selective Attention

While there is significant overlap between those tasks thought to measure "selective attention abilities" and those thought to measure "perceptual abilities," in general attentional tasks are those that require participants to selectively enhance the processing gain of task-relevant information, while attenuating the processing gain of irrelevant information (i.e., the presence of some distracting information that must be suppressed is key).

A commonly utilized measure of visual selective attention is the Useful Field of View task, which requires participants to locate a target in their visual periphery (at varying degrees of eccentricity from 10 degrees to 30 degrees) from among a field of distractors. Performance on this task has been shown to be more predictive of the visual skills relevant to driving a car than performance on standard vision measures employed by most DMVs (e.g., standard eye charts—Owsley et al., 1998). Green and Bavelier (2003), found AVGPs to perform significantly better than NVGPs in this task. Then, in a follow-up training study, individuals trained 1 h per day for 10 days on an action video game (*Medal of Honor: Allied Assault*) improved significantly more on this task than did individuals trained on a nonaction game (*Tetris*).

While the Useful Field of View taps the ability to deploy attention across space, AVGPs have also been shown to have an advantage in their ability to deploy attention across time. The attentional blink, a popular measure of such ability, presents participants with a rapid stream of black letters, with a single white letter appearing at some point in the stream. On 50% of trials, a black "X" appears at some point after the white letter. Participants are tasked with first identifying the white letter, and then indicating whether an "X" was present in the stream. A wealth of studies have shown that if the "X" appears within 200–400 ms of the white letter, participants often fail to perceive it, and incorrectly report that it was not present (hence the term "attentional blink"—Raymond, Shapiro, & Arnell, 1992). Extended action video game experience has been associated with a shortened attentional blink, in both correlational and intervention studies (Dye & Bavelier, 2010; Green & Bavelier, 2003).

Beyond the deployment of attention in space and time, one final aspect of visual attention is the ability to attend to multiple stimuli simultaneously—often thought of as the "capacity" of visual attention. This capacity is often measured with the multiple object tracking (MOT) paradigm. This task requires participants to track several moving targets (i.e., blue dots) among a field of moving distractors (i.e., yellow dots). After several seconds, the blue target dots change color to appear the same as the yellow distractor dots, and participants are asked to continue tracking the original target dots. AVGPs have been shown to track a larger number of dots than NVGPs in correlational studies (Dye & Bavelier, 2010) with the causal relationship between action gaming and enhanced tracking abilities confirmed in an intervention study (Green & Bavelier, 2006).

Sustaining Attention, Impulsivity, Speed/Accuracy Tradeoffs

While selective attention refers to the capacity to focus on important information while filtering out distracting information, sustained attention refers to the ability to remain focused on a given task or stimulus for an extended period of time. Many of the concerns raised about possible negative outcomes of video games have come in the form of characterizing avid video gamers as "trigger happy," or arguing that the fast-paced nature of many games may make it difficult for children to remain focused in a relatively slow-paced classroom environment. However, the literature to date has offered little evidence in support of these concerns for adults (at least with respect to action games specifically, see next).

Two common measures of sustained attention are the Test of Variables of Attention (TOVA) and the AX-Continuous Performance Test (AX-CPT). In the TOVA, on each trial, participants are shown one of two stimuli—a square that appears on the top half of the screen or a square that appears on the bottom half of the screen. The participants are instructed that if they see the former stimulus (square on the top half), they are to press a button as quickly as possible (i.e., "go"). If they see the latter stimulus (square on the bottom half) they are to make no response (i.e., "no-go"). The overall task consists of two blocks that differ in the proportion of "go" to "no-go" trials that are present. In one block most of the trials contain squares in the upper half of the screen (i.e., "go" trials). The measure of most significant interest in this block is thus whether the individual can withhold a response when the rare "no-go" stimuli appear. In the second block, most of the trials contain squares in the bottom half of the screen (i.e., "no-go" trials). The measure of the most significant interest in this block is thus whether the individual can stay on task and respond quickly when the rare "go" stimuli appear. In cross-sectional work, AVGPs showed faster response times than NVGPs in both blocks of trials. Critically though, there was no difference in accuracy between the groups (i.e., the AVGPs were, if anything more capable of sustaining attention and were no more impulsive; Dye, Green, & Bavelier, 2009a). The AX-CPT is a similar task where participants respond as quickly as they can to a target stimulus under some conditions, and withhold the impulse to respond under other conditions. AVGPs have also been found to perform faster in this task, again with no harm to their accuracy (Cardoso-Leite et al., 2016).

In general, the pattern observed previously, with AVGPs responding faster to stimuli, but showing no corresponding decrease in accuracy, is consistent with the broader literature. To quantify this, Dye and colleagues

(Dye et al., 2009a) created what is known as a "Brinley plot" of the literature, wherein for each task reported in the literature, AVGP reaction time was plotted against NVGP reaction time. The authors found that across a wide range of average response times (i.e., from tasks where most participants responded in less than 300 ms, to tasks where most participants took more than 1 s to respond) AVGPs were approximately 12% faster than NVGPs, with no concomitant change in accuracy. This data is thus consistent with a true improvement in cognitive skill in AVGPs as a result of action video game experience, rather than, for instance, a simple speed-accuracy tradeoff.

Cognitive Control

A similar body of research has investigated the relationship between action video games and cognitive control abilities. Cognitive control refers to a variety of high-level cognitive abilities that require coordination of various sub-processes related to, for example, perception, memory, and planning. Task switching, or the ability to flexibly switch between different tasks, is thought to be one key aspect of cognitive control. This ability is typically measured by having participants alternate between two different tasks that are both performed on the same stimuli. For instance, participants might be presented with a global shape, composed of several smaller, local shapes (e.g., a square made of small circles), and be cued to identify either the global or local shape on different trials. Colzato, Van Leeuwen, Van Den Wildenberg, and Hommel (2010) used this task switching task to compare the cognitive-control abilities of AVGPs against that of NVGPs. While there was no significant group difference for overall reaction times, AVGPs reacted faster on trials that required them to switch to the alternate task. This same basic finding of action game-related advantages in task switching has been observed by a number of independent laboratories and indeed, is among the most consistently replicated findings in the field (Cain, Landau, & Shimamura, 2012; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Strobach, Frensch, & Schubert, 2012).

Another key aspect of cognitive control is dual-tasking/multitasking (i.e., wherein participants are given multiple tasks to perform at overlapping points in time, as opposed to in sequence as in task-switching paradigms). For example, Strobach et al. (2012) employed a dual-task measure wherein participants responded as quickly as possible to both a visual and an auditory stimulus that were offset from each other by a variable temporal delay (where shorter offsets make it more difficult to quickly perform the second task).

In both correlational and intervention designs, action gaming was shown to result in improved performance on this dual-tasking skill.

Practical Outcomes

The broad positive effects induced by action video game play have led many investigators to translate this research into practical applications. One such application has been to incorporate action video game training into treatment of individuals with amblyopia (colloquially termed "lazy eye"). This is a visual disorder wherein the brain disregards information from one, otherwise functional eye (usually due to issues such as strabismus or cataracts during early childhood). Previous research had struggled to produce effective treatments for adults with amblyopia; however, Li, Ngo, Nguyen, and Levi (2011) found significant improvements in visual acuity, and in some cases stereovision, in adult amblyopia trained on an action video game (note while the control group trained on a nonaction game also showed improvements, these effects were not as large). In addition to rehabilitation, action games have also been utilized in the training of both pilots and laparoscopic surgeons (McKinley, McIntire, & Funke, 2011; Schlickum, Hedman, Enochsson, Kjellin, & Felländer-Tsai, 2009).

Areas Where Little or No Improvements Have Been Observed

Action games lead to strong benefits in a large number of cognitive and perceptual areas. However, it is important to note that action games are not a panacea, and there are some cognitive domains where little to no evidence of improvement is found. For instance, exogenous attention (i.e., attention that is naturally drawn to salient stimuli such as flashes of light) has consistently failed to show change in response to action video game experience (Castel, Pratt, & Drummond, 2005; Dye, Green, & Bavelier, 2009b; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). This situation may reflect that this ability is at least partially subserved by less plastic subcortical brain regions, as compared to the more plastic cortical regions that underlie most of the selective attention/cognitive control abilities discussed previously. Furthermore, while there is not a great deal of research on the topic to date, it appears that those cognitive abilities that are not heavily utilized within action games, for instance, verbal cognition and fluid reasoning, are also not enhanced via action gaming (again speaking to idea that it is the nature of the experience that drives changes in cognitive function).

BRIEF REVIEW OF THE PERCEPTUAL AND COGNITIVE EFFECTS OF ACTION VIDEO GAMES IN CHILDREN

Genre Unspecific Studies From the 1990s and Early 2000s

Much of the early research on the cognitive effects of video games on children did not separate out the effects of different genres of video games and instead lumped all "gamers" together into a single group. For instance, Kuhlman and Beitel (1991) sorted a sample of 105 7- to 9-year-old children into three groups: non-, moderate-, and highly-experienced video game players. The experimenters found a main effect in their measure of interest, which was a coincidence anticipation task (i.e., a task that measures participants' ability to respond in rhythm with a dynamic stimulus), with highly experienced gamers outperforming nongamers. They also found an interaction between video game experience and gender, wherein female nongamers performed significantly worse than male nongamers, but there was no significant difference between female gamers and male gamers (an effect that was echoed in later work in action games—Feng, Spence, & Pratt, 2007). Along similar lines, Yuji (1996) separated a sample of 4- to 6-year-olds into video game playing and nonvideo game playing groups based on their responses to a simple 10-question survey of their possession of, and enthusiasm toward computer games. Children who were classified as video game players were found to have faster reaction times, with no loss in accuracy, than children classified as nonvideo game players.

While the two studies described previously are both correlational in nature, there is also some work from this time period that employed causal methods. For instance, Subrahmanyam and Greenfield (1994) split a cohort of 61 fifth graders (10.5–11.5 years old) into an action gaming, and a control gaming group. The action group was trained over three sessions with the video game *Marble Madness*, whereas the control group was trained on a simple word game. The authors found that *Marble Madness* training led to greater improvements between pretest and posttest in the outcome measures of spatial performance, with individuals with initially poor spatial skills showing the greatest improvements. Along similar lines, De Lisi and Wolford (2002) trained a group of 8- to 9-year-old students on either the video game *Tetris* (which is not an action video game, but was predicted to improve mental rotation ability), or the video game *Where in the World Is Carmen Sandiego* (as an entertainment-matched control game). Students in each group had equivalent mental rotation ability at pretest, but at posttest, students in the *Tetris* group performed significantly better, with the largest effect among female participants who had below-median performance at pretest.

Action Video Game Correlational Studies in Children

Because of the various ethical (e.g., action games are often violent) and logistical (e.g., fewer children have access to action video games than adults) issues, the majority of the research on action games specifically has been conducted using young adult participants. However, there is still a reasonable body of research on the effects of action video games on children and youth.

Trick, Jaspers-Fayer, and Sethi (2005) conducted one of the earliest studies examining the relationship between modern action video game experience and cognitive abilities in youth populations. In a correlational design, they compared performance in different groups of children on an MOT task. As is common in cognitive measures of younger children, the experimental task was "dressed up" in a gamified form so as to better hold the interest of the young participants. In the case of the MOT task, the gamification consisted of having participants track "spies" that disguised themselves in a crowd of "happy faces." as opposed to the adult version where colored target dots changed their color to appear indistinguishable from distractor dots. This study utilized five age groups (6, 8, 10, 12, 19), split between action video game players, action-sports players (i.e., players of real-life sports such as hockey or soccer), and nonaction players. For each age group, action game players were found to perform significantly better than nonplayers on the MOT task (with action-sports player performance lying in between those two groups).

Subsequent correlational studies found similar results wherein youth in age groups of 7–10, 11–13, 14–17, and 18–22 years old were tested on a variety of cognitive measures, and performance was compared between AVGPs and NVGPs within each age group. One such study (Dye et al., 2009b) utilized the Attentional Network Test (ANT), a commonly used task that provides reliable measurements on three components of attention: alerting, orienting, and executive control. This computerized task typically presents subjects with a row of arrows either above or below a fixation cross in the center of the screen, and the subject is tasked with indicating the direction of the central arrows. The arrows flanking the central arrow are either congruent (point in the same direction) or incongruent (pointing in the opposite direction), with the difference in reaction time between these two types of trials providing a measure of executive control/attentional spillover (see Dye et al., 2009b for additional discussion of this measure). Additionally, on some trials, the onset of the arrows is preceded by a cue that either alerts subjects to the upcoming presentation of the arrow (alerting network), or to the upcoming location of the arrow on the screen (orienting network). Similar to the modified MOT task above, the version of the ANT employed in this study was designed with fish pointing right or left, rather than arrows, so as to be more child friendly. Across all measures, action video game players were faster than nonaction players, without a concomitant decrease in accuracy. For the specific attentional networks, action gamers in each group exhibited greater benefits from orienting cues, and possessed increased attentional resources that spilled over to incongruent cues. No, difference in performance resulted from alerting cues, suggesting that some attentional networks are more susceptible to action game-related effects than others.

Another experiment, utilizing the same age groups as those described in the experiment above, found an advantage for action gaming in three different measures of cognitive skill described previously (Dye & Bavelier, 2010). In the Useful Field of View task, AVGPs in each age group had lower thresholds than their NVGP counterparts, whereby they could accurately identify the location of the target with a shorter presentation interval. In the attentional blink task, AVGPs were found to have smaller "blinks," whereby they needed less time for their attention to recover. In the MOT test, AVGPs in each age group were able to accurately track more objects than NVGPs, suggestive of a greater attentional capacity.

Along similar lines, researchers in Saudi Arabia recruited 156 children (mean age 9.2 years), and categorized them as either AVGPs or NVGPs based on the reported gameplay from both the children and their parents. Action gamers performed significantly better in numerous cognitive measures, including measures of spatial working memory, attention, and response inhibition (Al-Gabbani, Morgan, & Eyre, 2014). Of additional interest was that the fairly large sample size allowed the investigators to run a separate analysis of just the female participants, and found that the effect of action gaming remained.

Experimental Studies

Although most action games have a degree of violence that makes them unacceptable for training studies involving children, several groups have circumvented this issue by employing custom-made research video games. One such study by Rueda, Rothbart, McCandliss, Saccomanno, and Posner (2005) modified a training program previously used to train macaques for space travel into a gamified series of computer tasks, designed to tap various cognitive and executive functions. Over the course of five training days, children completed 9 or 10 different exercises that consisted of controlling or interacting with different objects or animals (e.g., observing a duck diving into a pond and, based on its trajectory, estimating where it would surface, or responding as fast as possible to sheep, while inhibiting responses if the sheep turned into wolves). This experiment employed a large battery of pretest/posttest measures. Although many of the group comparisons were not significant, significant differences were found in intelligence measures of 4-year-olds in the training group, and a marginally significant intelligence advantage for 6-year-olds in the training group.

Another intervention study conducted by Mackey, Hill, Stone, and Bunge (2011), enrolled children ages 7–10, from low SES backgrounds. Children were assigned to one of two active training programs, a program designed to improve speed of processing, and a training group designed to improve reasoning and relational thinking. In sixteen 60-min sessions, both groups were trained with a variety of computerized (commercial video games on a computer and on a Nintendo DS) and noncomputerized games, selected by experimenters to tap the underlying skills of interest. Researchers were present during the training to provide encouragement and increase the difficulty level of the training games when appropriate. Both training groups saw improvements in the targeted skills, with the speed of processing group showing improvements in the cognitive speed tasks, but not the reasoning tasks. The reasoning group showed improvements in a test of nonverbal intelligence (TONI), with an average increase of 10 points in IQ, but no improvements in the cognitive speed tasks.

Practical Applications

In an example of a study that combined theoretical and translational work, Franceschini et al. (2013) examined the impact of action-game training on both standard attentional skills (of the type described previously) and on reading ability in a cohort of dyslexic children. As is standard in such studies, half of the children were assigned to train on an action game, while the other half were assigned to train on a control game. In a particularly clever twist though, both the action and control games were created from the same global "game"—*Rayman's Raving Rabbids*. The global *Rayman's Raving Rabbids* game contains a number of smaller "mini-games." The authors thus selected a subset of the mini-games that contained a great deal of action (i.e., the games had many quickly/unpredictably moving targets, high perceptual load, an emphasis on peripheral processing) for the action group to train on and selected a different subset of mini-games, that contained no action, for the control group to train on. After 12 h of training, those children trained on the action games showed improved visual attentional skills (replicating the standard effect seen in the field), and significantly improved reading ability, as compared to the controls. These reading improvements appeared to have been driven by increased reading speed, without any concomitant decrease in accuracy. A follow-up test 2 months after completion of the study suggested that the results had persisted.

Possible Negative Effects

While the research on action video games has tended to find either beneficial or in some cases, null effects across age groups, there has been some, broader level research that has found negative correlations between global video game use (i.e., not separated by genre) and attention. For instance, Swing, Gentile, Anderson, and Walsh (2010) tracked self- and parent-reported video game use, as well as teacher-reported attentional problems, of third, fourth and fifth graders over the course of 13 months. For each age group, controlling for gender, they found significant correlations between reported video game use and teacher-reported attentional problems. Importantly, these effects remained significant across time when controlling for previous attention problems (i.e., video game use at the first time point predicted attention problems at the final time point, independent of attention problems at the first time point). However, because this study was focused at the superordinate level of "video games," it remains difficult to discern what types of games may have been responsible for these correlations.

IMPACT OF OTHER EMERGING MEDIA INTERACTIONS

Whereas over the past two decades cognitive psychology research on the impact of technology has tended to focus on media such as video games and television, in recent years other forms of human-technology interactions have become of increasing interest. For instance, the phenomenon of media multitasking, wherein an individual engages with multiple media simultaneously (e.g., monitoring multiple browser windows on one's computer while also partially attending to one's phone, and listening to music in the background), has received growing scientific attention since the first major investigation into its effects was published in 2009 by Ophir, Nass, and Wagner. In their seminal study (Ophir, Nass, & Wagner, 2009), a comprehensive survey of media multitasking behavior was created, wherein participants are asked how often they engage with 11 different media types each week (e.g., listening to music or web browsing) as well as how often they use each type of media concurrently with each other type (e.g., listening to music while web browsing). This information was used to compute the media multitasking index (MMI). Ophir and colleagues administered their survey to a large body of Stanford undergraduates, and based on the results of that survey, separated students into two groups: (1) heavy media multitaskers (HMMs), consisting of individuals whose MMI scores were one standard deviation above the group mean and (2) light media multitaskers (LMMs), consisting of individuals whose MMI scores were one standard deviation below the group mean. HMM and LMM participants were then invited into the lab to undergo a series of cognitive tasks. HMMs were found to perform significantly worse than LMMs on numerous measures of attentional control, primarily on conditions that required effective filtering of distracting stimuli. Since this seminal investigation, numerous follow-up studies have found similar associations between excessive media multitasking and impaired attentional control (e.g., Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Gorman & Green, 2016; Lottridge et al., 2015; but see also Alzahabi & Becker, 2013; Minear, Brasher, McCurdy, Lewis, & Younggren, 2013).

Although there is, as of yet, little direct work on this phenomenon in young children, there is good reason to think that the general behavior is common among younger age groups. A 2009 survey by the Kaiser Family Foundation found that 8- to 18-year-olds spent on average over 10 h with media each day, with 29% of that time spent using more than one media type at once (Rideout, Foehr, & Roberts, 2010). In perhaps the most comprehensive examination of the effects of media multitasking on youth to date, Cain, Center, Leonard, Gabrieli, and Finn (2016) measured the media multitasking tendencies of a group of 12- to 16-year-olds, and administered a large battery of cognitive tests and personality measures, in addition to collecting the statewide standardized testing scores of these participants. Higher media multitasking scores were related to lower working memory capacity, as measured by both a count span and an N-back task. Media multitasking was also negatively related to academic performance (i.e., lower math and English test scores). Finally, media multitasking was negatively related to a measure of growth mindset (the belief that one's intelligence is malleable) and positively related to self-reported impulsivity. Notably, media multitasking was not related to certain other measures, such as speed of processing, manual dexterity, conscientiousness, and grit.

Another study examining the relationship between media multitasking and cognitive functioning in youth found a significant correlation between media multitasking and distractibility during a sentence congruency judgment task. This distractibility was associated with increased right prefrontal cortex activation during the task. As this brain region is thought to be associated with top-down attentional control, greater activation may be indicative of heavy media multitaskers needing to "work harder"' when performing certain cognitive tasks (Moisala et al., 2016). Consistent with this view, youth media multitasking has also been found to correlate with self-reported attentional problems (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; though note that not all studies have seen negative effects—Lui & Wong, 2012).

TECHNOLOGICAL INTERVENTIONS DESIGNED FOR IMPROVING COGNITION IN YOUTH

The success of action video games at engendering general cognitive improvements has spurred many investigators to design their own custom-made training programs, often in the form of standard psychological tasks (such as those described previously) dressed up with some sort of reward structure and a leveling system (often referred to as "gamification"). However, this type of gamification has proven to be a more difficult task than one may have thought at the outset. For instance, Katz, Jaeggi, Buschkuehl, Stegman, and Shah (2014) created a training game (based on an N-back working memory task) with five distinct motivational elements: real-time scoring, theme changes, prizes, end of session certificates, scaffolding to explain lives, and a leveling system. They examined the effects of these elements on eighth grade students by employing (1) a version with all five elements, (2) a version with none of the elements, and (3) five other versions which each removed a single motivational element. The results demonstrated no positive effect of any of the gamification elements (in fact, the effects were negative). The authors suggested that this impaired performance resulted from the motivational elements distracting subjects from the task at hand.

In a more successful example of gamifying a training task in a training-transfer experiment, Jaeggi, Buschkuehl, Jonides, and Shah (2011) created a graphically rich working memory task with dynamic themes and engaging background stories linked to the themes. Importantly, the vocabulary and knowledge control training task was also dressed up in such a manner. Elementary and middle school children trained on this task showed improved fluid intelligence scores, compared to children trained on the control task. The observed gains in fluid intelligence were far larger in that half of the sample comprising participants whose performance improved the most at the working memory training task; the effect of training persisted even when accounting for baseline ability. The children who improved the most at the training task were those who rated the training task as challenging, without being overwhelming, suggesting that optimal task difficulty may be critical for producing transfer.

This data, in combination with numerous similar studies performed on adults (Melby-Lervåg & Hulme, 2013; Redick et al., 2013) ostensibly suggests that, while progress has been made, we are not yet at the point where we can reliably and effectively translate what we know about commercial games (such as action games) in to the realm of dedicated cognitive training programs.

ISSUES GOING FORWARD

Dynamic Game Genres

The research on the genre-specific effects of certain types of video games is quickly becoming complicated by the fact that the formerly reliable boundaries between many game genres have slowly begun to dissolve. Indeed, while it was previously the case that the fast-paced, attentional-demanding mechanics of action game were unique to that genre, these mechanics are now also being incorporated into a number of genres that traditionally were not considered "action" genres. These include role playing games (i.e., *The Elder Scrolls: Skyrim*) and adventure games (i.e., *Assassins Creed: Syndicate*). Action-based mechanics can now also be found in the newer genre of real time strategy and multiplayer online battle arena games (i.e., *StarCraft* and *League of Legends*). The fact that an ever-growing number of games include "action" components, combined with the fact that video game use among teens and young adults is now greater than 90%, means that it is increasingly difficult to find participants who qualify as "nonaction game players."

Complex Mixtures of Media Effects

As described earlier, action video game experience has been both associated with, and causally related to improved perceptual and cognitive abilities, whereas media multitasking behavior has been repeatedly associated with impaired cognitive abilities. Few researchers have examined these effects in conjunction with each other. However, the research that does exist suggests that the combined effects are nonlinear in nature. For example, Cardoso-Leite et al. (2016) replicated the base effects of both the action gaming and media-multitasking literatures, wherein action gamers performed better than nongamers, and heavy media multitaskers performed worse than light media multitaskers on diverse cognitive measurements. However, the positive effects of action video game experience were only found among intermediate media multitaskers, with heavy and light media multitaskers who were also action video gamers showing no advantage. This pattern of results may not have been obvious a priori, as one may have assumed that the beneficial effects of action games would have been sufficient to overcome the typically deleterious relationship between media multitasking and cognitive ability. The pattern also strongly suggests that it will be critical for researchers in both domains to measure participant experience with gaming and media multitasking.

Other Ethical Obstacles in Children

Thus far we have discussed only a few of the ethical issues inherent in training children with video games (e.g., as related to violence). However, while the violence issue is potentially solvable (i.e., by creating/utilizing nonviolent action games), another effect—known as the displacement effect—may not be. In essence, the displacement effect refers to the simple idea that any time spent on one activity (such as playing a video game) is time not spent on another activity (such as reading or doing school-work). Weis and Cerankosky (2010) attempted to examine this issue by first recruiting families who intended to purchase a video game system for their children in the future. The researchers then offered to purchase the video game system for the family in return for participation of the child in the study. Half of the children were randomly assigned to receive their video game system right away, while the other half received the system 4 months later. The children who received their video game system immediately were found to have weaker reading and writing skills at a posttest assessment, as compared to the other group, a difference that the authors attributed to the presence of the video game system. Thus, any future training studies in children need to ensure that the intervention is not displacing what are potentially more valuable activities.

CONCLUSIONS

As video games become increasingly popular, the importance of understanding their impact has increased as well. A key conclusion of this research has been that the genre of the video game is what matters when one examines the consequences of frequent play. Within the domain of cognitive psychology, the measurable effects of action video games in particular have tended to be positive for both children and adults. This research has already had some success in the translational sphere (i.e., as applied to amblyopia and dyslexia treatment, as well as training for pilots and surgeons). However, the research to date also suggests that translating what is known about action games to produce dedicated cognitive training tools will not be a trivial endeavor.

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