

CHAPTER 8: VIDEO GAMES AND COGNITIVE PERFORMANCE

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Abstract

Video games have consistently been shown to influence a wide variety of perceptual and cognitive processes, such as low-level visual abilities, selective attention, speed of processing, and high-level executive functions. Importantly, not only are these effects significant in the laboratory, but they are of a scope and scale sufficient to be utilized in real-world applications. The purpose of this chapter is to explore the numerous benefits of video game training to general cognitive functioning, as well as the practical applications of this training, in order to highlight the cognitive enhancements that can be obtained from regularly playing certain video games.

The human brain is an exceptional learning machine. Given appropriate training – including sufficient training time, proper spacing of training sessions, and useful feedback – humans will tend to show improvements on essentially any perceptual or motor task. However, the gains in performance seen as a result of training are very often highly specific to the exact training task and do not extend to untrained tasks or functions¹. For example, in one classic demonstration of the specificity of perceptual learning, participants were presented with two vertically oriented lines – one above the other². On different trials, the line on top was displaced very slightly either to the left or to the right relative to the line on the bottom. The participants' task was simply to indicate the direction of the displacement. With extensive practice on the task, participants' performance improved substantially (i.e., they were able to discriminate finer and finer displacements). However, when a seemingly minor change was made to the display (it was rotated by 90 degrees such that the two lines were oriented horizontally), participant performance returned to baseline levels, indicating that none of the learning benefits gained during the initial vertical training transferred to the horizontal condition^{2,3}. This general finding of task specific perceptual learning has been observed repeatedly over the past three decades, not just for stimulus orientation, but also for myriad other stimulus and task characteristics such as position, spatial frequency, motion direction, motion speed, and even the eye of training.

While the issue of learning specificity has perhaps been most thoroughly documented in the domain of perceptual learning, it is certainly not isolated to this domain. Indeed, task specific learning has also proven to be one of the major obstacles in the domain of cognitive training, where many paradigms designed to more generally “train the brain” instead appear to lead to improvements primarily on the training tasks themselves (e.g.,⁴⁻⁷). Even in more complex physical activities, such as clay pigeon shooting⁸, baseball⁹, or tennis¹⁰, changes have

primarily been observed in only those sub-tasks utilized in the activity. For example, following baseball training, changes were observed in Go/NoGo reaction time tasks, which use the same processes that are used when deciding whether or not to swing at a pitch in baseball, but there were no changes found for simpler reaction time tasks.

From a rehabilitative standpoint, the tendency toward learning specificity is a severe hindrance, as it is necessarily the case that in order to be of practical use, the effects of training need to extend *beyond* the strict parameters of the trained task. Interestingly, one intervention that *does* appear to lead to more generalizable improvements in cognitive performance involves an experience that was not originally designed for practical ends – video game training. Video games have consistently been shown to result in global transfer to a variety of perceptual and cognitive measures, from those that tap low-level visual abilities, all the way up to task switching and high level decision-making. Critically, not only are these effects “statistically significant” in the laboratory, but they are of a scope and scale sufficient to be utilized in practical, real-world applications. The remainder of this chapter will explore the benefits of playing video games.

EARLY VIDEO GAME RESEARCH

Specific scientific investigations of the potential effects of video games began to take off in the early 1980s (perhaps not surprisingly, at virtually the same time that the societal popularity of video games began to rise steeply). This early research focused primarily on hand-eye coordination and spatial skills. For instance, Griffith and colleagues¹¹ examined whether regular video game players, in this case broadly defined as individuals who played 2-59 hours of any video game per week, had better hand-eye coordination than non-video game players. They also found that individuals who regularly played video games had enhanced performance on a rotary

pursuit task (keeping a wand in contact with a moving dot) as compared to non-players, suggesting that there is an association between video game play and cognitive abilities.

As will become evident throughout the chapter, much of the work on the effects of video games has employed this type of cross-sectional design, which takes advantage of the fact that some individuals freely choose to engage in substantial amounts of video game play, while others play little to no games. One major issue with this type of research, though, is the well-known axiom that correlation cannot be used to imply causation. Thus, in the case of cross-sectional data on video games, one cannot determine whether the act of playing the video games actually caused the observed improvements, or if, instead, individuals who have innately high levels of ability are drawn to video games. To adjudicate between these possibilities, a well-controlled experiment must be employed. Here, individuals who do not naturally play the video games of interest are specifically trained on those video games over a period of hours, weeks, or months and laboratory measures of perception, cognition, and/or motor skill are compared before and after the training to see the effect of the training. In this vein, Gagnon¹² had a group of participants play two different video games for 5 hours: a 2D game called *Targ*, and a 3D game called *Battlezone*. Spatial abilities (rotation and visualization) were assessed before and after the training. Consistent with the causal hypothesis, playing these games for just 5 hours was associated with improvements in scores on the spatial tasks as well as in hand-eye coordination. Similar results were later observed throughout the 1980s and 1990s using different video games, assessing different populations (e.g., younger children^{13,14}), and examining different abilities (e.g., divided attention¹⁵ or mental rotation^{16,17}).

Together this early research provided strong support for the idea that video game play has the capacity to broadly influence perceptual, cognitive, and motor skills. It also provided the

framework around which later work was built, from issues related to methodology (e.g., cross-sectional versus experimental methods), to theory (e.g., the relationship between demands of certain games and their cognitive effects).

EFFECTS OF ACTION VIDEO GAMES

While clearly building on the early research, the research that has taken place over the past fifteen years has also been strongly shaped by changes in the video game industry. As technology has advanced, the graphics, game mechanics, and overall sophistication of video games has rapidly improved. Furthermore, as more and more games were developed, a number of distinct game genres emerged. One such genre, the action video game (AVG) genre, includes games that rapidly present players with an ever-changing, complex array of information across a wide visual field. Players usually need to make quick and accurate decisions and responses in order to stay alive or reach a mission objective, and successful players must possess well-developed skills in a variety of cognitive domains such as selective attention, working memory, task-switching, and inhibitory control¹⁸. Many AVGs use the first-person shooter format (such as in popular series like *Halo*, *Call of Duty*, and *Medal of Honor*), but certain sports and adventure games are considered to be “action” based as well (see Spence & Feng¹⁹ for a systematic description of the characteristics of AVGs). The extreme perceptual, cognitive, and motoric demands of this specific genre have thus made it the focus of the majority of the work in the field. Indeed, there are now numerous documented benefits of playing AVGs to all aspects of cognition, from very low-level visual and attentional processes, to high-level executive functions.

Visual Perception. Action video game experience has been consistently associated with improvements in the ability to utilize low-level visual features of stimuli. For instance, the contrast sensitivity function (CSF) represents the ability to distinguish between slight differences in contrast, or shading, across a uniform background²⁰, and is commonly regarded as one of the foundational elements of vision. In Li et al²⁰ expert action video game players (AVGPs), individuals who reported having played AVGs for at least 5 hours per week for at least the previous 6 months, were compared to non-action video game players (NVGPs) on a standard contrast sensitivity task. The AVGPs were found to have significantly better contrast sensitivity as compared to NVGPs, meaning that AVGPs were able to distinguish finer changes in gray level than NVGPs.

As discussed earlier though, the cross-sectional approach leaves open the question of causation. Thus, in a second experiment, action game novices were trained on either an action video game (*Unreal Championship* and *Call of Duty 2*) or a control video game (*The Sims 2*) for 50 hours spaced over the course of many weeks. The control group in such experiments serves a number of distinct purposes. First, the control acts as a control against simple test-retest effects. Experimental training designs involve a pre-test phase, a training phase, and post-test phase. Because the goal is to be able to attribute changes in performance from pre-test to post-test to the intervention, one must first know if there is a simple benefit from taking the test twice. Second, the group acts as a control against various more subtle participant reactivity effects such as the Hawthorne effect, wherein performance can improve simply due to being observed. As such, the control video game in these experiments is chosen to eliminate a number of reactivity-type confounds (e.g., it is chosen to be as engaging and interesting as the experimental game, to lead to an equal amount of identification with the character, to induce a similar degree of flow, etc.).

Consistent with the causal hypothesis, a dramatic improvement in contrast sensitivity (43-58%) was observed in those individuals trained on the action video game, and this improvement was larger than what was found in the control group. Other low-level visual benefits of AVGP experience have been observed for tasks involving simple peripheral perimetry²¹ and dot motion perception²², and in terms of basic perceptual processing speed²³.

Furthermore, although video games are commonly associated primarily with the visual system, the perceptual benefits of AVG experience are not limited to the visual domain. Donohue, Woldorff, and Mitroff²⁴ examined the ability of AVGPs and NVGPs to perform simultaneity and temporal-order tasks in both the visual and auditory modalities, and found that AVGPs outperformed NVGPs in both. Similarly, Green, Pouget, and Bavelier²⁵ examined perceptual decision making in both the visual and auditory domains, and again found that AVGPs outperformed NVGPs in both (with a causal relationship observed in a 50-hour training study).

Recent research has suggested that the mechanistic change underlying the improved performance across perceptual tasks is in the ability to learn perceptual templates for the task at hand²⁶. In other words, AVG experience leads to an enhanced ability to detect what low-level stimulus characteristics are most discriminative for the task at hand, and to utilize this information to make effective decisions.

Attention. A number of attentional processes are also influenced by action gaming. For instance, many studies have now shown clear enhancements in spatial selective attention. Although there are many tasks in the psychological literature that tap spatial selective attention, one common measure in the action video game literature is the Useful Field of View (UFOV) task. In the UFOV task, participants view a briefly presented (e.g., 20 milliseconds) display that

contains both a central target and a peripheral target (see Figure 1). The peripheral target can appear at three different eccentricities (10, 20, 30 degrees) from the center of the screen.

Following stimulus presentation, a strong pattern mask is presented to eliminate afterimages.

Participants respond by first indicating the identity of the central target and then the location of the peripheral target. AVGPs have consistently been shown to perform this task more accurately than NVGPs at all eccentricities^{18,27-30}, with similar results found in NVGPs specifically trained on action games^{18,27,29}.

Similar results have been seen in many other tasks where task-relevant information needs to be selected from amongst distracting information across space. For instance, performance on crowding tasks is thought to offer a measure of the spatial resolution of visual selective attention. In these tasks, individuals are asked to identify a briefly displayed peripheral target (e.g., determine whether a T shape is presented right side up or upside down) that is presented in the presence of distracting shapes. When the distracting shapes are presented far from the target, performance is usually quite good, but when the distracting shapes are presented close to the target, performance decreases significantly. Thus, the distance between the target and the distractors at which an individual can perform the task at a criterion level of performance offers a measure of the “crowding region”. Green and Bavelier³¹ found that this crowding region is significantly smaller both in AVGPs, and in individuals specifically trained on AVGs, as compared to NVGPs, meaning that AVG experience allows for more effective spatial filtering of distractors.

Finally, several studies have reported enhanced performance in AVGPs in more standard visual search tasks³²⁻³⁴. In these tasks, individuals are asked to find a specific target (e.g., either the letter ‘b’ or the letter ‘d’) from amongst a field of distracting letters. When the target is

presented alongside only a few distractors, participants find the target rapidly. As more and more distracting elements are added, search times increase reasonably linearly. The slope of this increase can thus be taken as a measure of the speed of visual attentional processes. In Hubert-Wallander et al.³², the slope of the search function was shallower in AVGPs (i.e., reaction time increased less steeply with each additional distractor added) than in NVGPs, suggesting either more efficient distractor suppression, or overall faster speed of processing.

Beyond spatial selection, the benefits of AVG experience have also been reliably seen in attention across time. Green and Bavelier¹⁸, for example, examined the effects of AVG experience on the attentional blink (AB) task. In the AB, stimuli are rapidly presented one at a time in the center of a computer screen. Participants are asked to detect/identify two targets from within this stream of stimuli. In the typical AB task, when the two targets are presented temporally close (within ~500ms of each other), accuracy for detecting/identifying the second of the two targets is markedly decreased as compared to longer target separations. This task is thought to reflect a fundamental temporal limitation of selective attention³⁵. In the Green and Bavelier¹⁸ study, while NVGPs showed a typical attentional blink effect, the AVGPs had a much smaller attentional blink effect (with several of the AVGPs having no attentional blink at all). This suggests that the AVGPs either had more processing resources available, or were able to process items more quickly, thus avoiding the typical attentional bottleneck that occurs in this task. A similar effect was found when NVGPs were trained on AVGs, such that individuals who trained on an action game showed a reduction in their AB, whereas those who trained with a puzzle game showed no such benefit. As was true of spatial selective attention, the general finding of enhanced temporal attention has been reproduced in young children²³, and using a

number of other tasks including other rapid serial visual presentation tasks³⁶, and in measures of backward masking^{20,37}.

A final aspect of visual attention that appears to be enhanced by AVG experience is attentional capacity. For example, individuals who play AVGs have also been shown to perform better on tasks in which they are required to monitor and track multiple objects within a display (e.g., the multiple object tracking task - MOT). Trick, Jaspers-Fayer, and Sethi³⁸ presented children from 5 different age groups (6, 8, 10, 12, and 19 years) with a MOT task called “Catch the Spies” in which they were required to track between 1 and 4 “spies” who were trying to blend in with a crowd. Interestingly, after controlling for age, they found a significant increase in the number of objects tracked by children who played AVGs as compared to sports video game players and non-gamers. Similar results have been observed in a different cohort of children²⁸ as well in adult populations^{27,39}, although only Green and Bavelier²⁷ showed a significant effect in a dedicated training experiment.

Memory. A number of memory processes have also been shown to be associated with playing action video games. For example, visual short-term memory (VSTM) has been shown to differ between AVGPs and NVGPs. Boot et al.³⁹ examined differences in AVGPs and NVGPs on a VSTM task originally developed by Luck and Vogel⁴⁰. In this task, participants are presented with a display of colored bars for 100ms, followed by a 900ms blank, and then another display of bars. The second display of bars can either be identical to the first display, or else one of the individual bars can be changed (either its color or its orientation). Participants are asked to determine whether or not the first and second displays were identical. Boot et al.³⁹ found that AVGPs were significantly better on this task as compared to NVGPs, indicating that they had superior memory performance. This same effect in AVGPs and NVGPs was also seen in

McDermott et al.⁴¹. However, it is worth noting that in Boot et al.³⁹, individuals specifically trained on action video games did not show similar benefits. It is also the case that no effects of action gaming have been seen in either extremely short (i.e., iconic) or long-term memory^{42,43}.

While the above tasks mainly involved simple retention, working memory tasks require both retention and manipulation. One could argue that this is a better match to the demands of AVGs, which commonly require players to not only remember multiple items at a time, but also to be able to continuously and fluidly update what information is being remembered. Using this logic, Colzato, van den Wildenberg, Zmirgrod, and Hommel⁴⁴ recruited 26 AVGPs and 26 NVGPs, and examined their performance on an N-back working memory task. In the N-back task, participants are presented with a series of digits or letters one after another. They are asked to press one key if the current letter is the same as that which was presented N-items earlier. For instance, in a 2-back task, if participants had seen the following letters: A, D, F, G, H, G, K, L, M, L, they would have been expected to answer “yes” on the 6th letter (G – which is the same as the 4th letter) and on the 10th letter (L – which is the same as the 8th letter). This task thus clearly requires that participants monitor and continually update their working memory stores. As expected, the AVGPs were more accurate on the task than NVGPs, suggesting that video game play is associated with the development of a flexible working memory that actively updates and clears irrelevant information from the memory store. However, a similar study found that while AVGPs were faster on the N-back task as compared to NVGPs, they were no more accurate⁴¹; a finding similar to that obtained by Boot et al.³⁹ who used an operation span task. As such, it is currently unclear how video games influence working memory capacity, but there is at least the suggestion that action gamers perform differently from non-gamers. This an area that requires

further investigation, particularly given the current interest in video games as a rehabilitative tool for elderly individuals, many of whom suffer working memory decline in old age.

Executive Functions. Lastly, a number of higher order executive functions have been shown to be influenced by action video game training. “Executive functions”, also known as “cognitive control”, is an umbrella term that describes a collection of high-level cognitive abilities, all of which are goal-oriented, and under top-down, effortful control. For example, planning, inhibitory control, and task switching are all classified as executive functions.

The ability to flexibly change from one task to the next in a rapid manner is vital when playing fast-paced, complex action games, and is one of the most important aspects of cognitive control. Colzato, van Leeuwen, van den Wildenberg, and Hommel⁴⁵ first investigated whether regular AVGPs would differ from NVGPs on a task-switching paradigm (see Figure 2).

Participants completed a global/local task in which large, global shapes that were comprised of smaller, local shapes were presented on the screen, and participants were asked to respond to the identity of either the overall global shape (e.g., a square made of small circles) or the local elements that comprised the global shape (e.g., the small circles that make up the large square). Participants alternated between 4 global and 4 local blocks, and received cues when they were required to switch the level at which they were responding. While AVGPs did not have faster reaction times overall as compared to NVGPs, they showed reduced reaction time costs following the task switch, demonstrating that they more efficient at switching sets during the task. This finding has since been replicated and extended by using more complex tasks that require goal switches or vocal responses⁴⁶, although it should be noted that this effect disappears when proactive interference on the task is increased by including three possible tasks and rapidly alternating between them⁴⁷. As has been true in other domains, the causal role of action video

games in enhanced task-switching performance has been shown in a number of training studies^{46,48,49}; an effect that appears to be modulated by genetic polymorphisms related to dopamine degradation⁵⁰. In addition to task-switching performance, AVGPs have also been shown to perform better on measures of general multitasking ability^{51,52} (although see Donohue, James, Eslick, and Mitroff⁵³).

There is also suggestion that video games may have an influence on inhibitory control. Oei and Patterson⁴⁸ trained NVGPs on one of four video games, and assessed performance on a variety of measures before and after training. One of the measures was a Go/NoGo task in which participants are required to make rapid button presses in response to stimuli presented on the screen on the vast majority of trials, but on a subset of trials participants are required to withhold responding. Withholding a prepotent response requires immense cognitive effort and control, thus this task is a classic measure of inhibitory mechanisms. In this particular task, a false alarm rate (number of times they incorrectly responded on “withhold” trials) is calculated, and higher false alarms are indicative of poorer inhibitory control. Interestingly, they found that only the participants who played the complex action puzzle game showed improvements in their Go/NoGo performance following training, such that they had a reduction in their false alarm rate. Similar benefits in inhibitory control have been seen when comparing AVGP and NVGP participants on the Test of Variables of Attention, which is a test commonly used in the clinical diagnosis of ADHD²³.

Higher-level visual imagery seems to be affected by AVG experience as well. For instance, in a standard mental rotation task, participants are presented with one test item and four probes. One of the probes is an identical copy of the test item that has been rotated. The other three are mirror images of the test item that have been rotated. The participants’ task is to

determine which of the four probes is the same as the test item. Typically, males perform better than females on this spatial imagery task, and performance on this task is associated with general spatial abilities²⁹. However, training on an action video game can not only result in significant improvements in rotation speed/ability, but game training has also been shown to partially reduce the gender disparity on this task (in that females showed greater benefits of the action video game training than did males)²⁹.

Lastly, there is evidence that video games may help improve problem-solving abilities. Shute, Ventura, and Ke⁵⁴ trained participants on an interactive puzzle/action game called *Portal 2*, and examined performance on a number of cognitive measures before and after training. They found that participants who received video game training had higher scores on a number of problem solving measures.

PRACTICAL APPLICATIONS

Although most publications in the academic domain of training and transfer center on the question of whether effects are “statistically significant”, practical applications demand that the effects are of a size that allows real-world benefits to be realized. Because the effects of action video games are reasonably large, several groups have attempted to utilize these off-the-shelf games to produce real-world impact. These attempts can be loosely organized into two areas – rehabilitation and job-related training.

Rehabilitation

Interventions for Elderly Adults. As we age, we begin to show decrements in key cognitive abilities such as visuo-spatial attention, speed of processing, multitasking, and memory⁵⁵. These decreases in cognitive functioning can lead to a number of difficulties in

everyday functioning leading to a loss of independence, impairments in mood and subjective well-being, and can generally decrease the quality of life in the elderly⁵⁶. Interestingly, recent studies have demonstrated that video game play may aid in preserving, and even enhancing, cognitive function in the elderly.

In a landmark study, Anguera et al.⁵¹ trained older adults (age 60-85) for 12 hours (3 hours a week for 4 weeks) on an action video game that was developed to enhance multitasking abilities (*NeuroRacer*). They found that, as compared to controls (who showed no improvement over the course of the experiment), individuals who trained on the action version of the game performed better on measures of multitasking following training. Interestingly, they also showed improvements in sustained attention and working memory despite not being specifically trained in these abilities. Critically, these training effects persisted for at least 6 months post-training, demonstrating that video game training can result in cognitive enhancements in a variety of domains that endures long after the training has concluded⁵¹. Related studies have shown that playing a visual speed of processing game resulted in a slowing of age-related decline, and enhancements in both cognitive functioning and subjective well-being⁵⁷ (see also Torres⁵⁸). Outside of the specific action genre, more general video game play has also been shown to lead to improvements in self-reported health and quality of life^{59,60}, and elderly participants who regularly play video games have been shown to have higher levels of subjective well-being and positive affect, and lower levels of depression, as compared to non-gamers⁶¹. As such, video game play can have numerous benefits and can help stave off many of the negative effects of normal aging (see Toril et al.⁵⁶ for a review).

Amblyopia. Video games have also been shown to have applications toward the treatment of amblyopia. Amblyopia, which is colloquially referred to as “lazy eye”, is a vision

disorder that affects approximately 1-5% of the population⁶². This disorder typically first emerges in childhood, and results in reduced or blurry vision in the affected eye⁶³. Amblyopia is associated with a number of developmental visual issues such as congenital cataracts (deprivation amblyopia), misaligned eyes (strabismic amblyopia), or unequal refractive errors in the eyes due to, for example, astigmatism in one eye (anisometropic amblyopia)⁶³. In each case, the brain receives inconsistent input from the two eyes and thus, to some extent, comes to “ignore” the eye sending the poor quality information. Conventional treatment involves the use of eye patch therapy, the success of which is dependent on catching the disorder in early childhood⁶³. However, recent studies have demonstrated that amblyopia can be at least partially alleviated through the use of video game interventions, even in adults.

Early video game interventions for amblyopia utilized somewhat simple games such as *Pac Man* in order to both strengthen the weak eye, as well as to engage and entertain children during treatment⁶⁴. The premise of the treatment program was to stimulate and strengthen the amblyopic eye by presenting different images to the two eyes. For instance, in *Pac Man*, this may involve presenting the image of the Pac Man and the ghost enemies to one eye, and the image of the maze to the other eye. While traditional eye patch therapy often takes upwards of 400 hours to show improvements⁶³, the interactive binocular treatment method resulted in improvements after only 2 hours of treatment for 87% of the children tested. Similar results have since been found using the same technique with adults. For example, Li et al.⁶⁵ had adults with amblyopia play the puzzle game *Tetris* with either a monocular or binocular display. While both displays resulted in improvements to vision after two weeks of training, the binocular condition resulted in greater improvements. Interestingly, this same group also found that simply playing AVGs with the bad eye (patching the good eye) resulted in significant improvements in vision as

compared to the groups who either played no game (controls), or who played a non-action video game. In some cases, the improvements resulted in vision returning to normal levels (including stereoscopic depth perception). As such, playing video games, particularly AVGs, is potentially an efficient and powerful therapy for amblyopia.

Dyslexia. While the idea that AVGs could be used as a rehabilitative platform for a purely visual disorder such as amblyopia may not be overly surprising, recent research suggests that the benefits may extend to other disorders as well. For instance, Franceschini and colleagues⁶⁶ showed that having a group of dyslexic children play a commercially available video game, *Rayman Raving Rabbids*, resulted not only in improved visual and visual attentional skills, but actually improved reading abilities as well. While the mechanism underlying this effect is not currently known, the authors suggest that although dyslexia is classically considered to arise as a result of issues in the language system (e.g., issues with phonology or morphology), part of the deficit may also be visual in nature (in that the visual system is the “front end” of the reading system). They thus argue that the types of visual improvements seen as a result of action video game playing should percolate down to improvements in reading.

Job-skills.

Laparoscopic Surgeons. There are a number of occupations that involve substantial visuo-spatial demands for which action video games could be a potentially useful training tool. For instance, laparoscopic surgery is a minimally invasive type of surgery wherein both surgical instruments and a small camera are inserted into the patient and the surgeon manipulates the instruments by viewing them on a television screen⁶⁷. This type of surgery presents a number of unique visuo-spatial and visuo-motor challenges, particularly with respect to the ability to extrapolate the 2D television images to the 3D person on which the surgeon is

operating⁶⁷. Several studies have now shown a correlation between laparoscopic surgical skills and video game experience^{68,69} (see Ou, McGlone, Camm, & Khan⁷⁰ for a review). In fact, in one correlational study, video game experience was found to be a better predictor of positive surgical outcomes than measures one would have a priori predicted would be more pertinent (such as years of training⁶⁹). Furthermore, specific AVG training studies have demonstrated that training on AVGs results in better performance on laparoscopic simulators, indicating that the relationship is indeed causal⁶⁷ (Schlickum et al., 2009). Finally, video game skill seems to be predictive of future surgical ability, suggesting that video game scores could be a useful tool for identifying future surgeons⁶⁸.

Pilots. In addition to surgery, video games have also been shown to improve flying skills in novice pilots. In some of the earliest work on this topic, Gopher, Weil, and Bareket⁷¹ took a group of flight cadets and trained them on a video game called *Space Fortress*. This group received feedback and helpful tips during their training sessions. A second group played *Space Fortress* with no feedback, and a third group played no video games (control). Participants in the two training groups played for 10 1-hour sessions, and their flight skill performance was assessed before and after training. Both groups who played the video game had better flight performance following training, with the feedback group showing the largest improvements. Additionally, both groups performed better than the controls, demonstrating that performance on an action video game can transfer to actual flying skill. Another recent study showed that experienced AVGPs performed similarly to pilots on a task that required them to land an unmanned aircraft (drone), despite the AVGPs having no prior experience with aircraft or aircraft software⁷². Finally, AVGs have been shown to enhance performance on the multi-attribute task battery (MATB), which is a task that measures operator workload and performance

in airline pilots⁵². Together, these findings demonstrate the utility of video games in educational environments, and show that the skills that are developed when training in the complex, fast-paced environment of AVGs may transfer to many other professions, and have numerous real-world applications from training to personnel selection.

WHICH PROCESSES DO ACTION VIDEO GAMES NOT INFLUENCE?

It is apparent that playing video games, particularly AVGs, influences and enhances a number of cognitive processes from a variety of domains, and that existing action gamers differ in their cognitive abilities as compared to non-gamers. However, not all abilities appear to be equally changed via AVG experience. One domain in particular that one might have expected to be strongly influenced by AVG experience is exogenous attentional orienting. Important information in AVGs often appears briefly in the periphery, requiring an extremely fast orienting response. Thus, it would seem to follow that exogenous orienting should be associated with AVG experience. However, the literature on the effect of AVG experience on exogenous attentional orienting is decidedly mixed. Castel, Pratt, and Drummond³⁴ demonstrated that existing AVGPs were faster to respond to targets on a classic Posner spatial cueing paradigm as compared to NVGPs, but both groups showed a similar inhibition of return (IOR) effect. The same basic result was also observed by Hubert-Wallander and colleagues⁷³, as well as Dye and colleagues who observed no strong changes in either the orienting or alerting networks using the Attentional Network Task²³.

However, other studies have suggested that AVGPs *do* perform differently than NVGPs on tasks that involve exogenous orienting. For example, West, Stevens, and Pratt⁷⁴ had AVGPs and NVGPs complete an exogenous orienting task in which irrelevant exogenous cues were

presented, and the sensitivity of attentional orienting to these cues was assessed. Interestingly, they found that AVGPs were more sensitive to the irrelevant exogenous cue, indicating that their attention was more easily captured by exogenous stimuli as compared to NVGPs. Conversely, a recent study used an anti-cueing task in which AVGPs and NVGPs were presented with a cue that appeared at the opposite location to a target⁷⁵. The critical measure was the eventual reaction time to the target. Interestingly, the AVGPs were faster on the task, indicating that they were *less* captured by the cue, suggesting that they had better control over exogenous attention⁷⁵. Two other studies showed similar results, such that AVGPs were better at overcoming distraction and capture by an irrelevant exogenous cue⁷⁶, and showed fewer saccades to irrelevant stimuli with a sudden onset⁷⁷, as compared to NVGPs. Together, these results indicate that playing AVGs may be associated with differences in exogenous orienting, although it is unclear whether gamers are more or less sensitive to exogenous cues (or whether the mixed results are due to some studies actually tapping substantial top-down processing demands, which are known to be enhanced via video game training, rather than bottom-up exogenous orienting alone).

WHAT MAKES ACTION VIDEO GAMES A POTENT TRAINING TOOL?

Video games, particularly AVGs, have a clear influence on a variety of cognitive processes, and have been shown to have numerous implications for practical, real-world training and rehabilitation practices. Unlike many cognitive interventions, video games appear to have unique properties that allow them to induce general transfer across a wide variety of cognitive abilities. What is it about video games, and AVGs in particular, that makes them such an effective training tool? Many video games, of course, are complex and simultaneously tax a number of cognitive abilities, which likely leads to many of the training effects that we see.

However, there are a number of other unique factors that may contribute to their utility as a training program. This section will briefly touch upon some of these factors (see Bavelier, Green, Pouget, & Schrater⁷⁸ for a more in-depth review).

First, unlike many cognitive training programs or laboratory tasks which tend to be dull and tedious, video games are fun, engaging, and rewarding⁷⁹. Indeed, there is numerous evidence to demonstrate that reward circuits in the brain are stimulated, and striatal dopamine released, during video game play⁸⁰, and that this stimulation is the direct result of task engagement⁸¹. Interestingly, these neural responses are stronger when playing another human being, rather than playing against the computer^{82,83}, suggesting that games containing a strong social component (i.e., most action games) are more rewarding than solitary games (i.e., most puzzle games). Activities that are more engaging and rewarding have long been shown to lead to better learning^{84,85}, thus it follows that AVGs should result in more learning and transfer than more sterile and less engaging laboratory tasks.

Second, video games are dynamic, with constantly changing landscapes, puzzles, challenges, and goals. Difficulty on these games gradually increases in most cases, but also tends to fluctuate such that some missions/matches/competitions are easier than others. Interestingly, this variety in practice has been shown to increase the probability that a skill will transfer to a new task⁸⁶⁻⁸⁸. In addition, because of the complexity and rich storyline of action games, people have a tendency to play the game steadily over the course of several weeks or months (i.e., utilize distributed practice). Several studies have demonstrated that distributed practice, in which trials are divided over several days or hours, leads to better learning and transfer⁸⁹⁻⁹¹. As such, the very nature of action games may lead to practice behaviors that are particularly conducive to learning and transfer.

Third, it has recently been suggested that video game play may lead to many of the benefits we see because individuals engage in “learning to learn” (see Bavelier et al.⁷⁸ for a review). The basic idea of learning to learn is that individuals develop a set of dynamic tools and rules that they can then apply to a variety of scenarios or tasks in order to learn faster^{92,93}. Bavelier et al.⁷⁸ suggest that when individuals play AVGs, they learn a number of general strategies, probabilistic rules, and models that can then be applied to a variety of different tasks, so long as those tasks share some overlap with AVGs. Generally, because video games are more complex, engaging, and demanding than many training paradigms, they seem to lead to more generalized benefits.

TOWARD THE FUTURE

The finding that video games, particularly AVGs, influence cognition is fairly well substantiated, but more research is needed to understand the precise mechanisms by which video game play affects cognitive change, and to better understand why some cognitive abilities are influenced while others are not. One area in particular that has been largely underrepresented is the study of game genres other than the action genre, such as real-time strategy games (RTS; e.g., *StarCraft II* or *League of Legends*), role-playing games (RPG; e.g., *World of Warcraft* or *Final Fantasy*), and turn-based strategy games (TBS; e.g., *Hearthstone* or *Pokémon*). Indeed, many studies only classify action/first-person shooters as VGPs, and will (perhaps erroneously) classify both non-gamers and gamers of these other genres as NVGPs. However, there is emerging evidence that genres other than action games can influence cognitive performance.

For example, Glass, Maddox, and Love⁹⁴ showed that NVGPs who were trained on the RTS game *StarCraft II* performed better on a global measure of cognitive flexibility after

training as compared to controls who trained on the simulation game *The Sims*. Similarly, older adults who trained for 23.5 hours on the RTS game *Rise of Nations* showed significantly greater improvements as compared to controls on measures of working memory, task-switching, VSTM, and mental rotation⁹⁵. This demonstrates that RTS games may have a similar impact on cognitive performance as action video games.

A study by Wu and Spence³³ provided participants with 10 hours of training on either a first-person shooter game (*Medal of Honor: Pacific Assault*), a driving game (*Need for Speed: Most Wanted*), or a 3-D puzzle game (*Ballance*), and examined performance before and after training on a visual search task. Both the first-person shooter and driving groups showed significantly improved scores on the visual search task following training, but did not differ from each other. The puzzle group did not show any improvements, however, thus demonstrating that a game must be fast-paced in order to lead to improvements.

Finally, Oei and Patterson⁹⁶ trained participants for 20 hours on one of five different mini-games (action, spatial memory, matching, hidden object, and a life simulation game). Performance on a battery of cognitive tasks was measured before and after training, and while they found that the group who played the action game improved their scores on measures of cognitive control and verbal span, the other four groups also showed improvements in visual search and working memory. Taken together, these findings suggest that it is essential that the field move away from a purely genre-based classification scheme (e.g., where first-person shooter games and RTS games are placed in different categories) and toward a classification scheme that takes into account the perceptual and cognitive demands of the games.

Conclusion

To summarize, playing video games, particularly AVGs, has been shown to benefit performance on a variety of cognitive tasks and paradigms. After only a few hours of playing commercially available video games, individuals have shown global improvements in perception, attention, memory, and executive functioning, and existing gamers have been shown to possess superior cognitive abilities as compared to non-gamers. These findings have numerous real-world applications, from rehabilitation to job-related training. While not all cognitive abilities are similarly affected, there is enough evidence of cognitive enhancement to encourage the development and use of video games both for fun, and for increased cognitive wellbeing.

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Figure Captions

Figure 1. A) Typical Useful Field of View trial. Participants fixate centrally, and are then presented with a display that contains a central target (i.e., the smiley face), a peripheral target (i.e., the star), and distractors (the white circles). After a variable duration (~20 ms), the display is covered by a noise or pattern mask. Then, participants are presented with a display that contains 8 spokes, and are asked to both indicate the identity of the central target, and on which of the 8 spokes the peripheral target had appeared. **B)** UFOV data adapted from Green & Bavelier (2003). Accuracy on the UFOV task (% correct) is compared before (Pre) and after (Post) training for individuals trained on an action game (Action) or on a puzzle game (Control). Only the Action group showed a statistically significant improvement in their accuracy on this task following training.

Figure 2. A) A typical task-switching paradigm. On each trial, participants are presented with a letter/digit pair, and are asked to either classify the letter as a vowel or consonant, or classify the digit as odd or even, by pressing a key with their left or right hand. Critically, participants receive two letter classification trials followed by two digit classification trials, and their response time is recorded. Performance is measured by comparing response time on task-repeating trials to response time on task-switching trials in order to obtain an index of switch costs. **B)** Data adapted from Strobach, Frensch, & Schubert (2012). Switch costs are compared before (Pre) and after (Post) training for individuals trained on an action game (Action) or on a puzzle game (Control). Only the Action group showed a statistically significant decrease in their switch costs on this task following training.

Figure 1. Useful Field of View

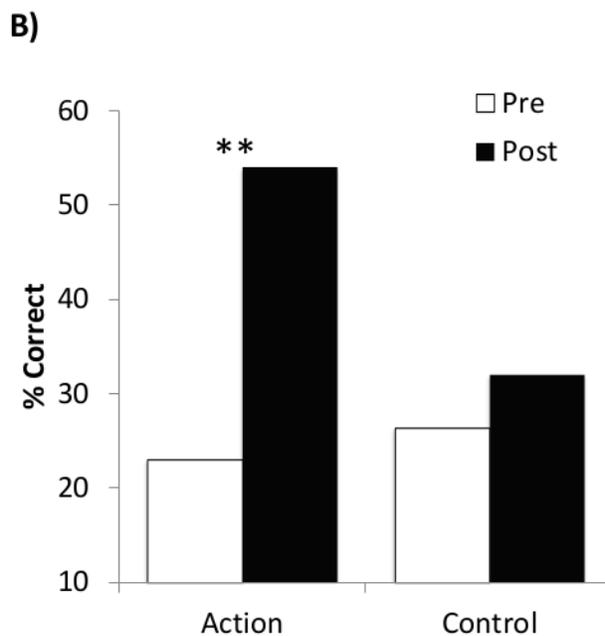
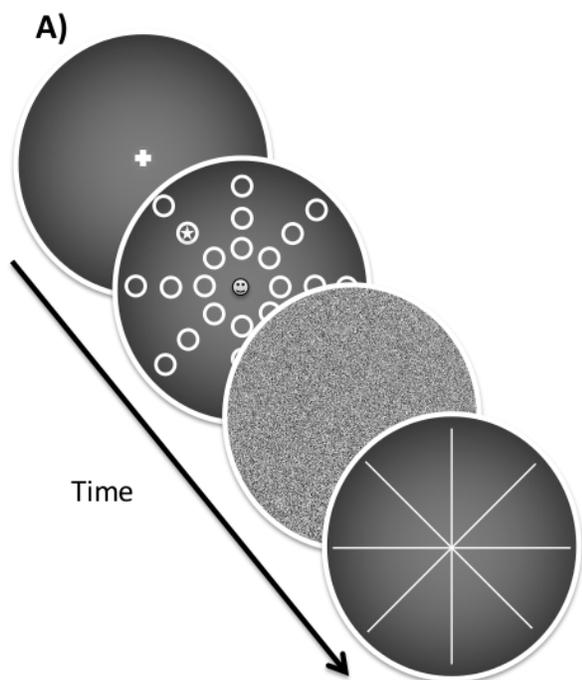


Figure 2. Task Switching

