Action Video-Game Training and Its Effects on Perception and Attentional Control

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Introduction

Over the past 40 years, video game play has grown from a niche activity into a pervasive and abundant part of modern life. Over half of the United States population now plays video games, with over 130 million of these individuals being considered "regular" video game players (i.e., playing more than 3 h of video games per week—ESA 2015). And although video games were originally, and for the most part continue to be, an *entertainment* medium, there has nonetheless been significant scientific interest in the possibility that video gaming may have significant effects on the human brain and human behavior. While much of this research has focused on potential negative outcomes (e.g., effects related to aggression or addiction—Anderson et al. 2010), there exists a growing body of research outlining positive effects of video game play as well. This chapter will specifically focus on the positive impact that playing one particular type of video game, known as "action video games," has on perceptual and attentional skills.

The "Curse of Specificity"

Before discussing the various effects associated with action video game play, it is worth considering why it is interesting in the first place that something like video game play could alter core perceptual or attentional abilities. Indeed, one's first

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intuition might be that, "Many video games place extreme demands on the perceptual and attentional systems—wouldn't it make sense that playing these games would lead to such benefits?". Interestingly though, such an intuition runs counter to the effects seen in many classic perceptual training experiments, wherein individuals were trained by repeatedly practicing a single perceptual task. It is certainly the case that, when given appropriate training, humans will tend to improve their performance on most tasks. However, it is typically the case that these improvements fail to generalize to new contexts or situations. For instance, in one classic experiment, participants were trained to identify two complex visual gratings. Although participants quickly learned this task, when seemingly minor changes were made to the experimental setup (e.g., doubling or halving the spatial frequency), participants returned to chance levels of performance and had to learn the task under the new set of conditions from scratch (Fiorentini and Berardi 1980). This type of failure to generalize learning has been an extremely common finding in the perceptual and cognitive domains (Sagi 2011). There has thus been extreme interest in recent findings that several types of experience—including the focus of this review, action video game training—appear to overcome the tendency toward task-specific learning and instead promote more general enhancements in behavioral performance.

"Action" Video Games

One common theme that has linked essentially all of the research that has been conducted on the effects of video games over the past several decades is that the content of the games is key. Playing "video games" does not increase empathy and pro-social behaviors; playing video games that contain specific types of pro-social content increases empathy and pro-social behaviors. Similarly, playing "video games" does not increase aggressive thoughts; playing video games that contain specific types of antisocial content increases aggressive thoughts (Anderson et al. 2010). In the study of perceptual and attentional skills, the content that has been of most interest is what has been dubbed "action" content.

Action video games have a number of properties that together distinguish this genre from other types of video games. These include extreme temporal processing demands (e.g., items that move exceptionally quickly or that pop in and out of view); the requirement to strongly attend to task-relevant items near the center of the screen while also monitoring a large field of view (as important targets usually first present themselves at the edges of the screen); substantial amounts of visual clutter (thus putting the ability to select task-relevant information and reject task-irrelevant information at a premium); complex motor response demands, and considerable perceptual and cognitive load (e.g. many independently moving items to track; many distinct plans to evaluate and select amongst; for a more thorough discussion, see Spence and Feng 2010). First-person shooters (e.g., Call of Duty) and third-person shooters (e.g., Gears of War) are common subgenres that involve this set of characteristics, but the action genre as it is commonly defined in the field also includes certain car-driving games as well as various newer hybrid genres such as 'action-role-playing games' (e.g., Skyrim) and 'action-adventure games' (e.g., Grand Theft Auto). The empirical findings that we will discuss below are specifically related to these types of games and not other types of games.

Studying the Effects of Action Video Games

In discussing the impact of action gaming, it is critical to note how studies are conducted in this domain and how the design of the study impacts the types of inferences that can be made (see also Green et al. 2014). In particular, the mass popularity of video games allows for cross-sectional approaches to be utilized in addition to pure experimental methods. Indeed, cross-sectional approaches—wherein the behavioral performance of individuals who play substantial amounts of action video games (often labeled "action video game players" or "AVGPs") is contrasted against the behavioral performance of individuals who do little gaming ("non-video game players" or "NVGPs")—are undoubtedly the most common study design in the field. Such studies have the advantage that participants with clearly defined and different types of experience can be recruited, and thus potential differences in behavior can be quickly evaluated. The clear disadvantage though is that such studies, like all correlational approaches, cannot be used to draw causal inferences. After all, if one observes that AVGPs greatly outperform NVGPs on a test of visual acuity, there is no way to determine if this reflects an effect of game experience or if instead individuals born with better acuity tend to gravitate toward action video games. Thus, in order to demonstrate a causal relationship, long-term intervention studies must be performed wherein a group of NVGPs is first selected and pretested on the behavioral measure(s) of interest. The participants are then randomly assigned to play either an action video game or a control video game (that is chosen to match the action game in dimensions such as identification with character, sense of learning/achievement, etc.) for anywhere from 10 to 50 h depending on the study. Critically, this training must be distributed over the course of many days/weeks as video game training, like essentially all learning, is far less efficient when it is highly massed over time (e.g., 5 four-hour long sessions) as compared to when it is distributed over time (e.g., 20 one-hour long sessions) (Stafford and Dewar 2014). Finally, at least 24 h after the last gaming session, participants are tested again on the measure(s) of interest. A causal relationship between action video game training and enhanced abilities is indicated by a significantly greater gain from pre- to post-test in the action-trained group than the control-trained group.

Effects of Action Video Games on Perceptual Skills

Vision: Action video game playing has been repeatedly linked to augmented performance in perceptual tasks. For example, one of the most fundamental aspects of vision is contrast sensitivity—the ability to detect differences in luminance in adjacent parts of the visual world (as changes in luminance frequently demarcate important parts of the scene, such as object boundaries). In cross-sectional work, AVGPs have been seen to have enhanced contrast sensitivity as compared to NVGPs (i.e., AVGPs could detect finer differences in luminance than NVGPs; Li et al. 2009). The same study also established a causal relationship between action video game play and enhanced contrast sensitivity via a 50-h intervention study wherein NVGPs trained on an action video game showed significantly greater improvements in contrast sensitivity than NVGPs trained on a nonaction video game.

In cross-sectional work, researchers have also observed enhancements in a number of basic aspects of peripheral vision. For instance, AVGPs have been shown to perform better than NVGPs in the Goldmann visual perimetry test (Buckley et al. 2010). Here individuals sit in front of a large white bowl that encompasses the majority of their visual field. Small lights are turned on at random locations throughout the field, and the individual must indicate whenever a light is observed. AVGPs have also been shown to have enhancements in peripheral acuity (i.e., visual resolution—an eye chart measures the same ability in the central visual field) as compared to NVGPs (Green and Bavelier 2007) as well as enhancements in certain types of motion processing (Hutchinson and Stocks 2013).

Speed of Processing: A number of papers have demonstrated that AVGPs show increases in speed of processing. For example, Dye and colleagues (2009) utilized what is known as the "Brinley plot" technique to examine this issue. Here, AVGP reaction times on a wide variety of tasks (from experiments run by several independent labs) were plotted against NVGP reaction times on the same tasks. AVGPs were found to respond approximately 12 % faster than NVGPs across all of the tasks considered, without any change in accuracy (i.e., the effect could not be attributed to a simple speed-accuracy tradeoff). A similar finding was seen when examining just those studies from the literature employing intervention studies (i.e., testing the causal link).

More recently, several groups have examined this question experimentally via the framework of the theory of visual attention (TVA). This framework allows researchers to segregate performance into a number of distinct aspects (e.g., related to basic perceptual thresholds, speed of processing, short-term memory storage capacity, top-down attentional control). Specifically, using this framework, Wilms and colleagues (2013) found that AVGPs showed a specific enhancement in the speed with which visual information is transmitted to short-term memory. Schubert and colleagues (2015) also observed greater speed of processing in AVGPs as compared to NVGPs (restricted to the lower visual field in their case) as well as heighted perceptual thresholds in AVGPs. However, no changes in these aspects were noted in NVGP participants trained on an action video game (as compared to NVGPs trained on a control video game), leaving the causal link still in question.

Perceptual Decision-Making: There is also evidence that action video game playing increases the efficiency of making perceptual decisions—in other words, the ability to accumulate perceptual information over time in the service of a particular decision, for example, as when having to decide in which direction a school of fish may be swimming. This phenomenon has been observed both in a cross-sectional work contrasting AVGPs and NVGPs and in a long-term (50 h) intervention study

(Green et al. 2010; although see Van Ravenzwaaij et al. 2014). Along similar lines, recent work suggests that the superior performance seen by action gamers in perceptual tasks is driven by an enhanced ability to generate perceptual templates of the task at hand (Bejjanki et al. 2014).

Multisensory Integration: While most of the research examining changes in perceptual processing as a function of action video game play has focused on the visual domain, some effects have also been observed in experiments requiring multisensory processing. For example, Donohue et al. (2010) found that when individuals were presented with visual and auditory information sequentially (e.g., either the visual stimulus first and then the auditory stimulus or the auditory stimulus first and then the visual stimulus), AVGPs were better able to distinguish the correct temporal order. This finding indicates a relationship may exist between action video game play and multisensory processing, although intervention studies are still needed.

Effects of Action Video Games on Attentional Control

Many of the largest and most consistently observed benefits of action video game play have been in attentional control tasks. These are tasks that require selecting and enhancing the processing gain of task-relevant items while ignoring/reducing the processing gain of task-irrelevant information. Here we divide the effects into spatial attention (i.e., as is needed when task-relevant and task-irrelevant information is presented simultaneously on different parts of the screen), temporal attention (i.e., as is needed when task-relevant and task-irrelevant information is presented on the screen at different times), and attentional capacity (i.e., the maximum number of items that can be attended); for effects of action video games on higher-level executive functioning, see Strobach and Schubert this volume.

Spatial Selective Attention: Action video games have been linked with many enhancements in spatial visual attention. For instance, one task commonly believed to assess the spatial resolution of visual attention is the crowding task. Here a peripheral target must be identified when spatially surrounded by distracting items. Green and Bavelier (2007) found that AVGPs showed enhanced performance in such a crowding task as compared to NVGPs (i.e., AVGPs could identify targets even when the distracting items were placed very close to the targets). The causal effect of the action gaming was confirmed via a 30-h intervention study.

Other common measures of spatial selective attention include various visual search tasks. For instance, in the Useful Field of View task, participants must locate a peripheral target (presented either 10°, 20°, or 30° from fixation) from amongst a field of distracting objects. Enhanced performance on this task has been consistently observed in AVGPs as compared to NVGPs, and several different groups have demonstrated a causal link via intervention studies (Dye and Bavelier 2010; Feng et al. 2007; Green and Bavelier 2003). Similar results have been observed in other spatial selective attention designs (West et al. 2008). Advantages have also been noted in standard visual search tasks. Specifically, AVGPs are less effected by increasing numbers of distractors when searching for hard-to-find targets than NVGPs (Hubert-Wallander et al. 2011).

Temporal Selective Attention: In addition to space, action gaming appears to also enhance the ability to attend to stimuli selectively across time. This ability is commonly measured with the attentional blink task. In one version of the attentional blink task, participants view a series of rapidly presented black letters. At some point in the stream, one white letter is presented. At the end of the stream, the participant will be asked to indicate the identity of this letter. Additionally, 50 % of the time, a black "X" is presented at a point after the white letter. The participant is thus also asked to indicate whether or not an "X" appeared after identifying the white letter. When these two targets are presented within around 400 ms of each other, participants have difficulty detecting the second of the two targets (i.e., the "X"). Thus, the presence of the initial target is said to have caused attention to blink. As time between the targets increases, accuracy in attending to the second target also increases. Playing action video games has been repeatedly associated with a reduction in the duration of this blink, both in cross-sectional and in intervention studies (Dye and Bavelier 2010; Green and Bavelier 2003). Similar results have been observed in various other measures requiring precision in temporal attention, such as in temporal masking tasks (Li et al. 2010; Pohl et al. 2014)—wherein the presence of distracting items presented either just before or just after a stimulus (at nearby, but not spatially overlapping locations) adversely affects target identification. Specifically, AVGPs showed a reduction in the extent to which such masking effects were observed as compared to NVGPs.

Attentional Capacity: Finally, the capacity of visual attention has been shown to increase as a result of action video gaming. One measure of attentional capacity, the multiple-object tracking (MOT) paradigm, requires individuals to track several moving distinctive targets (e.g., red dots) amongst a field of moving distractors (e.g., green dots). After a few seconds, the red dots change to become the green dots, meaning that the targets must be tracked despite being visually indistinguishable from the distractors. Enhancements in multiple-object tracking tasks have been seen in AVGPs as compared to NVGPs (Dye and Bavelier 2010), and a causal relationship has been established via an intervention study (Green and Bavelier 2006). The same study found an AVGP advantage in an enumeration task, which measures the ability to quickly and accurately report the number of briefly flashed items in a display.

Possible Neural Bases of Action Video Game Effects

While the vast majority of work in this domain has been behavioral in nature, a few recent publications have started to examine the underlying neural changes that may subserve the observed behavioral changes. For example, Mishra et al. (2011) examined EEG activity related to processing of task-relevant and task-irrelevant information as a function of action game experience. Interestingly, while both AVGPs and

NVGPs showed enhancements in processing the information relevant to the task (i.e., as would be consistent with increases in gain), the AVGPs' brain activity showed greater suppression of activity related to task-irrelevant information as compared to the NVGPs. Furthermore, the degree of suppression was well-correlated with differences in behavioral performance on the psychological task (where AVGPs again outperformed NVGPs), lending further support to the belief that improved ability to flexibly modulate neural gain is a key component of the neural basis of action video game-related improvements in attentional abilities. Several additional ERP and fMRI studies have also found a relationship between action gaming and changes in neural activity related to visuospatial selective attention (Bavelier et al. 2012a; Krishnan et al. 2013), including one intervention study (Wu et al. 2012).

Emerging Framework: Action Video Games and "Learning to Learn"

Work on action video game training, and indeed, cognitive training in general, has to date largely focused on the "immediate transfer" form of learning generalization. This is when training on some "Task A" results in immediate enhancements relative to expectations when first performing some new "Task B." We have recently suggested though that the broad benefits seen as a result of action video game play may not in fact reflect "immediate transfer" but may instead reflect what is known as "learning to learn" (Bavelier et al. 2012b). In learning to learn, training on some "Task A" may not produce any immediate benefits when first performing some new "Task B," but instead the training on "Task A" allows "Task B" to be learned more quickly than otherwise would have been the case.

As an illustrative example, consider a case where training on some "Task A" improves top-down attentional abilities in a truly general fashion. If, after this training, participants are then asked to perform a novel-shape categorization task (i.e., on each trial the participants are shown a novel shape that is drawn from one of two possible categories and they are asked to indicate the shape's category membership), no immediate transfer would be expected. Indeed, although their heightened top-down attentional abilities would allow the participants to extract more information from each novel shape that is presented, it does not provide them with information about the actual statistical structure indicative of category membership. This statistical structure must be learned via experience. The heightened attention though will allow the statistical structure to be learned more quickly by making better data available to the learning system.

Consistent with this theoretical framework, we have recently shown that AVGP and NVGP performance on a new visual discrimination task is initially very similar (i.e., within the first few trials—Bejjanki et al. (2014)). However, the AVGPs' performance on the task improved much more rapidly than the NVGP performance. Similar findings have also been obtained in a visuomotor task (Gozli et al. 2014).

Interestingly, many of the mechanisms believed to underlie action video game-based enhancements (e.g., heightened attentional control) are the same as those posited to occur via other forms of cognitive training. However, because generalization in these domains has only ever been evaluated in the traditional pretest/posttest manner (i.e., where performance is averaged over a single block of pretest trials and then compared to performance averaged over a single block of posttest trials), the extent to which "transfer" versus "learning to learn" is observed in these domains is as of yet unclear. Adjudicating between these possibilities would require a design wherein individuals undergo a full bout of learning on the generalization measures after training so as to be able to measure the time course with which the generalization measures are learned.

Potential Applications of Action Video Game Training

The broad benefits to perceptual and attentional control abilities induced by action video game play have led to a great deal of interest in potential practical applications of dedicated action video game training. For instance, research has shown that action video games may have the potential to improve the vision of individuals with amblyopia (colloquially known as "lazy eye"). This is of sizeable importance as previous research has suggested that it is difficult to improve amblyopic vision in adulthood via dedicated training. However, Li et al. (2011) demonstrated that training with either action video games or nonaction video games resulted in significant improvements in both acuity and, in many cases, stereovision (i.e., 3D) in adult amblyopes. Beyond rehabilitative purposes, several studies have also suggested that action video game training may result in useful benefits for individuals whose jobs involve demanding visual, visuomotor, or attentional demands. This includes both pilots and laparoscopic surgeons (McKinley et al. 2011; Schlickum et al. 2009).

Future Directions

One of the most important future directions in this domain is to begin to better understand the elements within action video games that are most responsible for the benefits to vision and visual attention at a mechanistic level. We know that essentially all commercially successful video games, including those in the action genre, share a set of characteristics that make them effective learning tools. These characteristics include mechanics such as providing intrinsic and extrinsic reinforcement, proper modulation of task difficulty, the use of active learning with immediate and informative feedback, engendering a beneficial level of physiological arousal, and providing substantial variety in experience. Because these characteristics are found in all commercially successful games though, they cannot be the key features that promote improved perception and visual attention (i.e., perhaps necessary, but not sufficient). By understanding the effects of games that fall outside of the classic "action genre" (i.e., real-time strategy games) that share some, but not all, components of action video games, we may be able to elucidate the critical game components needed to produce the desired improvements.

Conclusions

To summarize, there is now compelling evidence indicating that action video game play engenders clear enhancements in an array of perceptual, attentional, and cognitive skills. This evidence includes both a large number of cross-sectional studies and a number of well-controlled intervention studies that have indicated that the relationship between action game play and augmented performance is indeed causal. These findings hold the promise of numerous real-world applications, from rehabilitation of visual deficits to job-related training, but whether the results scale from lab measures to real-life remains to be firmly established.

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