The Cognitive Neuroscience of Video Games

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Introduction

The Atari video game platform was released in the late 1970's. Nintendo was born in the early 1980's. Since then, the percentage of Americans who play video games has grown at an astronomical pace. This explosion has been spurred on by advancements in both hardware technology and software development that allow a more intense and realistic gaming experience. In addition to these improvements in graphical capability, advances in online gaming now allow users to play with sometimes hundreds of others, which is slowly changing the perception of video game play from a solitary to a social activity. The Entertainment Software Association estimates that around 60% of Americans, around 145 million people in all, currently play some type of video game and despite the common view of video games being "for kids," the average age of a video game player is actually around 29 years old. Unsurprisingly, both popular and scientific interest in the potential consequences of game play has been driven by this dramatic surge in video game use. While the majority of research (and media attention) has focused on the potential for video game play to negatively affect temperament and social behavior, or on the potential to harness video games to help children learn, a subset of cognitive scientists have investigated the effect of video games on the more fundamental question of how people see the world.

In most of the biological sciences, the question of nature versus nurture is often debated. Researchers constantly strive to determine whether a certain skill arises from nature (is genetically based), nurture (is completely determined by experience), or as is usually the case, if the skill reflects a combination of nature and nurture. In cognitive science the relationship is often quite complex with the relative roles of nature and nurture interacting through development, with one playing a larger role in some developmental stages and vice versa. For example, humans require “normal” visual experience in infancy and throughout childhood to enjoy normal vision in adulthood. When infants are deprived of normal experience (by cataracts for instance), massive and permanent deficits may result. However, the same cataracts experienced later in life lead to no permanent deficits once removed. Thus, the effect of experience in this case is greatest in younger humans and grows progressively weaker through adulthood.

While there are myriad cases like this in which “less than normal” experience leads to deficits in perception and cognition, researchers that investigate the effect of video game play on perception and cognition ask a slightly different question – what is the effect of “more than normal” experience? To what extent are our perceptual systems constrained by genetics? One could argue that evolution is notoriously cost-effective and thus there is little impetus for our visual system to possess capabilities beyond those needed in our typical environment. On the other hand, in order for a species to be successful over an extended time span, they must be capable of adapting to changes in their environment. Therefore our question is simply, given an environment in which events happen faster, objects move more quickly, peripheral processing is placed at a premium, and the number of items that need to be kept track of far exceeds the circumstances experienced in normal life, is it possible to extend the normal processing power of the human nervous system? The astute reader will have instantly realized that there wouldn’t be a book chapter if the answer was no, and thus will not be surprised to find that in many areas of perception and cognition, video game experience leads gamers to possess perceptual and cognitive skills far beyond those observed in non-gamers.

The next obvious question relates to the practical significance of these enhanced perceptual capabilities. What are they good for? While it isn't difficult (or really even necessary) to convince a reader that changes in personality or socially adaptive behavior have obvious practical implications, it is somewhat more difficult to explain how reaction time differences on the order of a few tenths of milliseconds or increased processing of the far periphery could lead to measurable benefits in day-to-day living. The short answer to this concern is that the differences we are able to measure with sophisticated equipment in controlled laboratory settings may not have huge influences on the quality of day-to-day life for most humans (although for most of the psychological phenomena we describe we will nevertheless attempt to elucidate a real-life counterpart). However, there are several well-defined subsets of the population that could reap great benefit from such research. Of these, two in particular have been studied most extensively, these being: 1) populations that have experienced a deficit in perceptual processing and require a "boost" to recover normal vision (such as stroke victims or the elderly) and 2) populations that require "better than normal" perceptual capabilities (such as military personnel).

The perceptual and cognitive consequences of video game play

In a 1984 book chapter, Patricia Greenfield outlined many of the aspects of video games that could make them interesting in the study of perception and general cognition (Greenfield 1984). One of the more interesting aspects of this chapter, as is the case with most of the work from the 1980's, is that despite the fact that by today's standards many of the games described seem incredibly simplistic, they nevertheless led to measurable changes in behavior. We therefore encourage the readers when reading about a study examining the effect of simple games such as Pac Man or Space Fortress to consider what the effect may be for the much more demanding games of today or tomorrow?

In addition to the obvious point that spatial and sensory motor skills are at a premium in video games, Greenfield remarks that the level of cognitive complexity (in the case of Pac-Man discriminating among the different color "ghosts," learning their behavior and thus developing optimum strategies) was far beyond her expectations. She was therefore among the first researchers to suggest that perhaps video game play is not necessarily a "mindless" activity and that video games could be used to develop both visuo-motor and cognitive skills.

Although at the time of Greenfield's chapter there was little in the way of hard evidence demonstrating the perceptual, motor, or cognitive consequences of video game play, much progress was made throughout the decade in outlining some specific modifications in perception and motor processes as a result of video game play (Lowery and Knirk 1982; Griffith et al. 1983; Lintern and Kennedy 1984; Metalis 1985; Gagnon 1985; Dorval and Pepin 1986; Drew and Waters 1986; McClurg and Chaille 1987; Clark, Lanphear, and Riddick 1987; Orosy-Fildes and Allan 1989).

To a reader not familiar with the field of cognitive science, and more specifically with the field of perceptual learning, many of the studies that will be described will seem blatant in what they are testing and what we would expect to find in video game players. On the surface it seems distinctly intuitive that playing a video game would improve hand-eye coordination, or hasten reaction time, or benefit peripheral vision. However, one of the more enduring findings about visual learning is that training on one visual task rarely leads to improvement on anything other than the specific trained task (Fiorentini and Berardi 1980; Karni and Sagi 1991). For instance, if subjects are trained to discriminate between a straight vertical line and one tilted 1° off vertical, they will no doubt improve at that discrimination, but may not show any benefit when trying to discriminate a straight horizontal line and one tilted 1° off horizontal. There are cases where if subjects are trained in one part of the visual field, only this specific area shows a benefit, if subjects are trained with one eye, only that eye shows a benefit, etc. Such specificity of visual learning has been a major obstacle to the development of efficient rehabilitation methods for visually impaired individuals, such as amblyopes. In this context, it is actually quite surprising that playing a video game could affect such widespread aspects of vision and cognition as peripheral localization or the capacity of visual attention, let alone general cognitive ability (Drew and Waters 1986).

The effect of video games on reaction time and visuo-motor coordination

One of the first issues addressed by researchers investigating the effects of video games was the question of visuo-motor control. Anyone that has played a video game or seen someone play a video game realizes the premium put both on reaction time and hand-eye coordination. Many games require subjects to respond exceptionally quickly to new “enemies” (a monster that pops up out of nowhere that needs to be immediately dispatched for instance) and with many controllers having ten or more buttons, the ability to control one's hands in order to control a player on the screen is definitely emphasized as well.

In one of the earliest studies on the effects of video games, Griffith and colleagues examined the difference between video game users and non-users on a test of eye-hand coordination (Griffith et al. 1983). Using a rotary pursuit unit (essentially a wand), subjects were required to track a light stimulus that moved at various rates (from 1-50 rpm) and in different patterns (circular, square, and triangular). Video game users far outperformed their non-user counterparts on this task, particularly at high speeds, clearly demonstrating that video-game users have superior eye-hand coordination than non-users. However, the critical reader may have already had the intuition that despite the hypothesis that video game play is at the root of the effects in question, this particular experiment simply demonstrated a correlation between video game experience and superior eye-hand coordination. Given this data, another equally valid hypothesis could be that people with inherently better eye-hand coordination are drawn to play video games, whereas people with naturally poorer coordination tend not to play. In this case, the true causative factor would be heredity and not video game play. The only way to fully demonstrate causation in these cases is to train a random sample of non-gamers on a video game and measure changes in their performance. If non-gamers demonstrate similar improvements following video game training, one can infer the relationship between video game play and the effect in question is indeed causative. While this particular report did not include a training study, in general in this review we will tend to focus on studies that have included a training aspect in order to assure a causal role for video game play.

Another common measurement of visuo-motor skill is the simple reaction time. Orosy-Fildes and Allan (Orosy-Fildes and Allan 1989) performed a study in which 20 subjects were given a reaction time pretest (press a button when a light turns on). After the pretest, half of the subjects underwent a 15-minute practice treatment on an Atari 2600 video game system. All of the subjects were then post-tested on the reaction time test. Those that received the video game experience showed a reduction in reaction time of approximately 50 milliseconds not observed in the control group that received no game experience. Such a dramatic change after only 15 minutes of training is truly remarkable. Researchers have reported that the simple reaction time in children is also decreased by video game experience (Yuji 1996). Similar results will also be discussed in the elderly in a later section on practical implications of video game play (Drew and Waters 1986; Clark, Lanphear, and Riddick 1987).

So how could an increase in hand-eye coordination or a reduction in reaction time be beneficial in one's day-to-day life? Improvements in hand-eye coordination could be advantageous in a wide variety of professions that require manual labor, but a more obvious benefit of reduced reaction times is in braking in front of an obstacle while driving. Anyone that has ever had an animal cross directly in front of them while driving can attest that 50 milliseconds could make the difference between a hit and a miss.

The effect of video games on spatial skills

Another "obvious" potential change in video game users would be in the ability to gather and manipulate spatial information and many researchers have indeed examined the effects of video games on spatial skills (Lowery and Knirk 1982) (Sims and Mayer 2002).

Dorval and Pepin measured the ability to determine the three-dimensional structure of an object presented in two-dimensions and how the same object would appear if rotated in space (using the Space Relations Test of the Differential Aptitude Tests). They asked if scores on this test could be improved by training on the video game Zaxxon (Dorval and Pepin 1986). In Zaxxon, the player controls a spaceship in simulated three-dimensional space (Zaxxon was actually one of the few games at the time that simulated three-dimensionality) and attempts to shoot enemies and to avoid obstacles, while avoiding being shot by enemies. Subjects in the experimental group underwent 8 sessions of Zaxxon play, while a matched control group received no video game experience. Following training, the video game trained group showed significantly higher spatial skill scores than the control group indicating that spatial visualization is trainable with video game play. A study by Gagnon also reported comparable enhancements in measures of spatial skills in video game trainees (Gagnon 1985).

In a similar vein, McClurg and Chaille demonstrated that children trained on video games demonstrated improved scores on The Mental Rotations test (McClurg and Chaille 1987) and that younger children (5th graders) given video game experience performed better than older children (9th graders) without this experience. Thus, this seems to be a case wherein video game experience can trump the limits imposed by nature.

In 1994, Subrahmanyam and Greenfield performed another video game training study using children (Subrahmanyam and Greenfield 1994). Sixty-one 5th graders were first pretested on three tests of dynamic spatial skills. One such test required subjects to view three movies, each containing a small square moving across the screen. The trajectory of the square either in the first or in the third movie did not match that of the square in the second movie and subjects were required to report which movie did not match. Following the pretest, half of the children underwent three 45-minute sessions with the spatially demanding game Marble Madness while the other half played the word game Conjecture (control group). Following training, the children who received the Marble Madness training showed significant improvements over the control group.

Not all authors have observed significant effects of game playing on spatial skills. Sims and Mayer studied the effect of playing the game Tetris on mental rotation capabilities (Sims and Mayer 2002). While highly skilled Tetris players demonstrated better mental rotation skills than unskilled players, Tetris novices trained on Tetris did not show greater improvements than control subjects following training (both groups actually improved by a large amount). They therefore argued for a genetic difference between the skilled and unskilled Tetris players that lead to observed results.

This study not withstanding however, the improvements noted by the authors in this section have numerous potential practical implications. The most noteworthy is that many of the tests (the Spatial Relations Test of the DAT or the Guilford-Zimmerman Spatial Orientation Task) measure capabilities needed by many professions. For instance, the ability to infer the three-dimensional structure of an object from a two-dimensional representation is critical for architects and engineers. Performance in many other professions including pilots, mechanics, machine operators, and draftsmen could similarly be aided by increases in spatial skills (Gagnon 1985). Thus, video game play could play a real role in an individual's work performance in a number of professions.

The effect of video games on visual attention

In order to fully explain visual attention, we would likely require far more pages than contained in this entire book. However, the general idea is likely intuitive to most people. First, it is important to state that visual attention is relatively distinct from the concept of "attention," as in the ability to pay attention in class. At a very simple level, visual attention can be thought of as a "gate" to perception. There is far more visual information available to us than we are capable of processing, and thus visual attention is the mechanism through which some items are selected for further processing while others are left unnoticed. For instance, although you are currently reading this book chapter, there are other things you can "see." Perhaps a desk, a coffee cup, a chair, etc? Although they have physically been present the entire time, it is likely that while reading you don't really "notice" them. In this case the book chapter would be said to be the focus of visual attention and thus the other peripheral items were less or unattended. In all, the general take-home message is that when items are attended, they are generally processed more quickly, more efficiently, and to a greater degree than when items are left unattended. Thus one could argue that what really matters for human vision is not necessarily what a person can "see," but to what they can attend.

Another study by Greenfield and colleagues (Greenfield et al. 1994) demonstrated the effect of video games on the ability to divide and switch attention. In their study subjects were told they should press a button as soon as they saw a briefly flashed target stimulus. They were further told that the stimulus could only appear at two locations, A and B. They were also warned that on 80% of the trials it would appear at location A and would only appear 10% of the trials at location B (on the remaining 10% of trials the stimulus appeared on both sides). By manipulating the probability of occurrence at each location, subjects become biased to allocate more attention to the high probability location and less attention to the low probability location. Accordingly, subjects are generally faster to respond to high probability targets and much slower to respond to low probability targets, which is taken to reflect the difference in attentional allocation.

In an initial experiment, Greenfield and colleagues pitted expert video game players against non-players on this divided attention task (along with a control condition in which the stimulus appeared at each location equally often). First, replicating previous findings in the video game literature, video game players were found to have an overall faster reaction time than non-gamers. Also, as is consistently found in the attentional literature, they found that non-players responded faster to stimuli presented at the 80% location and slower to stimuli presented at the 10% location compared to their reaction times when the probabilities were equal (which represents an even division of attention). Interestingly, while the expert video game players showed a benefit (decreased reaction time) at the 80% location, their reaction time for the 10% location was the same as during the control condition. One item of particular note is that the video game players respond at least as fast, if not faster, in the 10% condition (the hardest condition) as do non-gamers in the 80% condition (the easiest condition). This finding indicates that the efficiency with which attention is divided is greatly increased in video game players. In a follow-up training study, a group trained on a video game showed a reduction in reaction time for the 10% location that was not seen in a control group, thus demonstrating the causative role video games play in the effect.

A real-world example of this type of task can again be seen in driving. It is usually the case while driving that the majority of attention should be allocated to the road ahead. However, this necessarily implies that items in the periphery will be processed less efficiently because they receive less attentional benefit. Video game players seem to show a dramatically reduced cost of divided attention and thus theoretically could be better at detecting peripheral items (for instance detecting a child chasing a ball toward the street) while driving.

In our own work, we have further attempted to characterize the aspects of visual attention that are modified by video game play. We have recently demonstrated that video game play enhances the overall capacity of the attentional system (the number of items that can be attended), the ability to effectively deploy attention over space, and the temporal resolution of attention (the efficiency with which attention acts over time). We tested video game players and non-players in several experiments, each of which was designed to tap one of these relatively distinct aspects of visual attention (Green and Bavelier 2003).

We measured the capacity of the visual system using the multiple object tracking paradigm (Pylyshyn and Storm 1988). This task measures the maximum number of moving items that can be successfully tracked within a field of distracting moving items. The number of items that can be tracked is thought to provide an index of the number of items that can be simultaneously attended and therefore of the capacity of the visual attentional system. Video game players were able to track approximately two more items than non-players, suggesting there is a definite increase in the number of objects that can be attended in video game players.

To assess the efficiency with which gamers and non-gamers distribute their attention over the visual field, we used a task initially developed to assess the driving fitness of elderly citizens. One interesting fact is that safe driving is not well correlated with visual acuity (the bottom line you can read on the eye-chart at the optometrist), but rather with the ability to successfully monitor a cluttered visual world. Therefore the designers of this task, the Useful Field of View task (UFOV), argue that rather than giving potential drivers an eye-chart test, a test such as the UFOV that evaluates the subjects' ability to deploy visual attention over the whole scene should be employed (Ball et al. 1988). In our version of the UFOV task, a subject is asked to localize a very briefly presented target (only 7 ms!) at eccentricities up to 30°. Again, video game players far outperformed non-players, even when distracting squares were added to the display. This establishes that video game players can more readily identify what they are looking for in a cluttered scene.

Finally, we measured the temporal resolution of visual attention by using the attentional blink paradigm. On each trial in this task subjects saw a stream of quickly presented black letters (presented one at a time for 100 ms each). They are told on each trial that a white letter will appear. At the end of the trial they will have to identify the white letter. They are also told that 50% of the time an 'X' will appear somewhere in the stream of letters after the white letter (anywhere from right after the white letter to 8 letters after the white letter). In addition to reporting the identity of the white letter, at the end of the trial they also need to say whether or not an 'X' was presented. For most subjects, when the ‘X’ is presented very close in time to the white letter it is often missed. The hypothesis for this is that because the subject is “busy” processing the identity of the white letter, they are unable to process any new information until they are finished. Therefore, if the ‘X’ appears while the subject is processing the white letter, it will be missed. Video game players show a much smaller “blink,” both in terms of duration and magnitude (the time during which gamers “miss” the target is shorter than non-gamers and even during this critical period gamers “miss” the target less often). This finding demonstrates that video game players can process a rapid stream of visual information with increased efficiency as compared to non-players.

We found similar results in each of the three paradigms in non-players trained on an action video game. After action game training, subjects improved their scores more than a group that played a control game. Therefore action video game play increases the efficiency with which attention is divided, enhances the spatial and temporal characteristics of attention, and leads to an overall increase in attentional resources.

The potential day-to-day benefits from these enhancements in visual attention are quite obvious. To use driving as an example once again, a driver that is able to monitor more objects at once, over a broader range of the visual field, with greater temporal resolution, is going to have information at their disposal that would allow them to be far safer drivers (although we will leave it for others to speculate whether changes in personality could potentially cancel out these benefits from vision).

How video games may change the brain

As cognitive neuroscientists we are interested not only in the perceptual consequences of a training regimen, but also the neural factors involved in learning. A group of researchers in Britain sought to understand the neurochemical consequences of video game play (Koepp et al. 1998). These researchers measured the amount of dopamine released when subjects played an action video game (in this case maneuvering a tank through a battlefield and destroying enemy tanks). Dopamine is one of many chemicals in the brain called neurotransmitters that allow the modulation of information passed from brain area to brain area. Dopamine is of particular interest because it is thought to play a role in a wide range of human behavior including pleasure, addiction, and learning. For instance, most drugs of addiction produce pleasure by increasing the amount of dopamine in the brain. Using a form of brain imaging (Positron Emission Tomography or PET) the researchers were able to determine whether playing a video game increased the amount of dopamine released by the brain. A massive increase in the amount of dopamine released in the brain was indeed observed during video game play, in particular in areas thought to control reward and learning. The level of increase was remarkable, being comparable to that observed when amphetamines are injected intravenously.

The role of this surge in dopamine and its implications are not currently well known, but work in rats suggests that dopamine may be important in the modification of the brain following perceptual training. Bao and colleagues conducted a study in which for one group of rats they paired the presentation of a particular tone (9-kHz) with stimulation of dopamine neurons, while another group received the tone alone. Following training, they observed an expansion of the part of the brain devoted to the tone only in the rats that had dopamine neurons concurrently stimulated (Bao, CHan, and Merzenich 2001). They therefore hypothesized that the dopamine neurons play a critical role in the learning that results in neural reorganization.

One could imagine that the large surge of dopamine observed when individuals play a video game plays a similar role as in the rats, leading to faster and more widespread learning. Understanding the neuroanatomical and neurochemical substrates of video game play and of the learning it induces will be one of the major challenges in the years ahead.

Practical implications for video game training

While the research outlined in the previous section has been mainly theory driven, the practical implications are numerous. Two main areas where the impact of video game training has been examined are in the rehabilitation of individuals with diminished perceptual or cognitive functioning (such as the elderly) and in the training of individuals whose professions require enhanced perceptual capabilities (such as military personnel).

Video games to rehabilitate the elderly

While there are some circumstances in day-to-day living that would benefit from increases in perceptual ability, in general most humans survive quite well with only "normal" processing capabilities. However, in many cases the elderly suffer from natural declines in these abilities. In general, the elderly suffer from a number of processing deficits including in reaction time, manual dexterity, hand-eye coordination, response selection, and general cognitive abilities such as short-term memory and reasoning (Welford 1977) (Drew and Waters 1986; Whitcomb 1990). While this decline is generally thought to be a natural consequence of aging, it is still an open question as to whether appropriate training could stall or reverse this trend and thus allow for a return to a more normal life.

Drew and Waters demonstrated that video game play could increase not only hand-eye coordination but also improve scores of general and verbal intelligence. Thirteen elderly subjects (ages 61-78 years) were trained on an Atari video game called Crystal Castles for two months (one hour of training per week). A control group received no game training. Before and after training groups were tested on the WAIS-R, the Purdue Pegboard, and the Rotary Pursuit task. The WAIS-R is a test of general adult intelligence with two subcomponents designed to assess verbal and non-verbal intelligence separately. The Purdue Pegboard test measures manual dexterity, both gross (at the level of the hands) and fine (at the level of the fingertips). As previously discussed, the Rotary Pursuit task measures hand-eye coordination. The results of video game training were quite significant for each measure. Video game trained seniors improved their scores of both verbal and non-verbal intelligence as measured by the WAIS-R. Their manual dexterity was improved as measured by the Purdue Pegboard and their eye-hand coordination was improved as measured by the Rotary Pursuit task. Furthermore, the seniors reported that following training they were more careful in daily activities and had fewer mishaps around the house. Therefore, this definitely appears to be a case where the video game training not only stopped the age-related decline, but also actually reversed it, with subjects attaining much higher levels than their control counterparts. However, some caution must also be taken in interpreting these results. While at first sight one may be tempted to conclude that video game play enhances not only visuo-motor skills, but also intelligence, an alternative is that measures of intelligence most commonly used, such as the WAIS-R test, are heavily dependent on speed of processing. Many tests of intelligence place a premium on speed of processing, and it has been shown that such intelligence tests strongly correlate with speed of processing measures. Therefore, video game experience may increase the ability to make speeded choices, without affecting other aspects of intelligence such as analytical skills or creativity. Whether or not this should constitute an increase in "intelligence" is a matter of some debate.

Clark and colleagues examined the possibility that video game training could reverse the age-related decline in performance on speeded tasks (Clark, Lanphear, and Riddick 1987). Seven subjects with a mean age of 65 underwent a 7-week video game training treatment. Prior to and after video game training the subjects (as well as a group of control seniors) underwent a reaction time test composed of two blocks. The seniors were seated in front of two lights, under which were two buttons. In one block of trials the seniors were to press the button below the light that went on as fast as possible (this is called the compatible condition). In the second block, they were to press the button beneath the light that did not go on (this is called the incompatible condition). Normal individuals are generally much quicker when the response is compatible with the cue (press the button under the light that goes on) than when the response is incompatible (press the button under the light that didn't go on) and the cost of incompatible trials is particularly magnified in the elderly. This is taken to reflect a difficultly in response selection (mapping a stimulus onto an appropriate action). During the 7 weeks of video game training, the seniors in the experimental group practiced one of two games (Pac Man and Donkey Kong) for at least 2 hours per week. The effect of this video game training on reaction time was indeed significant as the experimental group's average reaction time dropped around 25 milliseconds in the compatible condition and an even more impressive 80 ms in the incompatible condition, while the control group did not improve. The authors argue that because the largest improvement was in the incompatible condition, the video game experience led to enhancements particularly in response selection in addition to the widely reported decreases in simple reaction time. Superior response selection could theoretically aid seniors in any task where the stimulus and response are not naturally mapped (when you see an animal in the road, you should press the break pedal).

Although the results from these studies suggest that video game experience could be a powerful tool in slowing, stopping, or even reversing the age-related declines in perceptual, motor, and cognitive capabilities that the elderly population faces, it should be noted that these experiments were lacking in adequate controls for arousal, engagement, and motivation, which as will be discussed later could conceivably play a substantial role in the effects of video game experience. Although in these elderly individuals, video game experience was found to be beneficial as compared to no video game experience, it is unknown whether similarly challenging and cognitively engaging tasks (word puzzles, playing golf or chess for example) would lead to similar benefits. Therefore, while we can conclude video game play may be sufficient for enhancements in perceptual and cognitive functioning in the elderly, it is difficult to determine which aspects of video game play are necessary to induce changes.

Video games to aid children

Human beings are among the least precocious of all animals. Perceptual, cognitive, and motor skills develop throughout infancy, childhood, and adolescence, and often do not reach "adult levels" until adulthood. While there is evidence that proper experience can be used to retrain capabilities lost through the natural aging process, another open question is whether video game experience can augment the normal development of these systems in children. Continuing research in our own lab suggests that children who play video games show similar benefits as adults on many measures of visual attention (including the Useful Field of View and the attentional blink) (Dye and Bavelier 2004). Dubar and colleagues have suggested that the attentional skills of children are linked with their behavior as pedestrians (Dunbar, Lewis, and Hill 2001). They tested the ability of children of various ages to switch attention and concentrate using a simple video game and also observed the same subset of children crossing roads. Children who were better at the game, and thus more able to effectively switch attention, were more likely to show awareness of traffic when about to cross a road and crossed the road in an overall safer manner. One should definitely note however, that this was purely a correlational study, it is perfectly possible that heredity has endowed certain children with abilities that allow them to excel at attentionally demanding video games as well as show increased awareness when crossing the road. Hasdai and colleagues also report that training on a joystick-controlled computer game can assist children learning to operate a motorized wheelchair (children with progressive muscular dystrophy or cerebral palsy) (Hasdai, Jessel, and Weiss 1998). Therefore, although the work is in a very preliminary stage, from a purely perceptual and motor development standpoint, young video game players may indeed reap the same significant rewards from video game experience as those observed in adults.

Video games to improve the abilities of military personnel

We now move from populations with below normal perceptual and/or cognitive capabilities to individuals that would benefit from enhancements in these capabilities. Military personnel in general, and aircraft pilots in particular, are one population wherein enhancements in perceptual and cognitive processing could lead to enormous differences in job performance (which in the case of the military could often mean the difference between life and death).

By the early 1980's the military had begun to examine the effect of video game playing on its personnel (Jones, Kennedy, and Bittner Jr 1981; Kennedy, Bittner Jr, and Jones 1981) (Lowery and Knirk 1982; Lintern and Kennedy 1984). Several studies by Kennedy, Bittner and colleagues demonstrated the effect of the Atari game Air Combat maneuvering which was found to be a powerful covariate for carrier landing research and an excellent candidate for a performance test battery. They suggest that sonar or radar operators could reap large benefits from such training.

In addition to the interest shown by the US military, the Israeli military has also investigated the possibility of training personnel on video games to increase their performance. Gopher and colleagues, working in collaboration with the Israeli Air Force, conducted a study to determine whether the benefits of video game play could be relevant to flight skills in Israeli Air Force cadets (Gopher 1992; Gopher, Weil, and Bareket 1994). They argue that video games increase the efficiency with which attention is managed, particularly when the task load is high, and that these enhanced abilities could be of great benefit to pilots.

In their experiments Gopher and colleagues compared the flight skill of individuals that either had or had not been trained on the video game Space Fortress. Cadets given 10 hours of video game experience performed significantly better than a control group that received no game experience on various measures of flight performance. Of the 33 total flight scores (ratings by instructors based on flight performance), the game group performed significantly better on 25 of these scores. In another study, those trained on Space Fortress increased their probability of program completion by 30%. In fact, this game was so successful that the authors note that the game had been incorporated into the regular training regimen of the Israeli Air Force.

In addition to pilots, one can imagine many potential military personnel that could benefit from greater attentional capacity, control, spatial distribution, and more efficient response selection.

Video games to train surgeons

Another group that has been shown to benefit from video game training are laparoscopic surgeons. A recent report by Rosser and colleagues (Rosser Jr. et al. January 2004) suggested that video game players may in fact be better laparoscopic surgeons than non-gamers. Laparoscopic surgery is a minimally invasive form of surgery in which a camera and operating instruments are introduced into the body via small incisions. The surgeon then conducts the surgery by maneuvering the instruments based on viewing the images from the internal camera. Visual attention, manual dexterity, and hand-eye coordination are of even more importance than in normal open surgery. Rosser and colleagues found that surgeons who played video games more than 3 hours per week committed 37% fewer errors, were 27% faster at laparoscopic drills, and were 33% better at suturing tasks than non-video game playing surgeons. Using a multiple comparison analysis, the authors found that a surgeon's video game experience is a better predictor of surgical skill than number of years of practice or number of operations completed! The authors suggest that video games could be used as an important "warm-up" for laparoscopic surgeons or that the development of surgeon specific video games could greatly enhance surgical aptitude.

The difficulties of video game research

While the work reviewed in this chapter presents a rather rosy picture of the effects of video game training, in practice it is not that simple of an endeavor. Several difficulties exist that make the study of the effect of video games challenging. One major difficulty is that no two video games are created exactly equal, which means that the perceptual and/or cognitive effects one can expect from each are not necessarily easily comparable. As our own particular interest is in visual attention, we tend to use first-person shooter (FPS) video games. These games require effective monitoring of the entire screen (enemies often first appear in the periphery), high temporal precision (the speed of the game often far exceeds the speed of day-to-day life) and high attentional capacity(many enemies often appear simultaneously). The requirements of other types of games are often similar, but distinct enough that it is difficult to predict their perceptual consequences. For instance, sports games require many of the same visual attentional skills – does perceptual learning occur in the same manner in sports games players? And even within a genre, the individual games have slight variations – how much do these slight differences actually make? These are unfortunately purely empirical questions and although they are currently under study in the lab, as of now it is nearly impossible to pin down the "critical components" of video games that lead to modifications in one domain or another. Consequently, it is difficult to predict beforehand what would be the "best" game to modify a certain aspect of perception or cognition. In practical terms, this is a real limitation when retooling video games as a training tool. The same game that may be very helpful to a patient with hemineglect, a rather common deficit in visual attention after right parietal lobe damage, may not be of much use to a patient with poor vision, such as amblyopes.

Another difficulty is that training can be more or less efficient depending on how it is administered (Linkenhoker and Knudsen 2002). We have often observed that the difficulty of the video game is critically important in the amount of learning that occurs. For maximum learning to occur, the game difficulty must be such that it is "just barely too difficult" for the subject. If the game is too easy or too hard, learning appears to be less efficient. Therefore, we actively monitor the progress of our subjects and increase the difficulty of the game as they progress, always pushing them to reach a goal just beyond what they can attain. This makes intuitive sense – imagine the amount a person would learn about playing baseball by playing with major league players on their first outing. They are likely to learn little about baseball other than it hurts to get hit by the ball. Similarly, putting subjects in a video game environment far beyond their abilities may teach them primarily how to restart when the computer kills them. Unfortunately, while the fact that the wrong training schedule would be detrimental to learning is highly intuitive, determining what the correct training schedule should be is far from intuitive, and is as of now as much an empirical question as a theoretical one. The "right" training schedule is likely to be a function of the game, the skill you hope to modify, the age and current perceptual skills of the subject (should you use the same schedule to train a stroke patient as a child?) as well as many other variables that have barely been considered so far by researchers (such as motivation, arousal and the like).

In this endeavor, there are also other confounds that we are only in the very early stages of considering. For instance, basic metabolic phenomena appear to be altered when playing particular video games – heart rate, respiration, etc. One might imagine that playing competitive games could also be accompanied by increases in adrenaline. In our own work, we have often observed that action game trainees seem more physically aroused than control game players. Is this a critical component of the learning that occurs?

Because of these myriad factors, it is critical that the reader not believe that it is "easy" to induce perceptual or cognitive changes through video game experience. It is certainly not the case that any type of experience with any type of game will change any perceptual, motor, or cognitive skill.

Video games in the future and their potential effects

While it is obviously difficult to predict the future of technology, there are many possible directions video game development could take. From a graphics perspective, in the near future the advances will likely be simple increases in the capabilities of current machines (more memory, greater processing power, better video cards) that will allow a more realistic scene to be rendered (greater texture, lighting and shadow effects, resolution, etc). This increased level of detail allows a smoother experience and could do nothing but augment the effects described throughout the chapter.

One possibility for the more distant future is fully three-dimensional games. This would mean that the games take place not only on your computer screen or television monitor but instead right in front and all around you. Head mounted displays could also be used to simulate immersive virtual environments. One current problem with virtual reality is that subjects exposed to a virtual environment often experience nausea, oculomotor disturbances, or disorientation. One study found that 80% of participants experienced some level of discomfort when exposed to a virtual environment (Stanney et al. 2003). These adverse effects may largely be due to limitations in processing power, with systems unable to keep up with subjects that have many degrees of freedom in movement (body movement, head movement, eye movement, etc). However, even with infinitely powerful processors, the sensory mismatch between vision and the other senses may still result in what has been dubbed "cybersickness." It is difficult to even speculate as to the perceptual and cognitive effects of consistent experience with a virtual video game environment. One would assume though that the effects would be, if anything, increased. The presence of auditory, visual, and sensory information in a video game could lead to enhancements in the way the different sensory system function together and combine their inputs into a coherent percept.

Beyond the physical video game display, how people play games together will likely continue to undergo massive changes. Online multiplayer gaming has become a hobby of many Americans and the trend toward online gaming should continue. Games already exist that can be played online with literally hundreds of other individuals. While most avid gamers are relatively skillful in determining how to beat an artificially intelligent opponent, playing against human opponents requires the development of complex reasoning and decision-making skills. Furthermore, advances in artificially intelligent game agents could lead to similar enhancements in these traits.

Finally, there are currently many researchers interested in developing video games designed specifically to enhance particular perceptual or motor skills. As mentioned earlier, video games could be designed to maximize the learning of traits required by laparoscopic surgeons. The possibilities for the development of video games to aid specific populations are nearly endless (military specific games, games to aid stroke victims or children with reduced visual acuity). Video games have proven to be a powerful tool to reshape and enhance visual-motor, spatial, and visual attentional skills and it seems likely that within the coming decade they will begin to be taken advantage of in this manner.

Conclusion

Video games currently play a substantial role in our culture as more than half of all Americans play some type of video game. The available research in the perceptual and cognitive domain indicates that such activity is likely to alter a wide range of perceptual, motor, and cognitive traits. Video game play has been shown to dramatically enhance visuo-motor skills. In particular, video game players have been shown to possess decreased reaction times, increased hand-eye coordination and augmented manual dexterity. Video game play has also been shown to improve spatial skills such as mental rotation, spatial visualization and the ability to mentally work in three-dimensions. In addition, video game play has been shown to enhance numerous aspects of visual attention including the ability to divide and switch attention, the temporal and spatial resolution of visual attention, and the number of objects that can be attended. The possibility that video games provide a medium that facilitates learning, and thus promotes changes in performance and brain organization, has led some to propose that video games are the teaching tool of choice of the 21st century. The surge in new videogames being developed to enhance one particular trait or another is probably the best testimony of the level of excitement in this new field.

Whereas the benefits of video games to some aspects of cognitive and motor skills seem undeniable, this work is still truly in its infancy and many questions of great theoretical and practical importance remain to be addressed. On a practical level, in order to efficiently use video games to train a particular function, we need to first determine what characteristics a game should possess to maximally benefit the skill in question. We also need to determine the most efficient training schedule, as poorly designed training regimens are likely to lead to null results. Finally, one needs to ensure that for all the gain, there is no major loss in performance in other areas of cognition or at the emotional and social level. On a theoretical level, video game research is opening a fascinating window into the amazing capability of the brain and behavior to be reshaped by experience. Understanding the mechanisms that unleash such widespread plasticity is one of the many challenges facing this field.

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