How Video Games Benefit Your Brain

Jing Feng and Ian Spence
University of Toronto

Abstract

After more than three decades of development, video games are now increasingly used for purposes other than entertainment. These games play a role in fields as diverse as education, cognitive training, physical exercise, and rehabilitation. Developing a good game for meaningful purposes requires a comprehensive understanding of the critical characteristics that trigger the training benefits. In this paper, we present a comparative psychological analysis of the cognitive requirements of several different genres of computer game. We also review the experimental research that has focused on the cognitive and neuropsychological changes that game playing may induce in the brain. We discuss various fields of application for video games with serious purposes and suggest guidelines for designing such games based on psychological theory and experimental research in cognition and perception.

How Video Games Benefit Your Brain

More than three decades after their introduction, computer games are no longer solely for entertainment. Video games have been used in the classroom as educational tools, in hospitals for clinical treatment and rehabilitation, and in the military for training various skills. Middle school students in the US are using SimCity, a game by Electronic Arts, to design a future metropolis in a national urban planning competition (Future City Competition, 2008); rehabilitation departments in hospitals like Minnesota's Northwestern Hospital have been using the Nintendo Wii to help their patients achieve physical exercise goals (Drummond, 2008); and the US has developed America's Army, a first-person shooter (FPS) action game, for recruiting and training soldiers (America's Army, 2008). The objective of most non-entertainment uses of video games is to change the player's behavior in some way. The goal may be a simple one— obviously suited to video game training— such as training a pilot to improve accuracy in a landing approach. But the intent may be more subtle, ambitious, and wide-ranging, such as an overall sharpening of visual and attentional skills or the general speeding of reaction times. Indeed, an increasingly sought after goal of meaningful play is nothing less than to improve your brain.

Recent pioneering studies (Feng et al., 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007) have shown that FPS games can produce beneficial changes in perception, attention, and spatial cognition. However, it is not clear which aspects of the game are instrumental in stimulating these changes. Knowing which game characteristics are responsible for inducing change would be of both scientific and practical interest. Such knowledge could, for example, guide the development of new meaningful games designed to improve particular cognitive functions. As a preliminary step towards this goal, we review the perceptual and cognitive functions that may be affected by playing video games. Then we present a comparative logical analysis of the characteristics of several different genres of game with respect to their likely ability to modify these cognitive functions. We indicate which perceptual and cognitive functions are associated with particular game characteristics, including sensory processing, visual attention, memory, spatial cognition, and the subsequent planning of motor actions. Our analysis is based on recent experimental results and psychological theory and suggests a future program of experimentation that would test our predictions.

A Comparative Analysis of Cognitive Functions Exercised by Video Games

Video games exercise a wide range of perceptual and cognitive functions. Some games require a high degree of skill in performing relatively basic perceptual and cognitive tasks whereas others demand higher-level cognitive skills, such as the ability to solve difficult logical problems. Experimental studies have shown that certain genres of game yield greater training benefits than others. For example, Feng et al. (2007) demonstrated that participants who played an action video game for ten hours obtained significant performance improvements on *both* attentional and spatial tasks, while participants who played a maze game for the same length of time showed no gains. Compared to other genres where positive training effects have also been observed, such as Oregon Trail (for learning history) or Tetris (for enhancing spatial skills), FPS action video games seem to have a unique advantage in improving low-level functions such as spatial selective attention (Feng et al., 2007; Green & Bavelier, 2003) and spatial perceptual resolution (Green & Bavelier, 2007). Since fundamental perceptual and cognitive skills serve as the building blocks for higher level cognition, the ability of action games to improve basic skills has made them attractive candidates for further experimentation. Other genres may produce different cognitive effects and, for purposes of comparison, we also examine two other genres of game. Table 1 lists the salient attributes and requirements of each type of game as well as our estimate of the degree of involvement of the various cognitive functions likely to be active during game play. Our review of relevant psychological functions starts with low-level processes and continues through progressively higher-level cognitive abilities. The emphasis is on visual skills and abilities since most video games are highly visual in nature.

---Insert Table 1 Here---

Sensory processing.

When light falls on the retina at the back of the eye, it interacts with around 100 million specialized neurons (rods, cones, and other retinal cells), causing some of them to fire. Much low-level computation is done within the eye itself and intermediate results are transmitted to other areas in the brain via the optic nerve. Further processing takes place along the routes to the visual cortex at the back of the head. However, it is important to note that these routes are not passive one-way streets; lower-level computations are often modified in response to inputs from higher centers in the brain. The early visual system computes elementary functions such as brightness detection, edge detection, orientation detection, segmentation, shape perception, 3D perception, movement detection, and color processing (Palmer, 1999). These basic perceptual operations are sometimes referred to as “pre-attentive” processes because they occur without conscious awareness; attention is not required to ensure their completion.

Thanks to advances in computer graphics, many games now boast photo-realistic 3D visual environments that are much more lifelike than the abstract 2D environments common in early games. This makes for a better fit to our perceptual system which evolved in a 3D environment. Thus initial sensory processing in contemporary games occurs with stimuli that are reasonable simulations of what we might see in the real world. In an FPS game, a large number of potentially lethal events may occur virtually simultaneously in the 3D environment. Both friend and foe may be present on the battlefield and objects of interest may include infantry, guns, missiles, tanks, aircraft, ships, or any of the other staples of warfare. The player’s first priority is the rapid detection of potential threats and efficient pre-attentive scanning of the visual scene. Since the player in an FPS game generally has unrestricted freedom of action (where to explore), there is a very large landscape to search for threats. It is possible that extended FPS play might have some positive benefit on low-level sensory processing, but so far there is little in the literature to support this possibility. It has always been assumed that low-level sensory processes are largely resistant to the effects of training; however Green & Bavelier (2007) recently demonstrated an improvement in visual spatial resolution after training with an action video game. This raises an interesting question: is it possible that other low-level visual functions might be improved by playing video games?

Attentional capture and visual selective attention.

The visual system cannot process all of the information contained in the patterns of light that reach the retina; processing this continuous stream of data would entail an enormous computational burden. In any event, extended processing is not needed; evolution has ensured that the visual system reserves its computational resources for information that is likely to matter. Most raw visual information is unimportant for survival, or for any other relevant purpose, and may be ignored. Consequently, over millions of years, the visual system has evolved to be sensitive to changes in the position, luminance, or other elementary attributes of objects that may be significant for survival. Visual events that involve abrupt onset are particularly important and are said to "capture attention." Attention is diverted immediately to the location where the sudden change has occurred as, for example, when a new object has appeared (Yantis, 1996). Such events are rapidly analyzed by the brain using processes that require discrimination, recognition, and decision making, and are usually followed by some sort of motor action. Although the mechanism of *attentional capture* evolved in circumstances quite different from those of today, it continues to be important in all aspects of contemporary daily life; for example, it helps us to be aware of objects that are likely to trip us up while walking, or to notice approaching vehicles that could pose a danger when crossing the road.

But capture is only the first stage in the attentional process— we must discriminate and recognize the objects that have captured our attention while disregarding information that is not relevant. This is *visual selective attention*. Low-level processes (mostly bottom-up) and processes involving prior knowledge about objects and their interrelations (mostly top-down) are involved; the influence of higher-level cognitive processes is crucial. Working memory, long term memory, and executive control functions are brought into play. More than a century of experimentation in psychology has shown that many higher-level cognitive processes can be modified by training, and so it is reasonable to suppose that the practice offered by playing video games may produce changes in basic attentional processes because they are influenced by higher-level cognitive processing. As we have previously noted, processing of visual information is a two-way street; while lower-level perceptual processes provide the basic data for cognitive processes, these higher-level processes, in turn, can affect the operation of the perceptual and attentional systems.

The player of an FPS game must detect, identify, and keep track of the threats appearing in a variety of locations in a complex visual environment to avoid being killed. Thus practice in FPS gaming is likely to improve selective attentional abilities and this improvement may even transfer to other tasks. Practice in discriminating small differences is very likely to benefit the perceptual system. For instance, in an FPS game, the distinction between an enemy, a fellow soldier, and a static object far away can be very subtle, particularly when the player-controlled character is moving and the view is constantly changing. To avoid indiscriminately killing both friend and foe, the player has to identify these slight differences quickly and accurately, under the stress of having to survive in a potentially lethal environment.

Dividing attention, switching attention, and distributing attention.

We can *divide attention* among different objects, or several non-contiguous locations, or perform more than one task at the same time (Cavanagh & Alvarez, 2005;

Kramer & Hahn, 1995). Simultaneous tracking of several objects, attending to multiple locations, and performing two or more tasks concurrently all require divided attention. Naturally, any division of attention comes with costs— speed and accuracy are both likely to be affected— and there is a limit on how many objects, locations, or tasks may be attended to. This limited capacity largely determines our performance on many important everyday tasks such as attending to the road while interacting with in-vehicle information systems during driving (Wickens & Hollands, 1999). We can also move attention from the currently deployed location, object or task to a different one. This switch is accompanied by costs to the processing speed of the secondary location/object/task as it takes some time for attention to disengage and reengage. A rapid switch is normally beneficial in most situations as, for example, when a driver has to switch to a braking task from current speed and lane keeping tasks to avoid a collision. Distributing attention over a wide visual field allows us to "see" the peripheral world by localizing an object, recognizing it and distinguishing among different objects without fixating our eyes on these particular objects. This function was vital to our ancestors since they had to be aware of peripheral events to be successful in the hunt and also to avoid being hunted. It continues to be important today; for example, since we can only fixate one small area at a time, most of our monitoring of potential driving hazards requires the ability to distribute attention over a wide field of view, including in the periphery. Indeed, narrowing of the attentional field has been associated with dangerous driving in some older adults (Ball et al, 1988, 1993; Owsley et al., 1998).

The dynamic and highly complex visual characteristics of certain types of video game require the ability to maximize the *division of attention* and to *switch attention* quickly. FPS games, in particular, require the player to deal with a variety of challenges, which can follow one another in rapid succession. Many situations require an unexpected switch of attention, such as in the case of a sudden attack where the player's attention on a navigation task has to be suspended to deal with the immediate threat. Fast disengagement of attention from the current task and rapid engagement with the new task is often difficult for novice players. After a certain amount of practice with video games requiring divided attention or task switching, the player's performance in these skills will probably improve and may also transfer to other non-game tasks in the real world. Strategy games, like StarCraft, also often require the player to attend to multiple locations on a map or to monitor several status indicator gadgets in the periphery of the display. The requirement is not as intense as in FPS games, but strategy games may also produce training benefits in the ability to switch and divide attention.

It is very important for the player of an FPS game, or a racing game, to be aware of events that occur in the periphery, far from the central focus. Even though the player must focus on the center to complete most missions, threats can appear in any quadrant and if the player is not able to distribute attention over a wide field of view, unattended threats in the periphery can prove fatal. Thus FPS games offer abundant practice in expanding the attentional field of view (Feng et al., 2007; Green & Bavelier, 2003).

Memory.

Memory is the ability to store, maintain, and subsequently retrieve information. The two types of memory that are likely to be relevant to playing many video games are *working memory* and *long-term memory*. Working memory temporarily stores information for current manipulation (Baddeley, 1996; Cowan, 2000) and is closely linked to the attentional system. Generally, individuals cannot simultaneously hold more than about four items in working memory nor can they attend to more than about four objects at the same time. Working memory capacity is highly correlated with general intelligence (Oberauer et al., 2005). Failure to store and manipulate information efficiently in working memory will result in poor performance on many intellectual tasks. Long-term memory, as the name suggests, is the capacity to store information for a relatively long time, from several hours to decades. Working memory and long-term memory interact and supplement each other. Information enters long-term memory via the working memory process and working memory retrieves information from long-term storage according to the demands of the current task. Thus improvement in one type of memory can also benefit the other.

Rapid decision making is also dependent on the ability to manipulate items in working memory. For instance, the player in an FPS game often has to assess a number of simultaneous threats, quickly decide which enemy to engage first, and what weapon to use. Making the choice quickly and correctly is essential for survival. Since attention and visual working memory are closely interrelated, working memory plays a large role in FPS games. Thus it is possible that playing such games could result in improvements on working memory, although this has not yet been confirmed by experiment.

Long-term memory does not play a major role in FPS games. However, the player in strategy games and role playing games must rely on long-term memory to achieve superior performance, such as remembering game events in proper sequence as well as the rules and procedures required to achieve a particular goal. Practice with this genre of game might help to improve long-term memory. Tárraga et al. (2006) demonstrated that after playing a cognitive task simulation game that exercised attention, memory and spatial skills, Alzheimer's patients obtained better memory test scores.

Spatial cognition.

Spatial cognition is the ability to represent the spatial relations between ourselves and the environment and also among the objects in the environment. It is essential for many daily tasks, like map-reading, navigation, solving geometrical problems, and designing and building structures and machines. Some spatial skills like the ability to rotate objects mentally are highly correlated with mathematical skill (Delgado & Prieto, 2004).

Playing an FPS video game (Medal of Honor: Pacific Assault) has been shown to improve spatial skills (Feng et al., 2007). This game allows complete freedom of movement with the full extent of the environment accessible to the player; the viewpoint may be rotated through a full 360 degrees at any time. Just as in real life navigation, the brain is active in constructing a spatial representation of the initially unfamiliar environment. There are many different opportunities to develop spatial representations in the game because the scene of action changes frequently. In one scenario, the player has to navigate inside a damaged and sinking ship to rescue wounded people and eventually find the way out to the deck; and, in another setting, the player must navigate around an island without many clear landmarks to find specific locations appropriate to the mission. When the individual is placed in an unfamiliar environment, the brain automatically works to remember landmarks and routes, eventually constructing a progressively better spatial representation of its surroundings. This particular spatial ability has obvious survival value and is yet another consequence of natural selection.

Other video games have also been found to improve particular spatial skills, like the ability to rotate objects mentally (De Lisi & Cammarano, 1996). In the studies by De Lisi and Wolford (2002) and Terlecki et al. (2008), people who played games like Tetris obtained significant improvement in mental rotation ability. Since the tasks in the Tetris game itself and the mental rotation tests used were very similar, it is perhaps not surprising that a training gain was observed. However, unlike the case of FPS games, there is little evidence of transfer of training to other tasks.

Emotion.

Emotion can have significant effects on cognitive performance (Dweck, et al., 2005). Gray et al. (2002) asked their participants to watch a video clip from either a comedy (amusement), or documentary (neutral), or horror (anxiety) movie and found that compared to the neutral group, anxious participants performed better on visual tasks while happy participants performed better on verbal tasks. Being “emotional” is not always a bad thing, as we often perform more efficiently under stress, so long as the level of stress is not too high. FPS games present the player with a hazardous environment that is frequently life threatening. The emotional arousal that is induced may stimulate the brain into a more alerting state, possibly boosting many aspects of cognitive performance.

Motor actions.

Much of the perceptual and cognitive processing performed by the brain is a prelude to action, which generally requires good visuo-motor coordination. Visuo-motor coordination is the ability to use visual information to control and direct the motor system to complete a task. This is a basic skill required for everyday activities involving movement, such as walking, dressing, writing, driving, or playing sports. In the video game context, visuo-motor coordination is mainly between, but not restricted to, the hands and the eyes. The eyes control the focus of attention and the hands accomplish the tasks. Almost every video game that consists of a dynamic visual presentation and a fine motor control component is likely to be effective in producing improvements in visuo-motor coordination (Griffith et al., 1983; Yuji, 1996), although the amount of improvement may vary. For example, when shooting in an FPS game, the player must locate the target visually, move the aiming point to that spot, and click the mouse to fire. Similarly, in a game like Tetris, the player must decide how much rotation of the moving item is required and then press a key to make the rotation; this has to be done both quickly and accurately.

Action video games offer plentiful opportunities for practicing visuo-motor coordination skills. In an FPS game, for example, the player has to shoot accurately and quickly to succeed. The targets are often far away and are correspondingly small, demanding a high-level of visuo-motor coordination. Similarly, in a driving game, the car must be steered accurately to avoid collisions. FPS games provide a natural egocentric compatibility between the visual input and the motor output. The control of direction of movement and the changing visual landscape are matched to the player’s viewpoint. In some other spatial (but non-action) games, like Tetris, the controls that determine movement are not generally compatible with the egocentric (player-centered) viewpoint.

Psychological research has shown that the time taken to recognize photographs of a set of objects from viewpoints different than the egocentric view increases linearly with the difference in angle between the two viewpoints (Diwadkar & McNamara, 1997). Also, when participants are asked to point to an object from an imagined viewpoint, they are faster and more accurate when the imagined viewpoint has the same direction as the egocentric viewpoint (Shelton & McNamara, 1997). Thus the type of visuo-motor coordination required in Tetris is somewhat different and perhaps less natural than in most FPS games. However, since successful play requires a reconciliation of egocentric (body-centered) and allocentric (object-oriented) frames of reference, this aspect of the Tetris game may provide additional exercise for the brain systems that represent spatial relations among objects.

Speed.

In order to perform well in action video games, the player must respond quickly. In FPS games, enemies appear suddenly at unpredictable locations and the player must detect the threat, determine its level of danger, and defend appropriately. This is only possible if all perceptual, cognitive, and motor actions are rapidly accomplished. Speed is very important. Similarly, in racing games, quick reactions to vehicles or obstacles that appear suddenly are necessary to avoid collisions. Thus action games offer the possibility of improving an individual’s ability to react quickly.

Individual differences.

There are substantial individual differences in cognitive capacities. For example, working memory capacity can vary by several items among individuals. In many cases, specific differences are associated with particular groups of people. For example, seniors are poorer at suppressing non-relevant processes when manipulating information in working memory, on average, than young adults (Gazzaley et al., 1995) and both children and adults with ADHD have much more difficulty in switching attention (White, 2006). If we wish to develop meaningful games for diverse groups it will be necessary to take these differences into consideration.

It is important to provide entry levels of varying difficulty to allow individuals with different skills to participate in the game, to move to higher-levels after sufficient practice, and even to become experts eventually. Providing access at different levels of difficulty recognizes that not everyone is at the same place on the learning curve. Novices who must play a game that is too difficult for them quickly tire and quit. By the same token, players who find the game too easy will quickly lose interest also. Providing an appropriate level of difficulty not only helps to keep the player interested and engaged, but also offers progressively more difficult practice as the player gains experience, eventually resulting in greater benefits in the cognitive skills that are targeted for improvement.

Experimental Demonstrations of the Benefits of Playing Video Games

Recent behavioural studies (e.g. Feng et al., 2007; Green & Bavelier, 2003; 2006a; 2006b; 2007) on the effects of video game play on cognition have adopted a two-stage approach that first tests video game players and non-players to determine whether they differ, on average, in particular cognitive skills (e.g. selective spatial attention).

However, if a difference between players and non-players is found, we cannot conclude that playing video games has produced the difference. It is possible that a pre-existing difference between players and non-players may have contributed to the individual's decision to play, or not to play, certain types of video games. For example, someone who possesses superior spatial skills may take to FPS games like a fish to water whereas individuals with average, or below average, spatial skills may not find playing FPS games to be a rewarding experience, and consequently may choose not to play. Therefore, to be sure that playing a particular video game has contributed to the observed difference between players and non-players, it is necessary to conduct a training experiment with a group of non-players.

In a typical training experiment, half the non-players are assigned to the experimental condition where the participants play for several hours using the video game of interest (e.g. Medal of Honor, if the focus is on FPS games, as in Feng et al., 2007). The remaining players are assigned to the control condition where the game is from a different genre (e.g. Ballance, a maze game that lacks an action component, as in Feng et al., 2007). Before learning to play the game, participants perform one or more cognitive tests that are of interest to the experimenter. The assignment of individuals to the experimental and control groups is random after first matching pairs of individuals on their performance on the cognitive tasks. After playing the video game for sufficient time to become reasonably proficient (e.g. ten hours of total play time, as in Feng et al., 2007), the participants are again tested on the same cognitive tasks. If the experimental group shows significant improvement on the cognitive tests (and the control group does not), we may be reasonably sure that some characteristics of the experimental game are responsible for the change.

Using this approach, Green & Bavelier (2007) recently showed that playing an FPS game enhances an individual’s visual acuity. The task was to detect objects in clutter and the criterion was the smallest distance at which participants could distinguish a target object from a distractor object. When the distance became progressively smaller, the performance of the non-players deteriorated more rapidly than the players. To test whether playing an FPS game could boost performance, non-players were trained using an FPS game and, in fact, subsequently demonstrated significant improvement on the spatial acuity task.

Improvements in many aspects of attention have been attributed to playing action video games (Castel et al., 2005; Feng et al., 2007; Green & Bavelier, 2003, 2006a, 2006b). Players can enumerate more objects than non-players indicating a larger processing capacity (Green & Bavelier, 2003, 2006b). The enumeration task requires participants to state the number of randomly placed black squares in a briefly presented array. Similarly, in another task that requires attention and working memory, players are able to track more moving objects simultaneously (Green & Bavelier, 2006b) and they are also able to switch the focus of attention among different items more efficiently (Green & Bavelier, 2003; Greenfield et al., 1994). Players also have a greatly expanded functional field of view (FFOV) than non-players. The FFOV is the visual region in which the visual system can quickly and accurately localize and identify the onset of a target or any sudden transient change (Feng et al., 2007; Green & Bavelier, 2003, 2007). Training experiments have shown that playing an FPS game has a significant effect in expanding the FFOV. Furthermore, the benefit persists for at least five months (Feng et al., 2007).

Action video game playing can also improve spatial cognition as measured by performance on a mental rotation task (Feng et al., 2007). The ability to imagine a 3D geometrical object in a variety of orientations and to say whether two differentially oriented objects are the same is a widely accepted marker of spatial ability. Large individual differences, including a gender difference, have been found by many experimenters (Kimura, 1999). In Feng et al. (2007), participants who played an FPS game for ten hours revealed significant improvements on the mental rotation test compared to the participants in the control group who played a maze game. Moreover, the women improved almost to the level of the men and the training gains for both sexes persisted for at least five months (Feng et al., 2007).

Some genres of video game have been shown to produce benefits on memory tasks. For instance, McGraw et al. (2005) found that grade six students with ADHD demonstrated significant improvement in reading, specifically the ability to “code whole written words into short-term memory and then to segment each word into units of different sizes”, after playing a physical exercise game named Dance Dance Revolution (DDR). The authors suggested that the multi-tasking required by the game was a possible explanation for the improvement. DDR requires simultaneous encoding of the visually presented instructions, responding with the correct motor actions, and continuous monitoring of the reinforcement provided by the game. Similarly, using elderly patients with Alzheimer’s disease, Tárraga et al. (2006) demonstrated that combining a traditional psychomotor treatment regimen together with the online video game Smartbrain (http://www.educamigos.com), significantly augmented treatment effectiveness compared to the traditional method alone. After playing the game, which exercises abilities in various domains such as attention, calculation, memory, and spatial skills, patients achieved better scores on many fluency and memory tests. This advantage persisted for at least 24 weeks (Tárraga et al., 2006). The similarity between the tasks in the game and the psychological tests likely contributed to the success of combining the Smartbrain game with the traditional therapy.

Compared to classic perceptual learning where improvements are usually seen only on specific skills that are closely related to the training task, practice with some video games seems to show considerable generalization effects. FPS games are particularly effective in enhancing different aspects of cognition, including perception, attention and spatial skills. FPS games require intense use of spatial attentional skills. Since these low-level skills are fundamental building blocks for higher cognitive functions (e.g. spatial cognition), the improvement in the low-level cognitive skills will necessarily have a positive effect on higher-level cognitive processes that depend on them.

Another noteworthy aspect of video game training is its durability. Some studies have found that the training gains can last for at least several months (Feng et al., 2007; Tárraga et al., 2006; Terlecki et al., 2008). Note that the significant training effects in those studies were obtained after only a few hours of playing video games. The benefits obtained by playing video games for weeks, months, or years could be much greater. Substantial neurophysiological changes in the brain, including the expression of previously inactive genes that control the construction of specific proteins critical to the development of new neural circuitry, may have taken place. Studying the neurophysiological basis of cognitive learning associated with playing video games is likely to become an increasingly important domain of inquiry for brain scientists.

Video games can be very engaging. The best games are capable of holding a player's interest for hours on end. Playing a video game has been shown to trigger significant dopamine release in the brain (Koepp et al., 1998). Dopamine is a neurotransmitter that is closely associated with reward seeking, addiction, and learning. While helping to establish the neurostructural changes, large quantities of dopamine may also be very rewarding. This elevation of dopamine levels may be part of the reason why video game players spend such long hours at the console.

Meaningful Applications of Video Game Playing

There are many areas where the meaningful use of video games could be beneficial. We discuss a few potential areas of application below.

Older adults.

The decline of cognitive abilities during normal aging affects most areas of cognition, including attention, perception and memory. As a result, everyday activities become more difficult for older adults. Walking, driving, grocery shopping, and taking medicine are just a few examples of activities that are threatened (Kausler, 1994; Owsley et al., 1998; Salthouse, 1995; Schaie, 1996). In particular, rapid narrowing of the functional field of view (FFOV) is significantly related to falling (Kerr, et al., 1985) and poor performance in driving (Ball et al, 1988, 1993). The resulting accidents cost the taxpayer many billions of dollars annually. The aging processes that are associated with these behaviors are a consequence of senescence and death of cells in the brain. Churchill et al. (2002) have found that intellectual exercise and learning help certain brain neurons to survive, resulting in the maintenance and enhancement of cognitive abilities in older age. Since Feng et al. (2007) and Green & Bavelier (2003) have shown that FPS playing improves FFOV, there is the potential to develop senior-friendly FPS games to boost the performance of aging individuals who are at increasing risk of accidents related to diminishing FFOV capacity.

Young children.

Many cognitive functions, particularly working memory span and spatial skills, are highly relevant to children's performance in school. Working memory span is a good predictor of an individual's intelligence (Coull & Frith, 1998; Oberauer et al., 2005) and spatial skills are highly correlated with mathematical aptitude (Delgado & Prieto, 2004). Playing video games that exercise these cognitive functions is likely to improve children's performance in class. Moreover, games that also include the same kind of contextual knowledge that is found in traditional textbooks may also be beneficial. There is a significant opportunity to teach and test children's knowledge on a specific subject by presenting the information as part of the game and later requiring the children to apply the knowledge to complete tasks required by the game. Because video games are normally much more appealing to children than textbooks, they are more likely to spend time with educational games. Noteworthy first steps are exemplified by pioneering games like Making History (for learning history, http://www.making-history.com/hq/).

Clinical applications.

Cognitive training of the non-video-game variety has been effective with clinical patients who have specific cognitive deficiencies (Ball et al., 1988; White, 2006). However, video games possess two notable advantages over traditional cognitive exercise therapies: appeal and accessibility. Video games that are appealing are easy to find and unlike traditional therapies, which must usually be conducted in an institutional setting, video games can be played at home, in school, or even on a train or bus. This attractiveness and convenience increases the potential of video-game cognitive training as a treatment method. McGraw et al. (2005), who used a dancing exercise game to treat children with ADHD, and Tárraga et al. (2006), who used Smartbrain to supplement treatment for seniors with Alzheimer's disease, are two recent examples of the clinical use of video games.

Professional skill training.

Professional skills in many domains rely on a great amount of training. In addition to formal professional "on-the-job" training, practice with video games may be able to produce transfer of training effects that enhance professional skills. For instance, Rosser et al. (2007) found a significant positive correlation between video game playing and surgical skills. Surgeons who demonstrated mastery of action video games had better laparoscopic skills than their non-player colleagues. This suggests the possible use of video games to help improve the professional skills of physicians. However, it should be noted that Rosser et al. (2007) did not conduct a training study to back up this suggestion.

In the military domain, video games are being used to recruit and train soldiers

(Macedonia, 2002). The highly popular game America's Army was developed for such purpose (America's Army, 2008; Belanich et al., 2004). It has now been updated to a third edition and there are versions for many computer platforms. In Canada, the video game IMMERSIVE (Instrumented Military Modeling Engine for Research using Simulation and Virtual Environments) was developed by DRDC (Defense Research and Development Canada) using modules from a commercial FPS game, Unreal Tournament 2004. IMMERSIVE has been used to test the use of combat identification (CID) systems in an urban combat environment (Jamieson & Wang, 2007).

Guidelines for Designing Games for Serious Purposes

Developing good games for training purposes, while still making the learning experience fun, requires a thorough understanding of the demands of the game and the cognitive processes that are required to satisfy these demands. Although much more research is needed to help develop useful guidelines, we propose a preliminary workflow for meaningful game development from a psychological perspective, based on the analysis presented in the second section of this paper. We also use an example to illustrate the workflow: Designing a game for healthy older adults to expand their narrowing FFOV for safer driving. In Table 2 we summarize the game attribute(s) and requirement(s) associated with each cognitive process; this is the most critical aspect of our recommended workflow.

---Insert Table 2 Here---

Workflow for game design.

1) Determine the purpose and psychological domain of the game. In our example, the purpose is to improve older adults' ability to detect targets and abrupt changes over a wide field of view. The psychological domain is attention.
2) List the cognitive processes that are relevant. In the example, they are attentional capture, selective attention, divided attention, and the distribution of attention.
3) List the game attributes and requirements. According to table 2, the attributes include distinguishing the targets among distractors, simultaneous tracking of several objects, and dealing with many unexpected visual events over a wide field of view.
4) Select a game theme to integrate all the attributes. We might use a sport theme for training seniors in our example application.
5) Be aware of individual differences in cognitive abilities in the target group and design the game to allow for a range of entries with different difficulty levels appropriate to these individual differences. In our example, some seniors may have poor visual acuity, slower preparation for motor responses, and low resistance to distraction.
6) Test the effectiveness of the new game by measuring the cognitive performance of individuals (non-players) from the population of interest before and after playing the game. In our example, we would use healthy older adults as participants.
7) If testing shows significant improvements, the initial development is successful. Otherwise, iteration of the workflow will be required.

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Table 1 Perceptual/cognitive functions exercised by different genres of video game

Perceptual/cognitive function		Game attribute or requirement	FPS	Racing	Maze
Sensory	Feature detection	Segmentation	❑❑❑❑❑	❑❑❑❑	❑❑❑
		Dimensionality	❑❑❑❑❑	❑❑❑❑❑	❑❑❑
Attention	Attentional capture	Abrupt onset events	❑❑❑❑❑	❑❑❑	❑
	Selective attention	Discrimination	❑❑❑❑❑	❑❑❑	❑
	Switch of attention	Task switching	❑❑❑❑❑	❑❑❑	❑
	Divided attention	Multiple attentional foci	❑❑❑❑❑	❑❑	❑❑
		Multi-tasking	❑❑❑❑	❑❑❑	❑
		Multiple object tracking	❑❑❑❑	❑❑❑	❑
	Distributed attention	Peripheral awareness	❑❑❑❑❑	❑❑❑	❑
Memory	Working memory	Decision making	❑❑❑❑❑	❑❑❑❑	❑❑
	Long term memory	Integrate knowledge	❑❑	❑❑	❑❑❑
Cognition	Spatial cognition	Navigation	❑❑❑❑❑	❑❑	❑❑
		Mental rotation	❑❑❑❑	❑❑❑	❑❑
	Problem solving	Puzzles	❑❑	❑❑	❑❑❑❑
	Emotion	Arousal (threat)	❑❑❑❑❑	❑❑❑❑	❑❑
Motor actions (preparation)	Judgement (accuracy)	Aiming	❑❑❑❑❑	❑❑	❑
	Speed (reaction time)	Rapid action	❑❑❑❑❑	❑❑❑❑	❑

Key: ❑❑❑❑❑ Very high ❑❑❑❑ High ❑❑❑ Medium ❑❑ Low ❑ Very low

Table 2 Game attributes or requirements associated with perceptual/cognitive functions

Perceptual/cognitive function		Game attribute or requirement
Sensory	Feature detection	Complex visual environment, with target objects in clutter
		Photo realistic three dimensional visual environment
Attention	Attentional capture	Abrupt onset visual events
	Selective attention	Presentation of enemies and team members
		Tracking some of the objects
		Many unexpected visual events
	Switch of attention	Dynamic environment, forced reaction to abrupt onset events
	Divided attention	Attending to multiple locations
		Multi-tasking
		Simultanous tracking of several objects
	Distributed attention	Abrupt onset events in the periphery
Memory	Working memory	Rapid decision making
	Long term memory	Integrate knowledge
Cognition	Spatial cognition	Unrestricted navigation, freedom of movement
		Mentally manipulate spatial information
	Problem solving	Puzzles
	Emotion	High threat level
Motor actions (preparation)	Judgement (accuracy)	Targeting
		Egocentric compatibility of visual inputs and motor outputs
	Speed (reaction time)	Time restriction on performance