Learning by Playing: Taking the Low Road and Coming out on Top

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This critical review discusses the expanding body of research showing the cognitive benefits of playing video games and seeks to establish a neurological understanding of how skill-transfer perceptual motor skills learned in video games can occur in relation to the Perceptual-Motor Skill Transfer Model proposed by Rosalie and Muller (2012). Using this model as a framework, studies examining the neural changes induced by video game are examined and their results are extrapolated upon to determine the extent to which skill-transfer can occur between video game environments and real-world tasks. Overall, research into the effects of video games on cortical areas indicates that significant changes in numerous areas related to perceptual learning and motor efficiency occur, suggesting an improvement in cognitive abilities related to these areas. Opposing viewpoints are discussed and inconsistencies in research are addressed by pointing to the conditions indicated throughout the research by which video game training regimens can be best suited to initiate the most improvement in cognition overall.

Keywords: video games, skill-transfer, cognition, attention, neuroplasticity, flow

Over the past few years, the video game industry has become increasingly popular, with the Entertainment Software Association of Canada (2014) reporting that 62% of Canadians own at least one dedicated gaming console. With the ever increasing encroachment of this expanding industry throughout Canada, it is important to consider the implications this may have on society in terms of how it can affect the cognitive abilities of gaming populations. Examining these effects will help to uncover the potential of video games for improving the performance of gaming populations on real-world tasks that also carry heavy cognitive loads. In fact, this potential has already been implemented in training programs such as in the Israeli Air Force, where video games have been shown to improve actual flight performance, prompting their military to incorporate video game trainers into their training programs before fighter pilots are brought into real planes (Gopher, Weil, & Bareket, 1994). In the laboratory, the literature has tended to report that people who play certain action video games perform better on tests of cognitive ability, such as visual motion direction discrimination and auditory tone location (Green, Pouget, & Bavelier, 2010; Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014; Liu, Cheng, & Huang, 2011). Moreover, research showing these improvements also suggests that cognitive processing skills acquired during video gaming are able to undergo far-transfer, where training in various video game tasks can improve performance in other cognitively demanding domains, such as laparoscopic surgery or even learning economic principles (Dobrescu, Greiner, & Motta, 2015; Giannotti et al., 2013). Some researchers are unable to replicate these effects, and due to the elusive nature of the far-transfer phenomena, the transfer observed in most other research has become a major point of contention within the field (Boot, Blakely, & Simons, 2011). One of the prevailing models explaining this transfer is that of Bavelier, Green, Pouget, and Schrater (2012). This model suggests that far-transfer is accounted for by gamers learning to make statistical inferences about the parameters of the task by drawing on previous experience within video game environments. Focusing primarily on executive functioning within the brain, the model fails to recognize significant contributions made by low-road cortical processes used in everyday cognition to make quick decisions about incoming stimuli in situations where conscious thought would be too slow, such as when reacting automatically to unexpected stimuli. The low-road processes of skill transfer observed in video game research may be facilitated by the effects of video games on areas of the brain associated with the formation of procedural memories – memories of task performance – common to both practiced and novel tasks, making for a more complete picture of how skill transfer occurs.

To briefly illustrate the manner by which subconscious processing could be responsible for far-transfer, a proposed model of how far-transfer takes place for gamers ought to be described. Rosalie and Muller's (2012) Model of Perceptual-Motor Skill Transfer asserts that skill transfer occurs when behaviour is goal-driven and performance-based, as this develops the ability of the mind to make probabilistic inferences about the likelihood of performing a successful action. Furthermore, skill transfer is dependent on anticipatory mechanisms which allow for the successful and timely application of learned skills when they are needed. Uniquely, their model also notes how skill transfer is a continuum of four variables which each contribute uniquely on a case by case basis to facilitate skill transfer. These variables include knowledge of the task at hand, the physical contexts of the task's environment, the temporal context of how quickly the task must be performed, as well as social contexts of who is present when the task is performed (Rosalie & Muller, 2012). Arguably, video games have the potential to contain all four of these variables, as flight simulator games give players knowledge of flight details, while the controller used during gaming may provide physical cues to laparoscopic surgeons using similar controllers to perform surgery. As well, the fast-paced nature of gaming environments demand that gamers are well-equipped to deal with new obstacles quickly and accurately, while the different forms of multiplayer gaming may lead to a better understanding of various social contexts. Of interest to cognitive research however, are the perceptual demands that gaming environments provide, and how exposure to these environments can affect neural substrates involved in basic cognitive processes. These are important as, when the player becomes more acquainted with one video game, the cognitive skills required to advance are reasonably able to transfer from one video game to the next, but because of the generalizability of these basic procedures, the same procedural memories stored for success in a video game environment may also be applied in the context of daily living as well.

In order to suggest that procedural memories of identical task elements can be separated from the context in which they were learned, it is worth briefly examining evidence of this in cortical studies. Specifically, in patients with damage to the medial temporal lobe, anterograde amnesia leaves the patient with an inability to form new declarative memories of facts and events (Smith, Frascino, Hopkins, & Squire, 2013). However, these patients can become quite proficient at novel tasks which they are trained to do, all the while reporting that they have no memory of the training ever having taken place (Gabrieli, Corkin, Mickel, & Growdon, 1993). This suggests that procedural memories do not necessarily need to be joined with any specific declarative knowledge of the context in which they were learned, and that procedures involved in perceiving, attenuating, and reacting to stimuli may be able to be applied outside of the context in which they were first learned. Importantly, in regards to gamers, this shows that as gamers learn procedural memories of how to respond quickly to in-game stimuli, they might then be able to apply these same procedural memories in the real world to respond quickly to real-world stimuli.

Distractor suppression, which refers to the ability to filter out task-irrelevant stimuli, is paramount to facilitating the acquisition of a new skill as it allows for complete focus on the task at hand. Therefore, video games that are able to improve distractor suppression would in turn supplement the learning of new skills in the real world by allowing the mind to allocate more mental resources to the formation of procedural memories necessary for the successful completion of the task. A model proposed by Geng (2014) defines neural mechanisms by which distractors are suppressed, allowing for some insight into the manner by which new growth occurs in the brain in response to behavioral and environmental factors. Geng (2014) proposes the existence of two different attentional pathways. These either specialize in the reactive suppression of distractors where irrelevant stimuli are attended to before suppression can occur, or in the proactive pathway wherein distractors are actively suppressed before they can be attended to. Within this model, both forms of suppression are highly reliant on the functioning of the prefrontal cortex, as well as areas of the brain which encode where to look next and where to set the attentional priority of each stimulus based on both goal-driven and decision processes. The effect of video games on these areas can be seen in training studies where increases in gray-matter volume and density are measured with Functional Magnetic Resonance Imaging (fMRI) before and after undergoing video game training regimens (Kühn et al., 2014). After playing thirty minutes a day over a two month training period, one of the areas that showed the greatest increase in volume was the right dorsal lateral prefrontal cortex (rDLPFC). The rDLPFC is a major contributor to overall executive functioning, and most notably, the rDLPFC tends to activate significantly more in response to executive functioning involving visuo-spatial tasks (Kühn et al., 2014). This is important because, as executive functioning is largely responsible for the proactive suppression of distractors in Geng's model (2014), this increase in volume in executive areas of the brain as a result of gaming is indicative of increase in the likelihood of cognitive improvement taking place. Relating this to the Model of Perceptual-Motor Skill Transfer, the effect of video games on these areas of the brain may facilitate skill acquisition by increasing amount of cognitive resources available to be used in the acquisition of new skills. As per the model, with the effective application of attentional resources, a gamer will be able to pay more attention to subtle details that may indicate incoming stimuli, rendering their anticipatory mechanisms more capable of facilitating the successful execution of previously learned skills in the context of novel tasks.

Low-road methods of far-transfer involve the automatization of domain-general procedures activated in both the context in which the skill was initially learned, as well as the new context in which the procedure is now applicable (Rosalie & Muller, 2012). To understand this however, mechanisms by which skill in video games can enhance cortical mass in areas related to in everyday cognition must be identified. Such processes are likely dependent on a large variety of brain areas including the basal ganglia, prefrontal cortex, and the visual system, as these areas are all involved in task learning to some degree (Censor, Sagi, & Cohen, 2012). Researchers looking into these areas using fMRI examined the neuroplasticity of regions associated with the functioning of working memory before and after playing fifteen, two-hour training sessions of *Space Fortress*, a game designed by psychologists for measuring skill acquisition and expertise (Lee et al., 2012; Nikolaidis, Voss, Lee, Vo, & Kramer, 2014). In particular, lateral and medial occipital areas typically involved with relating motor actions to their outcomes were shown to have a significant decrease in activation for groups that underwent video game training (Lee et al., 2012; Nikolaidis et al., 2014). This decreased activation indicates that the training had made it easier for these subjects to predict the outcomes of their actions. With less effort needed to make predictions in anticipation of incoming stimuli, video gamers may have an improved ability to form new procedural response patterns in response to novel contextual cues, enabling them to make better predictions about how to respond to real-world stimuli as a result. This ties in directly with Rosalie and Muller's (2010) Model of Perceptual-Motor Skill Transfer as it provides evidence of improved anticipatory mechanisms as a result of video game play.

Another way by which these changes could be enacted is through effects of video game training on white matter tracts. White matter is made up of myelinated axonal fibers that interconnect neurons from the various regions of the central nervous system with one another. Specifically, the white appearance of these tracts is due to the fatty myelin that wraps around each axon at regular intervals. The myelin helps to facilitate faster mental processing by insulating the neuronal fibers carrying action potentials from the soma to the synapse. In relation to video game studies, research conducted by Green and colleagues (2010) indirectly shows the effects of video games on white matter, as while the accuracy of scores were the same between gamer and non-gamer groups, reaction times of the gamers were observed to be approximately half that of the non-gamers. When, after this initial assessment, a group of non-gamers received training with an action video game, their reaction times were improved to the point of being comparable to the gamer groups. This finding suggests that while the processing capabilities of the non-gamers had not improved with training, the efficiency of the system involved had been improved drastically. Studies pointing to the effects of practice in general on white matter density show that axons have increased myelination after practicing cognitively demanding tasks (such as juggling), supporting the idea that there is an association between practicing cognitively demanding tasks and improved connectivity within the brain as a result of increased myelination (Scholz, Klein, Behrens, & Johansen-Berg, 2009). Furthermore, such changes might explain the results gathered by Green and colleagues (2010), as changes in white matter density provide a mechanism by which reaction times of subjects trained in such games could be substantially improved while maintaining the same level of accuracy. In the context of Rosalie and Muller's (2012) model, this would indicate an improved ability to respond quickly in response to temporal contexts, allowing gamers to, at the very least, keep up with fast-paced environments in the real world with complex visual inputs similar to the ones encountered in video games. By improving mental processing speeds through increased myelination, low-road processes are better equipped to deal with the sudden appearance of task-relevant stimuli, without executive control even needing to take hold.

Not all researchers agree that video game training is transferable to real-life situations. For example, Boot and colleagues (2011) argue that these changes could be attributed to a number of methodological errors found in many of the studies that show these improvements. In particular, the recruiting strategies used by video game researchers often use posters which explicitly ask for participants who play video games. These participants may feel that that they are expected to perform better than others in the experiment, leading to an improved measure of cognitive ability that occurs as a result of demand characteristics. While acknowledging the existence of studies that do make use of covert recruitment tactics, Boot and colleauges (2011) also point out that the only way to actually argue an effect of video games on cognition is to do training studies. Many training studies exist, but Boot and colleagues draw attention to the fact that control groups are difficult to generate in these experiments as the game given to control group participants may have an effect of its own on the cognitive abilities of gamers, possibly confounding the results. Such difficulties in constructing control groups are easily surpassed by using methods differentiating between casual games, which feature simple repetitive tasks, and action video games, which present gamers with complex visual environments and a wide variety of tasks that must be accounted for along differing timeframes (Bavelier et al., 2012). These casual games have been noted to improve problem solving skills in children, but in terms of perceptual-motor skills, they generally offer little benefit (Monjelat, Mendez-Zaballos, & Lacasa, 2012).

The type of game played is one of the most important factors to consider when facilitating the enhancement of cognitive skills in other domains. The research of Green and colleagues (2010) specifies that only gamers who play action video games are able to enact this change as the complex environments of action games requires the player to quickly respond to multiple onscreen stimuli. As well, action video games present the player with the threat of success or failure, based on their actions, which guides their performance and motivation for the many goals they must keep track of at any one time (Bavelier et al., 2012). These conditions are commonly present in first-person shooter games, racing games, real-time strategy games, and many others, giving a wide range to the number of games that could be classified as action video games. To succeed in these environments, one must stay focused on the task at hand while also being able to perform complex task-switching maneuvers in response to new threats that may temporarily obstruct the player from reaching their ultimate goal. This differs in kind from any casual video games, which are games where the player needs to only think through problems at their own pace, or partake in simple repetitive tasks to achieve goals (Baniqued et al., 2014). This is important to note as it provides a possible explanation for some of the inconsistencies seen in the research showing that the type of game played is vital in determining the extent to which neuroplastic changes will be actualized.

While researchers being able to say that video games make you smarter certainly sounds neat in media reports, not all studies report that video games are able to improve cognition. For example, Baniqued and colleagues (2014), after administering a training regimen of video games to a group of non-gamers, found that no skill transfer had occurred from the video game environment to tests of any cognitive ability. In fact, the scores of the group that received training were nearly identical to that of the active control group in tests designed to measure skill transfer. Another study, conducted by Erickson and colleagues (2010), looked specifically at neuroplasticity in the dorsal striatum, an area of the brain known for coding basic stimulus-response behaviour. Using the *Space Fortress* paradigm, they found that dorsal striatum volume was not altered by video game training, but that dorsal striatum volume could actually be used as a predictor for performance and skill acquisition within the game itself. This finding presents a rather interesting caveat as its implications suggest that people with larger dorsal stratums might simply be more drawn to play video games. This would imply that it is not so much the video games that improve cognition, but rather that gamers tend to be people who are already good at overcoming challenging tasks. However, considering the amount of studies where positive effects of training on far-transfer has been observed in non-gamer groups, the conditions under which training occurs must be examined more closely as it may be that certain combinations of the contextual variables listed in Rosalie and Muller's (2012) Model of Perceptual-Motor Skill Transfer may determine what training conditions are the most conducive to successful skill-transfer for certain cognitive tasks (Kühn et al., 2014; Lee et al. 2012; Nikolaidis et al, 2014).

The motivation and mental state of the player also have a significant effect on the extent to which skills are transferred to other domains. Flow states, which are classified as extreme levels of immersion and focus on a task, are usually achieved when the challenge levels of a task are at or just above the skill level of the person performing the task (Csikszentmihalyi, 1990). If the task is too difficult, the person enters an anxiety state, and if the task is too easy, the person may enter a boredom state. In a study conducted by Liu and colleagues (2011), untrained subjects underwent a series of training sessions wherein they played an action video game as their flow states were monitored. In boredom or anxiety states, Liu and colleagues (2011) noted that cognition was not improved in any of the cognitive assessment tasks. However, players who were able to achieve flow states, as indicated by self-report scales administered periodically throughout the gaming session, were able to experience any significant skill transfer after training. This suggests that future studies into the effects of video games on cognition in everyday life ought to take into account the flow state of research participants in order to determine whether or not the mental state of the players affects the extent to which far-transfer occurs.

Given the right contingencies, video games can improve cognition and help facilitate the acquisition of skills in ways that are transferable to real-world applications and implementations by supporting systems involved with procedural memory. Importantly, these improvements come as the result of neuroplastic changes in areas of the brain not only associated with executive functioning (Bavelier et al., 2012), but also in areas known to enact and assist in the processes underlying the formation and expression of procedural memory (Kühn et al., 2014; Lee et al., 2014; Nikolaidis et al., 2014). To add on, these procedural memories become instrumental in facilitating the transfer of cognitive skills from video games to real-world situations. In particular, not only are the processing capacities of these systems improved, but their efficiency may also be improved as the density and volume of the white matter tracts is increased through training in perceptually demanding tasks (Scholz et al., 2009). While certainly contingent on the presence of certain factors such as the nature of the game and the mental state of the player, far-transfer as a result of video game training seems to be entirely possible (Green et al., 2010; Liu et al., 2011). With the formation of procedural memories for motor programs that are common to both video game environments and real-world tasks, commercialized video games show promise in improving cognition in the daily lives of people.

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