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Video games as a tool to train visual skills

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Abstract. *Purpose:* Adult brain plasticity, although possible, is often difficult to elicit. Training regimens in adults can produce specific improvements on the trained task without leading to general enhancements that would improve quality of life. This paper considers the case of playing action video games as a way to induce widespread enhancement in vision.
Conclusions: We review the range of visual skills altered by action video game playing as well as the game components important in promoting visual plasticity. Further, we discuss what these results might mean in terms of rehabilitation for different patient populations.

Keywords: Video games, perceptual learning, plasticity, visual attention, rehabilitation

1. Introduction

There is much interest in understanding the factors that promote learning and brain plasticity. We are all waiting for the ultimate training experience where for a few hours of our time we could restore our eyesight, augment our attentional abilities and speed up our decision-making. The *status quo* in the field of training-induced plasticity is unfortunately more sobering. Whereas individuals can improve at a given task by training on that very task for hours on end, skill enhancement is typically limited to the trained task and shows little to no generalization to different, even highly related, tasks. This specificity is best illustrated in the field of perceptual learning which documents that perceptual learning can be specific to the trained eye, direction of motion or even retinal location (Fahle et al., 2002). Such specificity is a major stumbling block when it comes to rehabilitation of function. Indeed, the goal of a rehabilitation regimen is to ensure that it improves the quality of life of the patient, thus calling for training that will generalize to a wide array of situations and tasks.

Developing methods of overcoming known limitations in the capacity of the human nervous system to reorganize has become a major challenge in the field of neuroplasticity. Various approaches are being investigated which fall roughly into two main domains: direct pharmaceutical manipulations (Hensch, 2005), and training-induced learning (Levi, 2005; Sabel, 1999; Taub & Uswatt, 2006). Here we consider the case of video games as a tool to promote training-induced learning. Over the past decade, the possibility that perceptual and cognitive abilities are enhanced in video game players has raised much attention (for a review, see Green & Bavelier, 2006c). Indeed, it is striking to learn the variety of different skills and the degree to which they are modified in video game players: improved hand-eye coordination (Griffith et al., 1983), increased processing in the periphery (Green & Bavelier, 2006a), enhanced mental rotation skills (Sims & Mayer, 2002), greater divided attention abilities (Greenfield et al., 1994) and faster reaction times (Castel et al., 2005), to name a few. Although intriguing, this literature has little to say about rehabilitation unless the causal effect of game playing is unambiguously established. Unfortunately, only very few studies have established a causal link between video game play and changes in performance. This review focuses exclusively on this small literature.

First, we will describe the range of visual skills altered by video game playing; in particular, we will focus on a specific subset of video games known as action

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video games, as those games seem most efficient for visual learning. Second, we will review the type of video games that seem best in promoting visual plasticity. Third, we will discuss the possible reasons why action video games may be an efficient tool when it comes to promoting brain plasticity and visual learning. And, finally we will consider what these results might mean in terms of rehabilitation for different patient populations.

2. Visual skills and video game training

2.1. *Visuo-spatial attention*

The efficiency with which attention is distributed across the visual field can be measured using a visual search task (something akin to looking for a set of keys on a cluttered desk). One such task, called the Useful Field of View paradigm (UFoV) (Ball et al., 1988) was adapted to this purpose by Green and Bavelier (2003). Subjects were asked to localize a briefly presented peripheral target in a field of distracting objects (Fig. 1a). The experimental display was then heavily masked before subjects were presented with a probe display where they were asked to determine on which of the 8 possible spokes the target had been presented. Participants were male action video game players (VGPs) who played at least 5 hours a week for the previous six months, and male non-gamers (NVGPs) who had little (preferably no) video game experience in the previous six months. VGPs could more readily identify targets in a cluttered field than NVGPs (Fig. 1b). Interestingly, these effects extended to eccentricities beyond ones typically subtended during video game play, indicating generalization of learning to untrained locations.

These results demonstrate a performance difference between VGPs and NVGPs. Of course, it is not enough simply to document enhanced abilities in video game players. After all, it might be a case of a self-selecting population, where individuals who are innately better at these particular skills find it easier and therefore more enjoyable to master the video games. The only way to fully demonstrate causation, that playing action video games leads to increases in perceptual and cognitive skills, is to train a random sample of non-gamers on a video game and measure changes in their performance before and after training. Crucially, the amount of improvement induced by this training should be compared to a baseline treatment that controls for test-retest improvements and the Hawthorne effect (that individuals who are paid close attention tend to perform better). In the training studies we have performed, subjects trained on action video games (e.g., Unreal Tournament, Medal of Honor) improved more on the experimental tasks than subjects trained on non-action games (e.g., Tetris, The Sims). In this review, we will focus on studies that have included a training aspect in order to assure a causal role for video game play, as this is critical when talking about the use of video game training in practical applications.

In the UFoV experiment, non-gamers trained on action video games were better able to identify targets in a cluttered field than those trained on a non-action game (Fig. 1c), although these training effects are smaller than the differences between VGPs and NVGPs (see also Feng et al., 2007 for a replication and extension of these results). As with VGPs, the effects seen in the training study also extended to eccentricities beyond the video game training set-up, again indicating generalization of learning to untrained locations.

2.2. *Dynamics of visual attention*

The dynamics of visual attention can be measured with the attentional blink paradigm (AB) which tests how quickly attentional resources recover after being directed to a target (Raymond et al., 1992). Subjects are presented with a stream of quickly presented letters (one at a time, each for 100 ms) and are told to identify the letter in white (only one is white among all black letters). They are also told that 50% of the time the letter 'X' will appear somewhere in the stream of letters following the white letter (anywhere from directly after it to 8 letters after it; see Fig. 2a). At the end of each trial, subjects are asked to report the identity of the white letter as well as to say whether or not an 'X' was presented. For most subjects, when the 'X' is presented very soon after the white letter it is missed. It is thought that the subject fails to detect the 'X' because attentional resources are allocated toward processing the identity of the white letter and are therefore unavailable to process any new information. If the subject has already processed the white letter his attentional resources will be free to detect the 'X'. The amount of time it takes before being able to process the 'X' is called the attentional blink. VGPs show a smaller blink – both in terms of duration and magnitude (Fig. 2b). VGPs can process a rapid stream of visual information with increased efficiency as compared to NVGPs. In training studies, participants trained on action video games recover faster from the attentional blink than those trained on a control game (Fig. 2c).

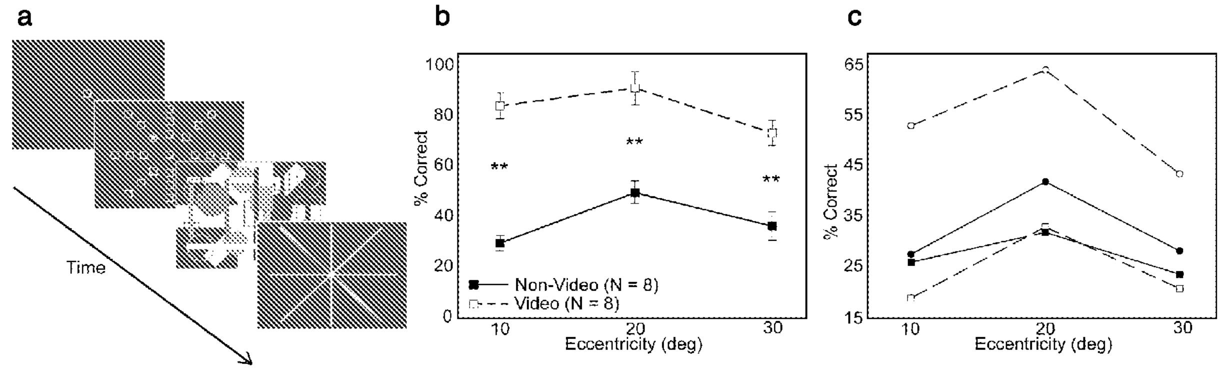

Fig. 1. Measure of attention over space using the useful field of view paradigm. (a) Sequence of displays. After a heavy mask, participants indicated the spoke on which the small target (filled shape within a circle) appeared. The spatial distribution of attention was tested by placing the target at different eccentricities. (b) Localization accuracy for VGPs & NVGPs. VGPs showed large enhancements in localization ability at all eccentricities. The superiority of VGPs at 30 degrees indicates that the enhancement of spatial attention observed in this population is not limited to trained locations. (c) Performance before (□, ■) and after (○, ●) training. At each eccentricity, the group trained on an action video game (open symbols, dashed lines) improved significantly more from their pre-test scores than did the control group trained on a non-action video game (closed symbols, solid lines). Error bars denote SEMs, $** = P < 0.01$. (From Green & Bavelier, 2003).

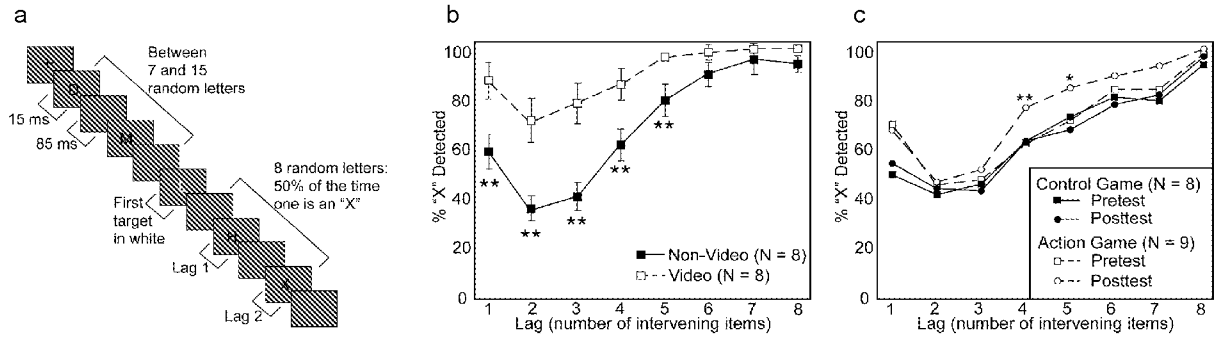

Fig. 2. Measure of attention over time using the attention blink paradigm. (a) Black letters were rapidly presented sequentially at fixation. At a random time in the stream, a white letter was presented. After this first target, an 'X' was presented at some point in the remainder of the trial, 50% of the time. After the trial, participants reported the identity of the white letter and indicated whether or not the 'X' was presented. Of interest is the performance of participants on detecting the 'X', given that they correctly identified the white letter. (b) VGP & NVGP performance. At early lags, VGPs performed better (less blink) than NVGPs; as lag increased, the effect of the attentional bottlenecks decreased, and, as expected, the performances of the two populations were comparable. (c) Performance before and after training. The group trained on an action video game recovered faster from the attentional blink than did the group trained on a non-action video game. Error bars denote SEMs, $* = P < 0.05$, $** = P < 0.01$. (From Green & Bavelier, 2003).

2.3. *Number of objects of attention*

Another property of attention is the ability to track several objects at once, as when keeping track of friends through a crowd. Previous research indicates that only a limited number of visual events (about 4) can be attended to simultaneously in this fashion. To measure the capacity of this attentional tracking system, the multiple object tracking paradigm (MOT) was used (Pylyshyn & Storm, 1988). The MOT task measures the maximum number of moving items that can be successfully tracked within a field of distracting moving items. In this task, participants are presented a number of randomly moving circles. At the beginning of the trial, some subset of the circles is cued. The cues then disappear and participants are required to keep track of the previously cued circles (now visually indistinguishable from uncued circles) as they continue to move around the screen. The moving circles must be tracked for several seconds before one is highlighted and the participant must make a yes (was initially cued) or no (was not initially cued) decision. On average, VGPs are able to track ∼2 more items than NVGPs. Training on action video games likewise increases a non-gamer's capacity to track multiple objects (see Fig. 3, Green & Bavelier, 2006b).

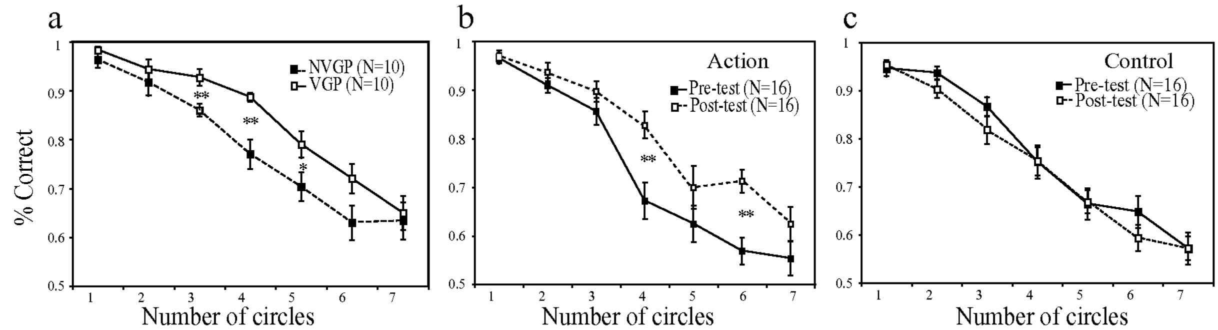

Fig. 3. Measure of overall attentional capacity using multiple object tracking. (a) VGP & NVGP performance. VGPs demonstrate a substantial increase in the accuracy with which multiple items can be tracked compared to NVGPs. The effect is most pronounced for the 3–5 item range. (b) Pre- and post-training performance of the action video game group. Participants show a marked improvement with training. (c) Pre-and post-training performance of the non-action video game group. Performance was identical before and after training in the control group. Error bars denote SEMs, $* = P < 0.05$, $** = P < 0.001$. (From Green & Bavelier, 2006b).

Enhancement of the number of attended objects in action gamers has also been confirmed using a counting task in which participants are presented with a random number of objects (from 1 to 12) for a short period of time and asked to report how many have been presented. The accuracy of VGPs stayed near ceiling for larger numerosities than that of NVGPs indicating a better ability at apprehending displays with large numerosity. This enhanced accuracy was observed in the absence of changes in reaction times suggesting that action gamers may be able to attend to more objects thanks in part to a more efficient visual short-term memory system (Green & Bavelier, 2006b).

2.4. Other aspects of attention

Not all aspects of attention seem to be equally affected by action game play. For example, exogenous attention, or the efficiency with which a salient cue in the environment captures attention, does not appear to change with video game play (Dye et al., submitted). Using a Posner cueing paradigm called the attentional network task (Fan et al., 2002), participants are asked to detect the orientation of a target arrow (pointed left or right) presented either above or below a central fixation point while the speed and accuracy of their responses are measured. A given trial may be cued as to the timing of the target presentation, or cued to its location. By contrasting each of these cued conditions with a no cue baseline, one can measure *alerting* (the ability to allocate attention at a given time), and *orienting* (the ability to allocate attention to a given location). While there is a baseline reaction time difference between VGPs and NVGPs (overall VGPs have faster RTs than NVGPs), the way an exogenous cue initially controls the allocation of attention was found to be comparable in VGPs and NVGPs. The lack of orienting and alerting effects are especially intriguing seeing as playing action video games relies heavily on being alert and orienting efficiently to any abrupt changes in the environment. It is exactly these types of results that make the field of training rehabilitation challenging; simply because something is present in the training phase, does not guarantee it will be altered with training. Video games are full of exogenous events (enemies appearing at random locations and times, grabbing your attention), and yet playing action video games does not impact exogenous attention (see also, Castel et al., 2005).

Overall, action video game training greatly enhances several aspects of visual attention, such as the ability to effectively distribute attention over space and time, as well as the number of items that can be attended. Yet, few changes are observed in the way an exogenous cue initially captures attention. These results call for more studies to better characterize those aspects of attention that are changed and those that are not, with the aim of understanding the mechanisms by which video game experience enhances visual skills.

The next important question for visual learning is whether or not playing action video games can produce more fundamental changes in visual functions. Indeed, action video game training will be most useful for rehabilitation if it not only enhances different aspects of visual attention, but also alters more fundamental aspects of visual processing. Although work in this area is only very recent, the available data suggest that action game playing, by modifying the spatial and temporal resolution of visual processing, may affect rather basic visual skills, such as visual acuity in the presence of flankers.

2.5. *Spatial resolution of visual processing*

Identification of a small letter in the middle of a white page is easier than if the same letter is surrounded by other letters. This phenomenon, termed crowding, reflects an important limitation of our visual ability. Patients with poor vision, such as amblyopes (Bonneh et al., 2004) often complain of not being able to read small print, with letters being unstable and jumbled as they stare at the page. Crowding can be measured by having subjects identify the orientation of a letter flanked by other letters, and determining the smallest distance between target and distractors at which the target can be correctly identified. It has been shown that this measure of spatial resolution is enhanced (i.e., crowding is reduced; Fig. 4) by playing action video games (Green & Bavelier, 2007). Accordingly, Green and Bavelier (2007) have shown that distractors have to be brought nearer to the target in action game players than in control participants before target processing is disrupted. These increases in spatial resolution were seen at both central and peripheral locations and, interestingly, even at locations beyond the trained region of space (i.e., covering a larger visual area than the video game training set-up), again suggesting generalization of the effect to untrained locations.

In the same experiment, Green and Bavelier (2007) showed that visual acuity, a measure of the fine detail that can be seen, is superior in VGPs than in NVGPs, not only in peripheral vision but also in central vision (acuity was measured at 0, 10, and 25 degrees eccentricity). Although suggestive, there was no effect of action video game training on foveal or peripheral visual acuity in a 30-hour training study, limiting the practical implications of this result. Training effects are generally much smaller than 'expert' (gamer vs. non-gamer) effects, so it is possible that a skill as basic as visual acuity may be modifiable by training, but only with many more hours of training than the other skills studied thus far. It is certainly the case that the VGPs enrolled in our studies have many more than 30 hours of training (most likely in the range of thousands of hours).

2.6. *Temporal resolution of visual processing*

Ongoing research indicates that temporal aspects of early visual processing are altered along with the spatial characteristics reviewed above. Temporal masking studies provide a measure of the time needed for visual processing. For instance, one can measure the contrast threshold of a gabor patch flanked in *time* (as opposed to *space*) by other gabor patches. In particular, it is well known that the visibility of a briefly presented target is disrupted when a mask is presented shortly thereafter (Bonneh et al., 2007; Polat & Sagi, 2006). Using such a visual backward masking paradigm, Li and colleagues (2006) have shown that action video game playing results in reduced backward masking, suggesting faster integration time of visual processing.

Changes in the spatio-temporal dynamics of visual processing could allow for greater sensitivity, and thus changes in aspects of vision as basic as contrast sensitivity or flicker fusion. These possibilities are presently being investigated. For now, the available studies indicate a clear shift in the spatio-temporal properties of visual processing at least in conditions where target and distractors compete in space or in time. Such effects are compatible with a large-scale change in the functional connectivity of the networks of neurons that support vision. Indeed, the generalization of learning observed across visual tasks and visual stimuli points to a common mechanism at the source of these effects. One appealing hypothesis is that action video game play leads to more efficient integration of sensory information, and therefore enhanced visual skill performance (Green et al., 2007). As yet, it remains too early to say whether these enhancements may be due to better noise exclusion, signal enhancement, or a combination of both (Dosher & Lu, 1998; Lu et al., 2006).

3. Not all video games are created equal

Not all types of video games change visual functions. The work reviewed above focuses exclusively on *action* video games. Training studies in which performance of the experimental group (trained on an action video game) shows greater improvement than that of the control group (also trained on a video game), clearly show that *action* video games have an edge when it comes to visual plasticity. What is it about certain games that contribute to changes in vision? Surely, the characteristics of the game itself are directly related to the types of processes that are modified by playing the game (e.g., ability to effectively ignore distractors, speed of processing, monitoring of the periphery, tracking multiple moving objects, etc.). To tease apart which facets of a video game contribute to the types of enhancements we have been discussing, Cohen and colleagues (2007) surveyed the literature and looked at the effects of playing different video games on visual attention.

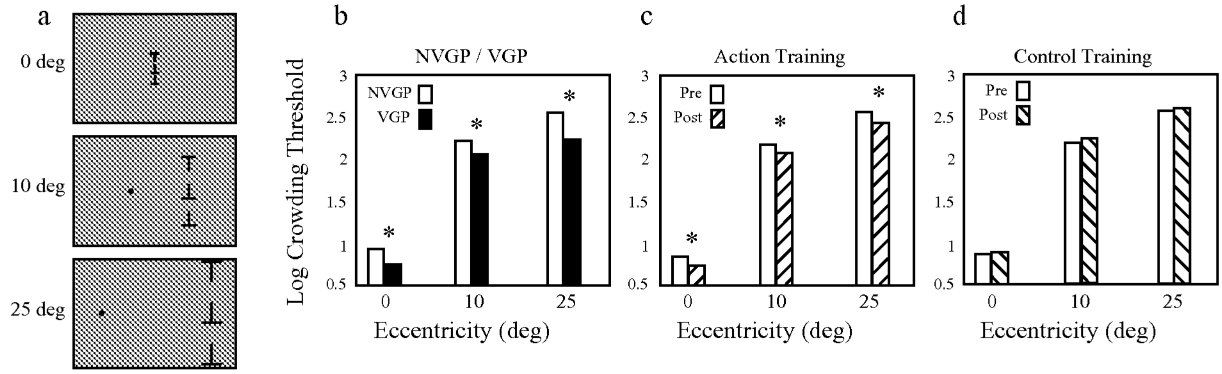

Fig. 4. (a) Crowding stimuli consisted of three T shapes randomly oriented either right side up or upside down. Participants indicated the orientation of the central T. In separate blocks, three eccentricities were tested (0, 10, 25 degrees). The flanking Ts were presented first away from the central T and then brought nearer and nearer until the participant's performance threshold was reached. (b) VGP & NVGP performance. VGPs demonstrate a significantly reduced crowding threshold compared to NVGPs, meaning they can resolve the central T orientation with closer flanking Ts. (c & d) Pre- and post-training performance of the action video game group and the control group. Participants in the action-trained group show a marked reduction in crowding with training. For the control group performance was identical before and after training. (*$= P < 0.05$). (From Green & Bavelier, 2007).

They describe a gradient of efficiency across the games used – with games requiring precise but rapid visual analysis to guide accurate aiming movements appearing to be the most efficient. We review here the effects of playing different video games on visual learning. Games that have been studied so far fall broadly into five categories.

The first category concerns first-person or third person action games, like Unreal Tournament or Medal of Honor. These games place heavy demands on visual attentional systems as players are constantly monitoring the periphery for frequent, widely distributed, unpredictable events that require quick and accurate aiming responses. To do well, players need to track many fast moving objects while ignoring distractors. Perhaps most importantly, these games require motor actions that are spatially aligned with the detailed visual world of the game; for instance, the precise visuo-motor control needed when aiming at small moving targets. Importantly, the stakes of missing the target are high as the gamer's character may die. Finally, these games have the advantages of having many entry levels ensuring that the gamers will face a challenging yet doable game experience. Not all games labeled action video games are equally efficient though. For example, individuals trained on an interactive version of America's Army played over the internet improved less on the attentional skills measured than individuals trained on Unreal Tournament. Two factors are suspected to have led to decreased learning in that case. First, the interactive version of the game made it difficult to control the pace of the game as well as the skill level of the opponent. The inability to tailor the training paradigm to the level of the player probably contributed to the reduced effects. Second, significant portions of America's Army are devoid of the fast-paced, visually-guided aiming actions believed to trigger visual learning (such as when the player needs to learn the code of conduct within the military).

The second category concerns sports or racing games. Anecdotal evidence from the study of children who play sports/racing games suggests these games may provide some visual enhancements (see also Trick et al., 2005). However, 12 hours of training on the sports game Harry Potter: Quidditch World Cup, led to no clear enhancements of visual skill. Whether different sports/racing games that have faster motion (e.g., Need for Speed), more objects to keep track of (e.g., NBA 2k7), or greater emphasis on peripheral processing (e.g., FIFA 07) would lead to different results is an open question.

The third category concerns games that require fast visuo-motor control, like the game Tetris, but in which the visual analysis does not require target identification amongst distractors and the motor control part is not focused on visually-guided aiming. Past work indicates lesser improvement after playing Tetris than playing an action game. Tetris differs from action video games in several ways. First, there are only a limited number of objects for players to attend to at any one time. Second, the spatial location of these objects is highly predictable. Thus, although attentionally demanding, the player knows where and when to pay attention at all times. Third, only a limited number of shapes are used throughout the game allowing the learner to memorize spatial configurations and moves, rather than having to adapt to a constantly changing environment (Destefano & Gray, 2007; Sims & Mayer, 2002). This last feature allows for the development of excellent expertise at the game itself, but what is learned is less likely to generalize to other environments. Yet, it is worth noting that Tetris has been reported to improve visual attention slightly more than slower games (see below) suggesting that the pace of the game is an important determinant of learning, with fast-paced games showing an edge when it comes to enhancing aspects of vision.

The fourth category is strategy games, like SimCity or Civilization, which a number of our studies have used as control games. These simulation and role-playing games are not fast-paced. The displays can be visually complex, and while there may be multiple things to keep track of in these games, it is never in a way that is taxing to the visual system, but rather in terms of cognitive tactics and planning. These games make it clear that being confronted with a complex visual environment is not enough to guarantee visual learning. It remains possible that if the games were sped up, strategy games could also show benefits on visual function.

Lastly, the fifth category consists of various computer puzzle and card games (e.g., Solitaire, Hearts, Minesweeper, Free Cell). In these games, players can choose how to allocate their attention. At no point are there unexpected events one needs to react to. Responses do not have to be particularly quick or spatially accurate, but rather rely on the development of good problem solving strategies often assisted by excellent use of mental imagery. As expected, these games trigger no changes in visual attention.

Clearly, *action* video games produce the greatest enhancements (both spatial and temporal) to the visual system. Given our present knowledge, we can list a number of video game features that seem desirable for promoting visual learning. The games should be fast-paced and unpredictable. The fast pace requires frequent interaction and allows for multiple opportunities for learning, as each action made is met with some form of behavioural reinforcement. The lack of predictability (events of unknown time of arrival and location) enforces distributed attention and leads to enough errors to signal that adjustments in behaviour are needed, promoting a high level of active engagement and learning. It goes without saying that the game needs to be motivating, as boredom will lead to non-compliance in a rehabilitation regimen. Thus, the difficulty of the game should be fully adaptable, as each player should be engaged at a level that is challenging yet not overwhelming. Indeed, task difficulty has been demonstrated to be a significant predictor of the generalization of learning (Ahissar & Hochstein, 2004). The factors listed so far should not come as a surprise to scholars of the field of learning. The notion of entry level is solidly routed in the principle of incremental learning, nicely illustrated by the work of Knudsen and colleagues in the barn owl (Linkenhoker & Knudsen, 2002). Adult barn owls are able to acquire new interaural time difference (ITD) maps, important for sound localization, after wearing prismatic spectacles that horizontally shift the visual field, but only when the prismatic shift is experienced in small increments. The use of large increments leads to systematic learning failures. Similarly, the importance of providing the system with an error message and of having motivating reward values associated with each action is well-documented in the reinforcement learning literature (Dayan, 2001; Sutton & Barto, 1998). Rather the new insights on learning brought about by video game training studies are two-fold. First is the possibility that the whole is more than the sum of its parts; video game training includes several factors that promote learning within a single training regimen. While each of the factors on its own may have only a weak effect, when combined together they can lead to widespread changes. Second, the video game work shows that significant perceptual enhancements can be brought about when the perceptual part of the training is tightly linked to perceptually guided actions such as aiming. Certainly, the fact that the outcome of these actions is associated with high reward values also helps. Another study in barn owls (Bergan et al., 2005) nicely illustrates these points. Two groups of adult owls were fit with prismatic spectacles for 10 weeks. One group was provided with food, while the other group had to hunt live prey to feed themselves. The auditory maps of the group that hunted showed much greater adaptive shifts (by a factor of 5) in their auditory maps even though the experiences of the two groups differed for only short periods of time each day. These findings highlight the idea that the use of sensory information to guide reaching or aiming movements can dramatically increase the amount of plastic change induced.

Much remains to be done to precisely unpack how different types of experiences affect different perceptual and cognitive functions. A detailed analysis of the component processes engaged during action video game play would be extremely useful as a way to document factors that facilitate visual learning. Other dimensions such as the role of immersive, multisensory or multi-modal games on learning should also be explored. Although enriched environments are often thought to be beneficial for brain plasticity (which in turn leads to the prediction that richer, more immersive games would lead to better learning), most of the previous studies have been carried out in animal models and have compared deprived to normally-raised animals (Bergan et al., 2005). Therefore, the extent to which this principle is applicable to the approach being considered with video games is unknown. As these types of questions are addressed, the potential efficacy and specificity of a video game training regimen will almost certainly increase.

4. How video game play might enhance learning

The variety of different skills and the degree to which they can be altered by playing action video games is surprising, especially considering the lack of generalization and transfer reported in the perceptual learning literature. Action video games differ from standard perceptual learning paradigms in several ways, but perhaps most importantly in the type of motor responses required. As reviewed above, the motor responses used when playing action video games are not simple yes/no button presses, but more refined and coordinated aiming motions. Players are essentially acting through an avatar, constantly moving around the scene and aiming at different targets. Why would implicating the motor system be important for inducing plastic changes? In contrast to the field of perceptual learning, many studies have documented large-scale training-induced changes in motor functions following extensive motor training, such as in musicians, athletes and braille readers. For example, using MEG, Elbert and colleagues (1995) demonstrated that practiced string players (e.g., violin, cello, guitar players) have an increased cortical representation of the fingers of their left (string) hand. And in braille readers, there is an increase in the motor cortex representation of the finger muscles most used during braille reading (Pascual-Leone et al., 1993; Pascual-Leone & Torres, 1993). This work establishes that cortical circuits, at least those involved in motor programming and execution, are capable of exhibiting sizeable plastic reorganization. The video gaming training literature raises the question of whether one can capitalize on these plastic capabilities and induce visual plasticity through intensive visuo-motor training. Perhaps it is the pairing of the two systems (motor and visual), which is enhancing visual learning in video game training. Today there are newer generations of games (e.g., Nintendo Wii) that are even more embodied, with controllers that allow players to respond with more realistic motor responses depending on the demands of the game. This type of visuo-motor enrichment, combined with the rewarding feedback of games could prove to be even more beneficial.

Of interest are not only the perceptual and cognitive consequences of training on video games, but also the underlying neural factors that might be involved in learning. Koepp and colleagues (1998) studied the neurochemical consequences of video game play using positron emission tomography (PET). They measured the amount of dopamine released when subjects play an action video game. Dopamine is a neurotransmitter that allows the modulation of information to be passed from brain area to brain area and is thought to play a role in a wide range of human behaviours (e.g., addiction, pleasure, and learning). For example, most addictive drugs produce pleasure by increasing the amount of dopamine in the brain. They found a massive amount of dopamine released in the brain during video game play, in particular in areas thought to control reward and learning. Importantly, research in rats shows that apart from providing the well-known sensation of excitement, dopamine may be important in facilitating brain plasticity following perceptual training (Bao et al., 2001). In this study, one group of rats experienced the paired presentation of a 9 kHz tone with stimulation of dopamine neurons. Another group received the tone alone. After training, Bao and colleagues observed an expansion of the part of the primary auditory cortex devoted to the tone only in the group of rats that had dopamine neurons simultaneously stimulated, leading to the hypothesis that the dopamine neurons play a critical role in perceptual learning. Large surges of dopamine seen in people while playing video games could play a similar role as in the rat study just described – faster and more widespread learning. Other neuromodulators such as acetylcholine and norepinephrenine, which like dopamine, have been implicated in both reward/arousal and increased cortical plasticity (Bao et al., 2001; Kilgard & Merzenich, 1998) may also play a role. Regardless of the exact mechanism, a better understanding of the neuroanatomical and neurochemical substrates of video game play and of the learning it induces will aid in the development of training and rehabilitation possibilities.

5. Video game training and rehabilitation

The differences that we measure in the laboratory elicited by training on action video games (e.g., faster RTs, increased ability to track multiple objects, faster attentional recovery time, less crowding), may not have huge influences on quality of life for most people, but there are several subsets of the population that could greatly benefit from these improvements, specifically, populations that have experienced a deficit in visual processing due to central nervous system deficiencies (such as amblyopes, stroke patients with visual field deficits, and the elderly). As we alluded to earlier, one of the major obstacles in developing efficient rehabilitation methods is the specificity of most perceptual learning paradigms. Yet, as we have just described, playing action video games changes several aspects of visual attention (spatial, temporal, and overall capacity), as well as other types of visual processing (crowding, temporal masking). Thus, for once, there seem to be positive effects that can be of use in real life situations.

Amblyopia is a developmental visual disorder, cortical in nature, and characterized by several functional abnormalities of spatial vision, including reduced contrast sensitivity, increased effects of crowding, and abnormal contour integration. While the long-standing view was that these visual deficiencies are irreversible after childhood, more recently, researchers have been availing themselves of the effects of perceptual learning to train adults with amblyopia (Levi, et al., 1997; Li & Levi, 2004; Li et al., 2005; Polat, Ma-Naim et al., 2004; Zhou et al., 2006). These training techniques sometimes involve many thousands of controlled trials on spatial vision tasks over the course of several months. Although performance on such tasks as Vernier acuity, positional acuity, letter recognition and contrast sensitivity does improve, most enhancements are very specific (e.g., with limited transfer to the untrained eye at the trained location for Vernier acuity – Levi et al., 1997). These sessions can be repetitive and boring for patients and so compliance to the training regimen is an issue. Research is ongoing in several laboratories to investigate the extent to which some form of game playing may be beneficial to this patient population. For instance, Waddingham and colleagues have developed the Interactive Binocular Treatment system (I-BiT^{TM}) for the treatment of amblyopia (Eastgate et al., 2006; Waddingham et al., 2006) which puts forward an interesting idea. Subjects play video games in a modified virtual reality set-up where the "interesting" part of the game is primarily displayed to the amblyopic eye while the fellow eye receives information about the background, with common elements in both eyes to allow for fusion, thereby training binocularity in an engaging way. This is a particularly appealing method as it has the potential to both improve vision in the amblyopic eye as well as teach the patient to use both eyes in concert rather than relying on only one eye at a time.

There is also much interest in developing training regimens aimed at diminishing the visual deficits caused by stroke. Two categories of therapy for stroke patients with blind fields are presently available. In scanning compensatory therapy, patients are trained to make compensatory eye and head movements to bring items from the missing to the intact visual field (Kerkhoff et al., 1992; Nelles et al., 2001; Pambakian & Kennard, 1997; Zihl, 1995). While this type of compensatory therapy is not aimed at changing the boundaries of the blind field, it does lead to notable improvements in everyday tasks such as reading, with patients demonstrating both increases in reading speed and a reduction in reading errors (Kerkhoff et al., 1992). The second category includes different types of vision restoration therapies whereby the so-called 'border zone' of the blind field is systematically stimulated in an effort to diminish the visual field deficit (Huxlin et al., 2007; Marshall et al., 2007; Sabel et al., 2004; Sahraie et al., 2006). The restorative therapies tend to be similar to the perceptual learning studies in that they use training regimens comparable to the experimental tests that are used to assess the amount of improvement. A number of these studies report improvement on the trained task in the blind field, but it remains unclear whether such changes improve the quality of life of the patient. A training regimen that has received much interest recently is vision restoration therapy (VRT) which requires patients to train their peripheral vision everyday by using a software package loaded at home on their personal computer (Sabel et al., 2004). The idea behind VRT is that regular stimulation at the border of the blind field may recruit surviving neurons and shift their receptive fields to represent part of the lost field, especially just inside the scotoma boundary. The relative success of each type of therapy is still very much a question of debate. A review by Booumeester and colleagues (2007) concluded that the efficacy of VRT depended on the method of the perimetric measurements and on the fixation control used. Whether VRT-trained patients may improve because of cortical plasticity or of advantageous eye movements for the learned task is still quite controversial (Glisson, 2006;

McFadzean, 2006; for a reply see Kasten et al., 2006). Of course from the patient's perspective any improvement is good, regardless of its underlying cause. A critical issue for training therapies whose goal is to alter cortical functioning – be it VRT or possibly video game playing – is to determine whether neurons within the ischemic zone may indeed be salvaged through stimulation. To the extent that the action video game training discussed here is believed to alter the efficiency of processing within the visual cortex, it does hold promise for inducing cortical changes. However, it is not known whether damaged cortex, be it by a stroke or trauma, can be recruited in such a fashion.

Another population that might benefit from training-induced increases of transfer of learning and plasticity is the elderly. There is a natural decline in many processing capabilities with age. These include decreases in manual dexterity, hand-eye coordination, ability to respond quickly (RTs), and general cognitive abilities (e.g., short-term memory). One obvious practical implication of video game training for the elderly might be to maintain or improve the ability to drive, as many of the skills useful for driving safely are enhanced by video game training. The question remains whether or not training might help to slow, stop, or even reverse some of these age-related effects.

6. Conclusions

The adult nervous system retains the capacity for plasticity both with everyday experience and following injury; yet, this plastic potentiality often remains difficult to reveal. While it is possible to show improvements on nearly any task with practice on that very task, training that produces performance enhancement in a range of situations remains elusive. It is, however, this transfer of learning that is key for efficient rehabilitation. One possible training regimen that has shown generalizable enhancements in terms of visual attention and more basic visual processing is playing action video games, offering a new avenue for visual rehabilitation.

A better understanding of the neural mechanisms underlying the effects of video game play and perceptual learning will lead to improved clinical treatments and the potential of training regimens with favourable outcomes. The difficulty is in choosing the right gaming experience, as not all video games affect visual processing equally. Currently, the largest enhancements to visual processing are seen with training on action video games. These games most likely combine a number of factors that when implemented together allow for extensive reshaping of visual functions. As such, they offer a unique opportunity to improve our understanding of the factors that promote brain plasticity and visual learning. Video games are not a panacea however; further research is needed into the link between a given brain function and the type of experience needed to enhance it. As the lack of effect of gaming on exogenous attention makes clear, not all brain functions are equally amenable to plastic changes. The challenge in the field of training-induced plasticity lies in understanding both the experiential factors that foster plasticity as well as the intrinsic constraints that may limit its expression.

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