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Perceptual Learning During Action Video Game Playing

C. Shawn Green,[a] Renjie Li,[b] Daphne Bavelier[b]

[a]*Department of Psychology, Center for Cognitive Sciences, University of Minnesota*
[b]*Department of Brain and Cognitive Sciences, Center for Visual Science, University of Rochester*

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Abstract

Action video games have been shown to enhance behavioral performance on a wide variety of perceptual tasks, from those that require effective allocation of attentional resources across the visual scene, to those that demand the successful identification of fleetingly presented stimuli. Importantly, these effects have not only been shown in expert action video game players, but a causative link has been established between action video game *play* and enhanced processing through training studies. Although an account based solely on attention fails to capture the variety of enhancements observed after action game playing, a number of models of perceptual learning are consistent with the observed results, with behavioral modeling favoring the hypothesis that avid video game players are better able to form templates for, or extract the relevant statistics of, the task at hand. This may suggest that the neural site of learning is in areas where information is integrated and actions are selected; yet changes in low-level sensory areas cannot be ruled out.

Keywords: Perceptual learning; Video games

1. Introduction

Humans have an incredible capacity to improve their performance on a given task given some manner of repeated practice. This is true across many domains, including the focus of this review—the perceptual domain (Ahissar, Nahum, Nelken, & Hochstein, 2009; Fahle, 2005; Karni & Bertini, 1997; Sagi & Tanne, 1994). There is no doubt that humans demonstrate marked perceptual learning as a result of experience; however, how to effectively manipulate the various characteristics of the learning process, including its rate and extent, remains largely unresolved (Ahissar & Hochstein, 1997; Cepeda, Pashler, Vul, Wixted, &

Correspondence should be sent to C. Shawn Green, Department of Psychology, Center for Cognitive Sciences, University of Minnesota, N218 Elliott Hall, 75 East River Road, Minneapolis, MN 55455-0344. E-mail: csgreen@umn.edu

Rohrer, 2006; Schmidt & Bjork, 1992; Seitz, Nanez, Holloway, Tsushima, & Watanabe, 2006; Vygotsky, 1978). In the field of perceptual learning it is this latter characteristic, the extent or generality of learning, which has proved particularly problematic. Although the literature has shown that humans can improve on virtually any perceptual task, these studies have also typically demonstrated a remarkable specificity of learning. Enhancements are observed only in the trained task, with little to no transfer of learning being observed even for very similar untrained tasks. This high degree of specificity is a major impediment in the attempt to train or rehabilitate individuals, where the overarching goal is typically to increase the individuals' quality of life (which thus necessarily requires general learning). Here we review the literature on one training paradigm, action video game experience, which leads to the type of highly general learning that is necessary if the outcome is to have practical, real-world applications.

2. What are action video games?

In the following review, we will discuss a number of perceptual and attentional processes that are significantly enhanced through action video game experience. However, before discussing these effects, it is important to first describe the characteristics that identify a particular video game as an ''action'' video game. This is particularly important, as it is only this limited subset of video games, and not all video games in general, that have been shown to have beneficial effects on vision (Cohen, Green, & Bavelier, 2007). Although there are no hard and fast quantitative rules that one can apply to perfectly classify video games into their various genres, action video games all share a set of qualitative features, including extraordinary speed (both in terms of very transient events and in terms of the velocity of moving objects), a high degree of perceptual, cognitive, and motor load in the service of an accurate motor plan (multiple items that need to be tracked and/or kept in memory, multiple action plans that need to be considered and quickly executed typically through precise and timely aiming at a target), unpredictability (both temporal and spatial), and an emphasis on peripheral processing (with important items most often appearing away from the center of the screen). First-person shooters (such as *Halo* or *Medal of Honor* where the player ''looks through'' his/her character's eyes) and third-person shooters (such as *Gears of War* and *Grand Theft Auto* where the player views his/her character from above or behind) are prototypical examples of action video games. Hence, when we discuss ''action video games'' or ''action video game players,'' we are referring specifically to this category and not to all video games in general. Indeed, one remarkable feature of the work reviewed below is that it demonstrates that not all types of complex and rich visual environments equally foster perceptual learning. Understanding those components specific to action video games that promote learning across a wide range of visual tasks may hold the key to the development of general-learning training paradigms.

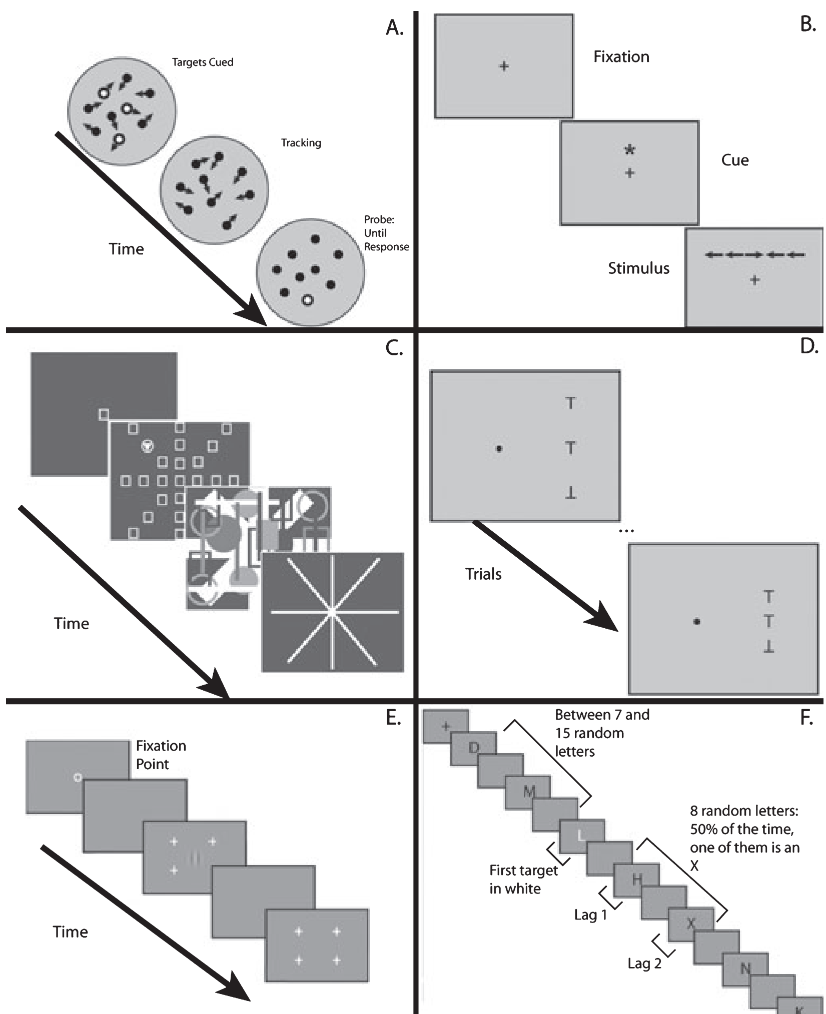
Action video game experience has been shown to enhance performance on a wide variety of tasks, from multiple-object tracking to contrast detection (for a recent meta-analytic review in which the size of many of these effects are converted into a common statistical framework, see Ferguson, 2007). For ease of exposition, these tasks can be loosely organized along three lines (although we note there is substantial category overlap for many of the tasks below): tasks that require the flexible allocation of attentional resources (Fig. 1A,B), tasks that measure the spatial characteristics of vision (Fig. 1C,D), and tasks that measure the temporal characteristics of vision (Fig. 1E,F).

3. Flexible allocation/amount of attentional resources

Enhancements in the availability of attentional resources and the flexibility with which they are deployed have been observed in action video game players (VGPs) in a number of tasks, including the multiple object-tracking task (Pylyshyn & Storm, 1988), an enumeration task (Dehaene & Cohen, 1994), the perceptual load task (Lavie, 1995), and the Attentional Network Task (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The multiple object-tracking task measures the number of moving target items that can be successfully tracked within a field of distracting moving items. The number of items that can be tracked is thought to provide an index of the number of items that can be simultaneously attended and therefore of the capacity of the visual attentional system (Fig. 1A). VGPs were able to track approximately two more items than nonaction video game players (NVGPs; Green & Bavelier, 2006b) with comparable effects being observed by Trick, Jaspers-Fayer, and Sethi (2005) as well as our group (M. W. G. Dye & D. Bavelier, unpublished data) in children who play such fast-paced video games (Fig. 2). Similar effects were also observed in the enumeration paradigm, where VGPs were able to accurately count more quickly flashed dots than NVGPs (Green & Bavelier, 2006b). In the perceptual load and ANT tasks (Fig. 1B), the subjects' task is to quickly identify a target in the presence of distractors. According to the perceptual load theory outlined by Lavie (2005), whenever available attentional resources exceed that which is necessary for a given task, the remainder unavoidably ''spills over'' to adjacent areas. When these adjacent areas contain response competitors, this spill over will be manifested as a compatibility effect (slower RTs when the target and distractor lead to different responses). Consistent with the findings above, increased compatibility effects were observed in the VGPs, even those as young as 7 years old (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2006a). Together these results suggest a clear enhancement in the availability of attentional resources and the flexibility with which they are deployed.

4. Spatial characteristics of vision

Several paradigms have been used to assess the efficiency with which VGPs process information spatially over the visual field. For instance, we have compared performance in VGPs and NVGPs on the useful field of view task (Fig. 1C), a task initially developed to assess the driving fitness of elderly citizens (Ball, Beard, Roenker, Miller, & Griggs, 1988). This task requires subjects to localize a briefly flashed (<20 ms) target shape at one of three possible eccentricities (10°, 20°, 30°). Spatial attention is required to perform this task as the target shape is presented within a field of distracting shapes, which must be rejected in order for the target to be efficiently localized. VGPs demonstrated far superior performance as compared to NVGPs on this task across all eccentricities (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2006a), a result that has also been obtained in school-aged children. Similar results were obtained by West, Stevens, Pun, and Pratt (2008), who contrasted VGPs and NVGPs on a continuous spatial oddball detection task. In their task, subjects were presented with a number of ‘‘swimmers’’ (either 15 or 30 moving circles with tiny oscillating line segment arms) distributed across a wide field of view (up to 30° of eccentricity). On a certain number of trials, one of the ‘‘swimmers’’ became a target (the ‘‘swimmer’’ stopped moving and increased the oscillation of its ‘‘arms’’ akin to someone drowning). The subjects' task was to accurately detect the presence of these targets. VGPs far outperformed NVGPs on this task across eccentricities and set sizes. Finally, we have also measured the



spatial resolution of visual processing in VGPs and NVGPs using a standard crowding paradigm (Toet & Levi, 1992). In this task, flanking objects above and below a center target negatively affect the ability to discriminate the orientation of the center target (Fig. 1D). The critical measure in this task is the size of the ''crowding region'' or ''region of spatial interaction,'' which is essentially the minimum distance between the center target and the flanking distractors that still allows for a criterion level of performance. Across a range of eccentricities (0°, 10°, 25°), VGPs showed significantly reduced crowding regions as compared to NVGPs (Fig. 3; Green & Bavelier, 2007). Together these results suggest a clear enhancement in the spatial characteristics of vision.

5. Temporal characteristics of vision

A direct demonstration of a change in the temporal dynamics of visual processing in VGPs has been obtained by measuring the rate at which contrast information is integrated. Presentation duration was parametrically varied from 10 to 180 ms in a standard two-interval forced choice contrast detection task (Polat & Sagi, 1993; Fig. 1E). In this task, VGPs were seen to have significantly faster integration times, as reflected by the ability to reach criterion performance with a shorter presentation time (Li, Polat, Makous, & Bavelier, 2009). Additional evidence for faster dynamics of processing in VGPs comes from studies comparing masking and the attentional blink across populations (Green & Bavelier, 2003; Li et al., 2007). For example, VGPs show a substantially reduced attentional blink (Fig. 1F)

Fig. 1. Subset of psychophysical tasks. (A) *Multiple-object tracking*: Subjects view multiple moving circles. At the beginning of a trial some subset (1–7) of circles are cued. These then become visually indistinguishable from the distracting circles for several seconds during which time the subject must mentally track the previously cued circles. Finally, one circle is probed; the subject must answer yes or no, was this one of the initially cued circles (Green & Bavelier, 2006b)? (B) *Attentional-network task*: Subjects first view a fixation circle followed by a cue that may be either temporally, spatially, or both temporally and spatially informative. Following the cue, the target stimulus (center arrow) appears and may be flanked by either compatible or incompatible distractors. The subject is to indicate the direction (left/right) of the target as quickly and accurately as possible (Dye et al., 2009). (C) *Useful field of view*: Subjects view a fixation box followed by a very brief (<20 ms) stimulus presentation. Stimulus presentation is immediately followed by a heavy pattern mask and a response screen. The subject's task is to indicate on which of the eight radial spokes the target (filled triangle within a circle) appeared (Green & Bavelier, 2006a). (D) *Crowding*: Subjects are asked to indicate the orientation of the center ''T'' (right-side up/upside down) while ignoring the flanking distractor ''T''s. As the flankers are brought closer to the center ''T'' they begin to negatively affect performance. The crowding threshold is the target-to-flanker distance at which target performance is at 79% (Green & Bavelier, 2007). (E) *Contrast detection*: Subjects are asked to determine in which of two intervals a low-contrast gabor is presented. Presentation duration was parametrically varied from 10 to 180 ms in order to measure the rate at which contrast information is accumulated (Li et al., 2009). (F) *Attentional blink*: Subjects view a rapid-serially presented stream of letters. They have two tasks: First, they must indicate the identity of the white letter in the stream; second, they must indicate whether the letter ''X'' appeared in the stream after the white letter. When the ''X'' is presented close in time to the white letter (i.e., ''Lag 2'' or the second item after the white letter), detection is often impaired (Green & Bavelier, 2003).

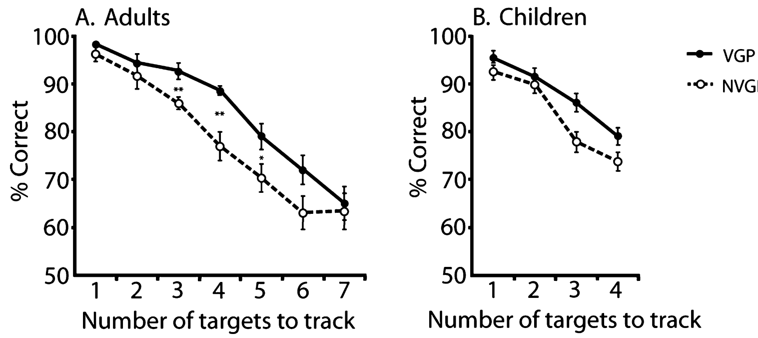


Fig. 2. Enhanced multiple-object tracking ability in action video game players (VGPs) and nonaction video game players (NVGPs). Although VGPs and NVGPs show similar accuracy when only one or two moving targets need to be tracked, VGPs clearly outperform NVGPs as the number of moving targets increases beyond this range (panel A—adapted from Green & Bavelier, 2006b; panel B—adapted from Trick et al., 2005)

as compared to NVGPs in both adults (Green & Bavelier, 2003) and school-aged children (Dye & Bavelier, 2007). Thus, together these results suggest an enhancement in the temporal characteristics of visual processing.

6. What is not changed by action video game experience

Although VGPs have been seen to possess enhancements in a number of aspects of vision, it does not appear that all aspects are modified. For instance, within visual attention, orienting or the process by which attention gets summoned by an exogenous cue appears to be similar in VGPs and NVGPs. In a task that used the Posner cueing paradigm to orient attention to the location of a 100% valid cue, Dye et al. (2009) showed

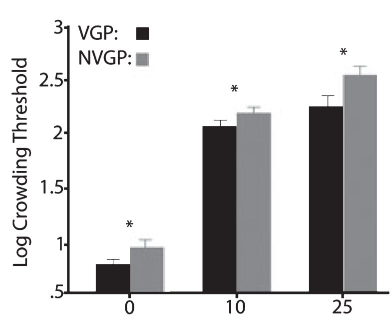


Fig. 3. Crowding thresholds. Action video game players (VGPs) show reduced crowding thresholds (minimum center-to-center distance between target and flanking distractors that allows for a criterion level of accuracy) as compared to nonaction video game players (NVGPs). This effect is seen when targets are presented foveally, at 10° of eccentricity, and at 25° of eccentricity, which is beyond the trained locations (adapted from Green & Bavelier, 2007).

equal performance across groups when an exogenous cue is used; this was found in both adults and children. Castel, Pratt, and Drummond (2005) reported similar inhibition of return between VGPs and NVGPs, also indicating similar exogenous attention across groups. However, these studies do not rule out the possibility that an exogenous cue may initially speed up processing in VGPs to a greater extent than in NVGPs; for instance, the greater temporal offset noted in VGPs than in NVGPs by West et al. (2008) in a temporal order judgment task is consistent with such an initial increase in processing. Yet a complete investigation of the dynamics of orienting as a function of video game experience is still lacking; at the SOAs tested so far, the net effect of an exogenous cue appears comparable across groups.

Another aspect that seems unchanged is alerting, or the ability to make use of a temporally informative cue. Using the Attentional Network Task, Dye et al. (2009) report a similar magnitude of the attentional alerting effect in VGPs and NVGPs. Finally, inconclusive results were found in the rate of visual search by Castel et al. (2005). Although a significant interaction was observed between game playing and set size (signifying the possibility of an effect), this interaction dropped out when the lowest set size was removed (suggesting that RT floor effects may have been at the root of the interaction).

7. Causation and training

Although many individuals play action video games as part of their everyday lives, comparing the performance of these ‘‘experts’’ with ‘‘nonexperts’’ does not necessarily allow us to conclude that action video game *experience* is at the root of any observed enhancements in perceptual processing. As is the case in any set of experiments where individuals who naturally choose to engage in a particular activity are compared with individuals who do not engage in the activity (e.g., sports: Kioumourtzoglou, Kourtessis, Michalopoulou, & Derri, 1998; Lum, Enns, & Pratt, 2002; music: Hetland, 2000; Rauscher et al., 1997; even radiology: Sowden, Rose, & Davies, 2002), population bias is a constant concern (as individuals who are naturally endowed with a given attribute or skill set will tend to participate in activities that reward that particular attribute or skill set). It is therefore essential to demonstrate a definitive causative link between a given form of experience and any enhancement in skills by training ‘‘nonexperts’’ on the experience in question, and observing the effects of this training.

Furthermore, an appropriately designed training study will include, in addition to an experimental group that is trained on the potentially enhancing regimen, a group that controls for a wide variety of potential confounds inherent to training studies. These potential confounds include the effect of test–retest (i.e., how much improvement can be expected simply from taking the test a second time) and just as importantly, psychological and motivational effects such as the Hawthorne effect (Lied & Karzandjian, 1998), wherein individuals who have an active interest taken in their training and performance tend to, all other things being equal, outperform individuals where no such interest is taken. Studies that include only a no intervention, no contact control group cannot distinguish between the content of the training regimen and these psychological/motivational factors as the source of any observed improvement (Drew & Waters, 1986; Goldstein et al., 1997; Kawashima et al., 2005; Willis et al., 2006).

Finally, as video games are known to strongly elicit the autonomic changes characteristic of the ''fight-or-flight'' response (Hebert, Beland, Dionne-Fournelle, Crete, & Lupien, 2005; Segal & Dietz, 1991; Shosnik, Chatterton, Swisher, & Park, 2000), it is important to assess performance levels at least a full day after the cessation of training in order to ensure that the observations are not contaminated by purely transient effects (e.g., level of circulating hormones, activity of neuromodulatory systems, etc.). As such transient effects are known to exist (for instance, the classic ''Mozart effect''; Rauscher, Shaw, & Ky, 1993), it is impossible to interpret studies where the posttest is administered immediately following the cessation of the training regimen as a permanent change in performance or behavior. As an aside, we note that the majority of the literature on video games and violence/aggression have tested participants shortly after playing rather than several days after playing, and thus they may reflect transient effects rather than the type of long-lasting changes studied here (Bushman & Anderson, 2009; Carnagey & Anderson, 2005; Carnagey, Anderson, & Bushman, 2007).

Training studies designed with the above characteristics in mind have been conducted in the majority of the experiments described in the previous two sections (Feng et al., 2007; Green & Bavelier, 2003, 2006a,b, 2007; Li et al., 2007; Li et al., 2009; although see Boot, Kramer, Simons, Fabiani, & Gratton, 2008, for a failure to see effects of training). In a typical training study, nonvideo game players were pretested on the tasks in question before being placed into one of two groups. The experimental group was trained on an action game for between 10 and 50 hours (depending on the study), whereas the control group was trained for the same length of time on a nonaction video game. At least a full day after the end of the video game training, performance was reassessed with those scores being compared to the pretest values. In all cases, the group trained on action video games was seen to improve by a significantly larger amount than the control group, thus establishing a causal link between action video game experience and enhanced processing. Furthermore, in two of these studies, the subjects were tested a third time, long after the cessation of training from several months to several years (Feng et al., 2007; Li et al., 2009). In both cases, the majority of the training-related enhancements had been retained over this time frame (Fig. 4). The lasting nature of the video game–induced changes is essential if the goal of such training is practical in nature.

8. Mechanisms

Whether by design, chance, or gradual evolution of the product, many task characteristics known in the field of psychology to greatly promote learning are present in today's video games (see Gentile & Gentile, 2008; Green & Bavelier, 2008). For instance, unlike standard psychophysical tasks, which are typically quite boring, video game experience is known to be physiologically arousing and psychologically motivating (Hebert et al., 2005; Przybylski,

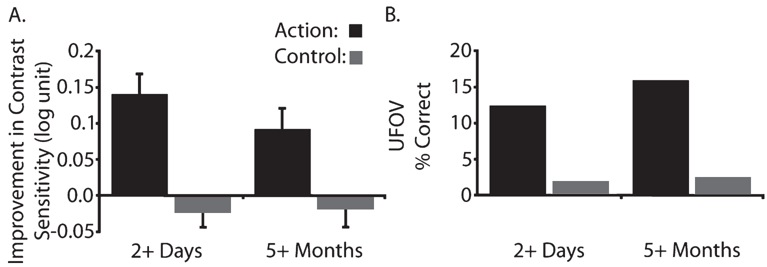


Fig. 4. Persistence of video game training effects. In order for a training paradigm to be practically relevant, the beneficial effects of the training need to be long lasting. The performance improvements in contrast sensitivity (panel A—adapted from Li, Polat, Makous, and Bavelier, 2009) and the useful field of view (UFOV) (panel B—adapted from Feng et al., 2007) are plotted as a function of time elapsed between training and posttest. Effects of training are not only seen a few days after training (2+ days) but also last for at least 5 months after the cessation of training (5+ months).

Ryan, & Rigby, 2009; Segal & Dietz, 1991; Shosnik et al., 2000). Perhaps not surprisingly for anyone who has suffered through a particularly dull class, arousal and motivation levels are known to substantially modulate learning and task performance. The function is thought to be U-shaped (arousal: ''Yerkes-Dodson Law,'' Yerkes & Dodson, 1908; motivation: ''Zone of Proximal Development,'' Vygotsky, 1978), with regimens that produce very low levels of arousal and motivation leading to less learning than regimens that engender relatively higher levels of arousal and motivation. Other traits inherent to video games known to promote learning include the utilization of small incremental increases in task difficulty (i.e., starting easy and progressing to more challenging—Ahissar & Hochstein, 1997; Linkenhoker & Knudsen, 2002; Sireteanu & Rettenbach, 1995—see also the concept of ''scaffolding'' in educational psychology), and variability in task and input (Brady & Kersten, 2003; Kornell & Bjork, 2008). Although a more thorough description falls outside of the scope of this review, we also note the large literature on the development of ''perceptual expertise'' in which training sets/tasks are also typically much more variable than in traditional perceptual learning studies and in which significant transfer (at least within the overarching training domain) is often observed (Palmeri, Wong, & Gauthier, 2004). Finally, action video games result in the activation of brain areas known to signal reward and promote cortical plasticity (Bao, Chan, & Merzenich, 2001; Koepp et al., 1998).

However, the actual mechanism(s) underlying the myriad changes discussed above (as well as the much broader literature on the effect of action video games on speeded RTs that unfortunately did not fall within the scope of this review—Dye, Green, and Bavelier, in press; Green & Bavelier, 2006c for reviews) remain to be elucidated. Many of the effects of video game experience have been seen in what are thought of as ''attentional'' tasks and thus could potentially be explained by mechanisms thought to underlie selective attention (Kastner & Ungerleider, 2000; Shipp, 2004; Yantis & Serences, 2003). However, recent results have demonstrated enhancements in tasks that cannot be readily attributed to selective attention (Li et al., 2009). Visual selective attention, as it is typically conceived of in the literature, is only called upon when a target needs to be selected in time or space from among distractors or when uncertainty exists regarding the spatial location or temporal onset of the target. Yet VGP-related enhancements have been observed in very simple tasks where targets were presented in isolation at known place and time of occurrence, precluding much contribution from attentional processes. For example, VGPs exhibit higher visual acuity than NVGPs as exemplified by their ability to discriminate smaller letters (Fig. 5A; Green & Bavelier, 2007). Similarly, VGPs exhibit enhanced contrast sensitivity as measured by their ability to read digits in dimmer shades of gray (Fig. 5B; C. S. Green & D. Bavelier, unpublished data—paradigm based on Strasburger, 1997) or detect low-contrast gabors (Li et al., 2009). Although 30 h of action video game training was not enough to induce changes in letter acuity or digit contrast in NVGPs, the causal effect of action game training on such basic visual skills was demonstrated by a 50-h training study of the contrast sensitivity function (Li et al., 2009). Therefore, an ''attentional'' mechanism cannot parsimoniously explain the entirety of the VGP data.

Several of the neural models developed for perceptual learning are consistent with the observed changes. Such neural mechanisms for perceptual changes typically include sharpening, gain enhancement, map expansion, and/or changes in feedback connectivity to better tune the visual system to task demands (Gilbert & Sigman, 2007; Li, Piech, & Gilbert, 2004; Schoups, Vogels, Qian, & Orban, 2001; Yang & Maunsell, 2004). The behavioral changes noted after action video game playing are more likely to be mediated by a combination of these mechanisms rather than one specific one. Indeed, the fact that action video game playing changes vision at so many different levels is not easily accounted for by present neural mechanisms of brain plasticity and is a somewhat counter-intuitive result in the face of the high specificity reported in the perceptual learning literature.

Recent work points to a few avenues by which transfer of learning may be fostered during visual training. Training on an easy task has been shown to lead to greater transfer of learning than training on a difficult task (Ahissar & Hochstein, 1997). More recently, transfer of learning has been shown to be under the control of the precision required by

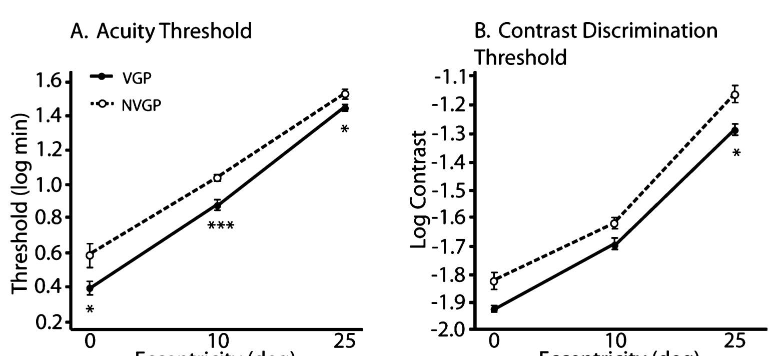


Fig. 5. Improvements in ''nonattentional'' tasks. Action video game players (VGPs) have enhanced performance in a number of tasks where the target appears alone at a known time and location (and thus would not require attention as it is commonly conceived of in the literature), including acuity (discriminate right side-up from upside-down ''T''—panel A, adapted from Green & Bavelier, 2007) and contrast discrimination (panel B, identify the low contrast letter—unpublished data). NVGPs, nonaction video game players.

the task tested at the time of transfer rather than the difficulty of the training task per se (Jeter, Dosher, Petrov, & Lu, 2009). Transfer of learning is reduced when the transfer task requires a high degree of precision as compared to a lower degree of precision, irrespective of the difficulty of the training task. Finally, enforcing that learning happens at more than one location during the training phase also appears to foster transfer of learning (Xiao et al., 2008). In some ways, the effects of action video game playing could be argued to conform to any or all of these theories; for instance, games start easy and become gradually more difficult, transfer to low-precision tasks requires only a few hours of training (10 h), and most games require attending to many locations. However, there are also effects that go well beyond the boundaries defined by these theories. Transfer to high-precision tasks is possible and only requires 50 h of action game playing, transfer of learning is seen at locations well beyond the trained ones, and, ask any novice, action video game playing is not an ''easy'' task. A lesson from this work is that many more factors are likely to conspire to promote transfer of learning. Among those, promoting speed of processing, enhancing self-enjoyment and self-efficacy, and facilitating flexible allocation of processing resources appear to be key components that when combined may lead to the remarkable degree of learning transfer noted after action game playing. A more systematic evaluation of these factors and how they interact with perceptual learning should be a fruitful avenue of research.

It is interesting to consider the case of action game playing in the context of the possible mechanisms for improvement in performance that have been proposed following perceptual learning. The two main ones include noise reduction, which has been associated with the effects of visual attention, and the availability of a better template for the learned task, which has been linked to several forms of highly specific perceptual learning (Lu & Dosher, 2008). An enticing hypothesis is that video game experience, like perceptual learning, improves the ability to extract task-relevant statistics from the environment and thus form better templates for the task at hand. But, unlike perceptual learning, these changes would not be hardwired as the result of exposure to the same, repeated visual pattern. Rather, the improvement would result from a dynamic resetting of the connectivity as the subject is asked to perform the task. By reshaping neural networks on the fly to extract more accurate statistics from their environment, VGPs may be able to display improvements in a variety of tasks, accounting for the wide transfer of learning discussed above. A possible neural site for such learning may be in areas where information is integrated and actions are selected (e.g., LIP, FEF, SEF) rather than in low-level sensory areas (Connolly, Bennur, & Gold, 2009), although we cannot exclude a reshaping of low-level areas on a very short time scale through feedback and/or lateral interactions.

9. Practical applications and future directions

The research outlined thus far has been primarily theory-driven; yet the potential practical implications of this work are numerous. For instance, there is some evidence that video game experience may delay, slow, or reverse the steady decline in perceptual, cognitive, and motor function that occurs as a result of the natural aging process (Basak, Boot, Voss, & Kramer, 2008; Clark, Lanphear, & Riddick, 1987; Drew & Waters, 1986; Whitcomb, 1990—although note that not all of the training games used above would meet our criteria for ''action video games''). Video game experience may also be helpful as training aides in other populations with visual deficits such as amblyopia (Li, Ngo, Nguyen, Lam, & Levi, 2008). In addition to these populations who suffer from less than normal perceptual processing, there are several classes of occupation that would benefit from ''more than normal'' perceptual processing. Accordingly, there is evidence that video game experience may be relevant in training jet pilots (Gopher, Weil, & Bareket, 1994) or laparoscopic surgeons (Rosser et al., 2007). Feng et al. (2007) have demonstrated that action video game training can reduce or eliminate the typical gender gap in spatial abilities (males typically outperform females in tasks such as mental rotation) that may have further practical implications, as these spatial abilities have been associated with success in science and mathematics (see also Mayo, 2009, for a review of the use of video games—albeit not necessarily action video games—in the teaching of science, technology, engineering, and math). What remains an open question, and will be exceedingly important if video games are to become viable tools for teaching a wide variety of skills, is the best way to interweave or embed desired content within a game environment without eliminating the characteristics (pace, immersion, divided attention, arousal, motivation, etc.) that make video games efficient learning paradigms.

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