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Increasing Speed of Processing With Action Video Games

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ABSTRACT—*In many everyday situations, speed is of the essence. However, fast decisions typically mean more mistakes. To this day, it remains unknown whether reaction times can be reduced with appropriate training, within one individual, across a range of tasks, and without compromising accuracy. Here we review evidence that the very act of playing action video games significantly reduces reaction times without sacrificing accuracy. Critically, this increase in speed is observed across various tasks beyond game situations. Video gaming may therefore provide an efficient training regimen to induce a general speeding of perceptual reaction times without decreases in accuracy of performance.*

KEYWORDS—*video games; processing speed; visual attention; impulsivity; learning transfer*

Playing action video games—contemporary examples include *God of War*, *Halo*, *Unreal Tournament*, *Grand Theft Auto*, and *Call of Duty*—requires rapid processing of sensory information and prompt action, forcing players to make decisions and execute responses at a far greater pace than is typical in everyday life. During game play, delays in processing often have severe consequences, providing large incentive for players to increase speed. Accordingly, there is anecdotal evidence that avid game players react more readily to their environment. However, it remains unknown whether any reduction in reaction time (RT) really generalizes to tasks beyond video-game playing and, if it does, whether it makes gamers more impulsive and prone to making errors. In short, are expert video-game players (VGPs) just “trigger happy,” or does video-game playing really improve RTs on a variety of tasks without a concomitant decrease in accuracy? The possibility of identifying a single training task that can lead to RT improvements across a variety of unrelated tasks is of great interest but remains controversial in the field of speeded-response-choice tasks (in which observers must choose among alternative responses or actions as rapidly as possible). On such tasks, decreases in RT are typically accompanied by decreases in accuracy. This is termed a speed–accuracy trade-off, with speeding up resulting in more mistakes. One exception is when individuals are trained on such speeded tasks. Performance on the trained task is then improved (faster RTs, but no speed–accuracy trade-off); however, little or at best limited transfer to new tasks is observed, limiting the benefits of training (Pashler & Baylis, 1991). Interestingly, flexible or integrated training regimens—requiring constant switching of processing priorities and continual adjustments to new task demands—have been argued to lead to greater transfer (Bherer et al., 2005). Action-video-game playing may be an extreme case of such flexible training.

Here we consider the possibility that action-video-game training leads to faster RTs on tasks unrelated to the training and, thus, for the first time may offer a regimen leading to generalized speeding across tasks in young adults.

ACTION VIDEO GAMES AND SPEEDED-CHOICE RT TASKS

The possibility that playing video games affects perceptual and cognitive skills has received much interest lately. Most past studies have compared VGPs to novice video-game players (NVGPs) using tasks that measure RTs in order to draw conclusions about performance. Although usually not the primary focus of these studies, they invariably show that the VGPs are faster overall than those who do not play such games (Bialystok, 2006; Castel, Pratt, & Drummond, 2005; Clark, Lanphear, & Riddick, 1987; Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994). This is perhaps unsurprising given the fast pace of games considered in these studies. There are, however, two surprising characteristics of these RT decreases: (a) the consistency in speed-of-processing advantages for VGPs across a range of tasks, and (b) the fact that there is no speed–accuracy trade-off. These points are illustrated by the following meta-analysis,

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which examines the reported RTs of avid action gamers versus those of novices across a number of studies.

Figure 1 shows a *Brinley plot* comparing the RTs of VGPs and NVGPs on a range of speeded-choice RT tasks. A Brinley plot is a type of scatter plot, with each data point reflecting the performance of two different groups on the same experimental condition—the performance of one group is plotted on the X-axis and that of the other group on the Y-axis. The data points included in Figure 1 come from seven studies containing a total of nine experiments, each including various experimental conditions. For each experimental condition, an average RT score for VGPs and for NVGPs was extracted, producing a total of 89 data points. These data points were extracted from tasks as markedly dissimilar as detection of a flashed stimulus, looking for a letter in a field of other letters, and indicating the direction of an arrow while ignoring arrows pointing in the other direction. Accordingly, the magnitudes of the measured RTs cover a wide range—from a few hundred milliseconds to nearly two seconds. There are several points of interest to note. First, VGPs were found to be consistently faster than NVGPs (with Cohen's *d* effect sizes ranging from 0.48 to 1.47 depending upon the task, suggesting moderate to large effects). Second, there was no difference in accuracy (92.76% vs. 92.75% across all conditions), suggesting that the VGPs were not sacrificing accuracy in order to respond faster. Third, and perhaps most importantly, the magnitude of this effect is well described by a straight line relating VGP and NVGP RTs, which suggests a single common underlying change in VGPs that results in faster processing across tasks and conditions.

It is important to note that a few studies (Clark et al., 1987; Green, 2008) have indicated that these faster RTs can be trained by action-video-game play, therefore establishing causality (as opposed to strictly correlative studies where population bias is a significant concern). RTs in NVGP individuals were assessed before and after action-video-game training, and these results were then compared to NVGP individuals trained on control

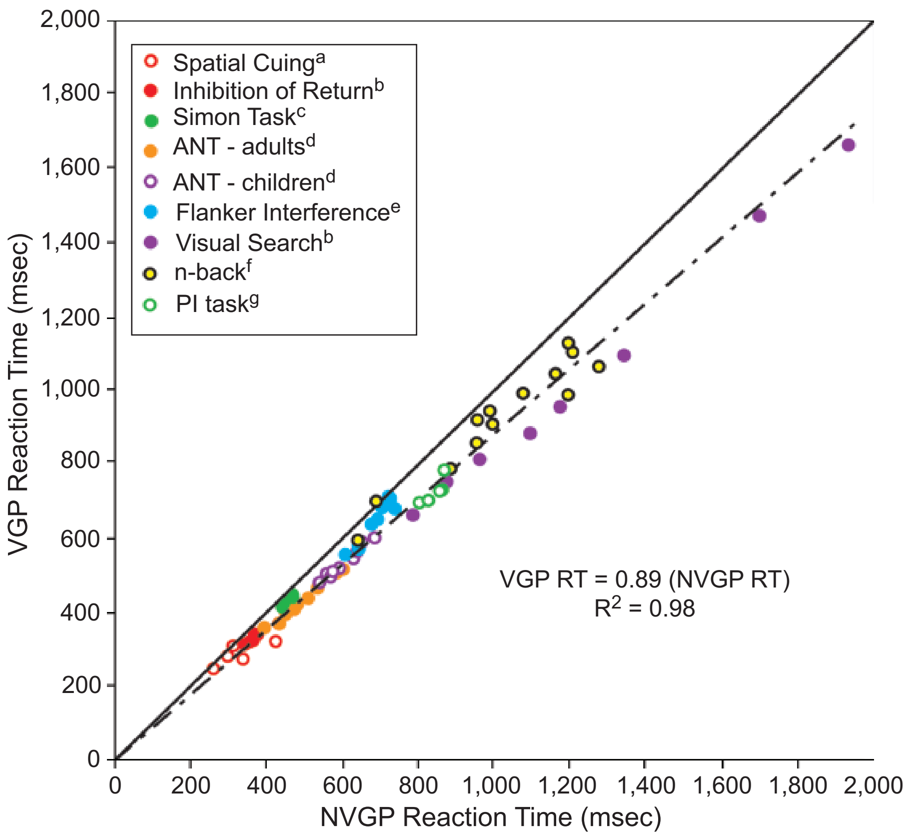

Fig. 1. A Brinley plot showing the reaction time (RT) of non-video-game players (NVGPs) on the X-axis versus that of expert video-game players (VGPs) on the Y-axis, for 89 different experimental conditions from nine different types of task. For each experimental condition, the RTs of VGPs and NVGPs were retrieved and plotted as one separate data point. A simple linear function (y = mx) was used to describe the relationship between VGP and NVGP RTs (dashed line). VGPs responded 11% faster than NVGPs across a wide range of RTs (VGP RTs = .89 × NVGP RTs, $R^2 = 0.98$). Importantly, similar accuracy was observed across groups, ruling out an explanation in terms of simple speed-accuracy trade-off (VGP accuracy = 0.99 × NVGP accuracy, $R^2 = 0.92$). The studies are (a) Greenfield, deWinstanley, Kilpatrick, & Kaye (1994); (b) Castel, Pratt, & Drummond (2005); (c) Bialystok (2006); (d) Dye, Green, & Bavelier (2009); (e) Green & Bavelier (2003); (f & g) Bavelier & Bailey (2007).

non-action video games. The control video games were chosen to be as engrossing as the experimental game, minimizing differences in motivation across groups and thus controlling for both test–retest effects (i.e., improvement expected simply from taking the test a second time) and Hawthorne-like effects (wherein individuals who have an active interest taken in their behavior tend to, all other things being equal, outperform individuals in which no such interest is taken). Furthermore, by evaluating subject behavior a few days before and a few days after the end of training (rather than immediately prior to and after training), these training studies attempt to exclude possible short-term effects of gaming on behavior, such as changes in arousal state or frame of mind.

Figure 2 shows a Brinley plot displaying data from two training studies conducted recently in our laboratory. In these training studies, 25 NVGPs were randomly assigned to either an action game (*Unreal Tournament*, *Call of Duty 2*) or a control game (*The Sims*), which they played for 50 hours over 8 to 9 weeks between pre- and posttesting. Across the four tasks tested before and after the training, action-game trainees demonstrated decreases in RT (a 13% decrease)—double that of control-game trainees (a 6% decrease). Again, the RT speeding was well fitted to a simple linear function with zero intercept, accounting for 97% of the variation between pre- and posttest in both action and control-game trainees. No differences in accuracy were observed.

Thus, unlike what has been reported in the majority of the literature on the training of speeded responses, the learning that occurs during action-video-game experience generalizes well beyond the act of playing games itself.

ACTION VIDEO GAMES AND IMPULSIVITY

The increased speed of processing noted in VGPs is often viewed as a "trigger-happy" behavior, in which VGPs respond faster but make more anticipatory errors (responding incorrectly because they do not wait for enough information to become available). Available research suggests this is not the case. First, the meta-analysis above reveals that VGPs have equivalent accuracy to NVGPs in the face of an 11% decrease in RTs. Second, a more direct evaluation of impulsivity using the Test of Variables of Attention (T.O.V.A.®) indicates equivalent performance in VGPs and NVGPs. Briefly, this test requires subjects to look at a computer monitor and make a timed response to shapes appearing at one location (targets), while ignoring the same shapes if they appear at another location (nontargets). In different parts of the experiment, the target can appear either often or very rarely (Fig. 3A). The T.O.V.A. therefore offers a measure of both impulsivity (is the observer able to withhold a response to a nontarget when most of the stimuli are targets?) and a measure of sustained attention (is the observer able to stay on task and respond quickly to a target when most of the stimuli are nontargets?).

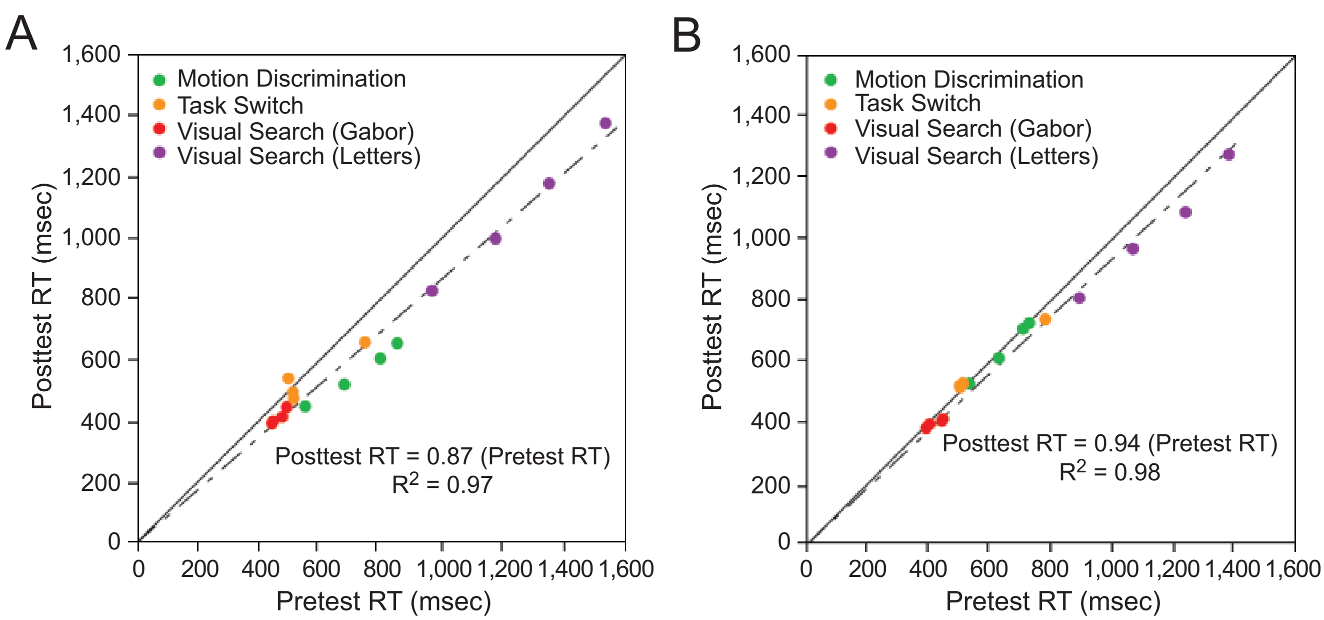

Fig. 2. Brinley plots comparing pretest and posttest reaction times (RTs) for action-game trainees (A) and control-game trainees (B) for four tasks: motion discrimination (based upon Palmer, Huk, & Shadlen, 2005), task switching (based upon Monsell, Sumner, & Waters, 2003), visual search for letters (based upon Castel et al., 2005), and visual search for Gabor patches (based upon Cameron, Tai, Eckstein, & Carrasco, 2004). For both action- and control-game trainees (7 males and 7 females in the action group and 7 females and 4 males in the control group), training consisted of playing randomly assigned videogames for 50 total hours over a period of 8 to 9 weeks. Members of the control group played the game The Sims™ 2 (Electronic Arts Inc.); members of the experimental group played the game Unreal® Tournament 2004 (Epic Games) followed by the game Call of Duty® 2 (ActiVision). The action-trained group demonstrated a 13% decrease in their RTs, whereas the control-trained group exhibited only a 6% decrease (from Green, 2008). Importantly, changes in accuracy for both groups were negligible, with the action game group showing a 0.3% decrease in accuracy (posttest accuracy = 0.997 × pretest accuracy, R^2 = 0.96) and the control group a 0.6% decrease (posttest accuracy = 0.994 × pretest accuracy, R^2 = 0.95), ruling out any explanation of the RT changes in terms of speed–accuracy trade-off.

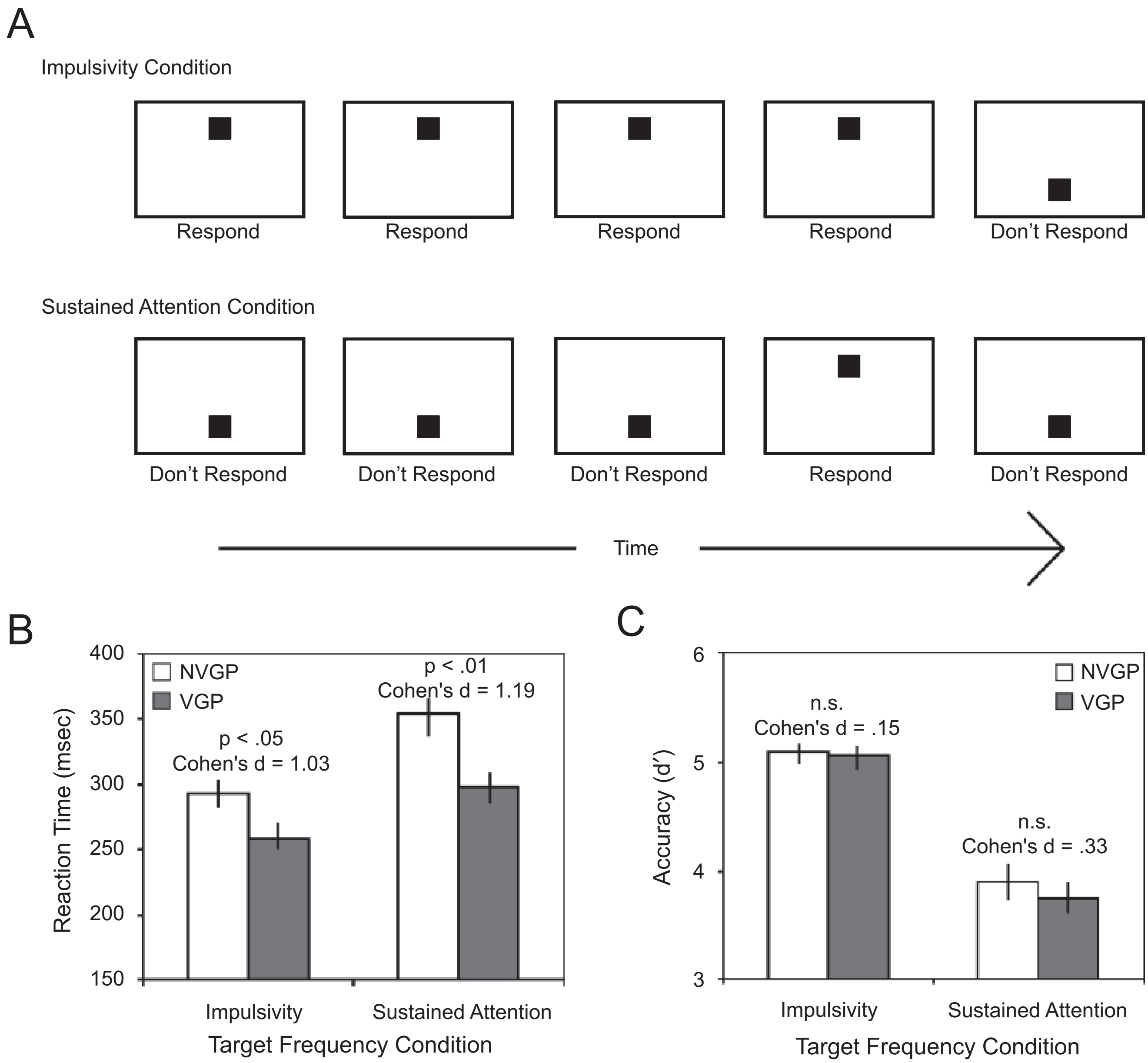

Fig. 3. The Test of Variables of Attention (A), used to assess differences in impulsivity and sustained attention between non-video-game players (NVGPs) and expert video-game players (VGPs), and results for both reaction time (B) and accuracy (C) measures. VGPs were faster at responding than NVGPs on both the impulsivity and sustained attention measures, but the groups did not differ on the accuracy measure, suggesting that the faster responses of VGPs were not due to impulsive responses to the stimuli and that they did not have greater problems sustaining their attention (n.s. stands for nonsignificant; p values are given for statistical significance and Cohen's d for the strength of the effect).

VGPs were selected based on self-reports of playing 5 hours per week (or more) of action video games in the previous year, and compared to NVGPs who reported little or no video gaming (and no action gaming for several years). VGPs responded more quickly than did NVGPs on both task components (Fig. 3B), confirming increased processing speed in this group. Crucially, accuracy did not differ for the two groups, this being the case for both the impulsivity and the sustained-attention measures (Fig. 3C). VGPs were therefore faster but not more impulsive than NVGPs and were equally capable of sustaining their attention. Thus, in contrast to the "trigger-happy" hypothesis, VGPs did not compensate for their faster RTs by making more anticipatory errors than NVGPs.

ACTION VIDEO GAMES AND ACCURACY MEASURES

Although earlier studies typically used speeded RT tasks, more recent studies of action-video-game players have focused on accuracy measures. This choice was motivated by the difficulty of making fair comparisons regarding cognitive processes across populations that have large differences in how quickly they make their responses. This problem is well acknowledged in the aging literature, and we refer the reader to Madden, Pierce, and Allen (1996) for a comprehensive discussion of the issue.

One area that has received considerable attention is the effect of action video games on visual cognition. Video-game players have been reported to show improved hand–eye coordination, increased visual processing in the periphery, enhanced mental-rotation skills, greater divided attention, and enhanced visuospatial memory. A series of published accuracy studies have established that playing action video games enhances performance on tasks thought to measure different aspects of visual attention, including the ability to (a) distribute attention across space, (b) efficiently perform dual tasks, (c) track several moving objects at once, and (d) process streams of briefly presented visual stimuli (Green & Bavelier, 2003, 2007). One such study focusing on visuospatial skills has suggested that action-game playing may provide a reliable training regimen to reduce gender differences in visuospatial cognition (Feng, Spence, & Pratt, 2007). In each of these instances, a causative role for action video games was demonstrated by conducting training studies with college students who did not play video games.

While these results in accuracy-based tasks have been previously interpreted as an increase in attentional resources in action-video-game players and/or an enhancement in the ability to allocate those resources across space and time, the Brinley plot in Figure 1 suggests an alternative hypothesis that parsimoniously explains the entire pattern of previous data, both RT- and accuracy-based. The consistent multiplicative VGP advantage in reaction time observed in the Brinley plot suggests a clear difference in the speed with which visual information is processed between the groups. In tasks in which RT is the primary dependent measure, this difference will be manifested as predictably faster RTs in VGPs than in NVGPs. However, such a difference in the speed of processing also predicts higher accuracy in VGPs in accuracy-based tasks in which the stimulus is typically quickly flashed or moving. This prediction was confirmed by Li, Polat, Makous, and Bavelier (2009), who show that VGPs acquire visual information more rapidly than NVGPs do. In fact, such a hypothesis predicts VGP advantages on virtually any task for which speeded visual processing is at the root of performance. To some extent, this hypothesis can be thought of as the converse of the generalized-slowing hypothesis for cognitive aging—that is, the suggestion that the observed decrements on a wide range of tasks in the elderly can be explained by a single underlying mechanism, decreases in the speed of information processing.

IMPLICATIONS AND FUTURE DIRECTIONS

A training regimen that efficiently increases processing speed is potentially greatly interesting, as faster RTs are reported to correlate with higher performance on tests of high-level cognition (Conway, Cowen, Bunting, Therriault, & Minkoff, 2002) and to be responsible for many of the observed changes in cognitive performance across the lifespan (Kail & Salthouse, 1994). For example, age-related declines in visual search, memory, and spatial-reasoning tasks appear to be largely due to task-independent slowing of processing speed in elderly subjects. Action-video-game training may therefore prove to be a helpful training regimen for providing a marked increase in speed of information processing to individuals with slower-than-normal speed of processing, such as the elderly or victims of brain trauma (Clark et al., 1987; Drew & Waters, 1986).

While the evidence reviewed here shows that these improvements generalize to a wide range of perceptual and attentional tasks, the extent of this generalization remains unknown. Because available work has focused on visual tasks, there is no information about generalization to other modalities, such as audition or touch. Similarly, because the focus has so far been on relatively fast tasks requiring decisions between just two alternatives (with RTs less than 2,000 milliseconds), it remains unknown whether more cognitively demanding tasks would benefit in any way.

While the mechanism of this generalization remains unknown, the need to maximize the number of actions per unit of time to achieve the greatest reward when playing action video games may well be a key factor. This will certainly be a promising avenue of research for future studies. A second important goal for future work is to gain a clearer understanding of the characteristics of the action-video-game play experience that favor performance enhancement. Much of what is currently known is descriptive (for instance, that fast-paced and visually complex games promote greater levels of learning than do slower games; see Cohen, Green, & Bavelier, 2007); there is a clear need to move toward more explanatory accounts. Hand-in-hand with such accounts, it will be important to isolate the characteristics of action video games that cause the observed changes and relate those characteristics to the mechanisms by which performance is altered. Finally, most of the games found to enhance performance are unsuitable for children in terms of their content and difficult for elderly gamers in terms of the dexterity of response and visual acuity required. Identifying which aspects of the games are relevant will allow the development of games that have a wide range of suitability and accessibility that can be used in clinical as well as educational applications. As with any research endeavor, a combination of basic theoretical research combined with evidence-led practical applications is the most likely to produce tangible results.

Recommended Reading

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