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Current Opinion in Psychology

Altering perception: the case of action video gaming

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The view that better perceptual skills can open the door to greater cognitive fitness calls for identifying interventions that enhance perception. We review here the impact of action video game play on perception. Cross-sectional studies indicate that action video game players outperform non-players by about ¾ of a standard deviation across all perceptual skills. More specifically, tasks relying on the dorsal system and peripheral vision appear most enhanced in action video game players. Despite their crucial role for establishing a causal role of action video game play on perception, the paucity of intervention studies limits interpretation. Yet, the existing dose–response curve already calls for at least 20 hours of play for significant effects to emerge. When considering the mechanisms at play, we propose that attentional control may mediate the noted perceptual benefits by increasing the quality of the perceptual information gathered, facilitating in turn the development of better perceptual templates.

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Current Opinion in Psychology 2019, **29**:168–173

This review comes from a themed issue on **Attention and perception**

Edited by **Sarah Shomstein**, **Andrew Leber** and **Joy Geng**

https://doi.org/10.1016/j.copsyc.2019.03.004

Introduction

The way we perceive the world around us greatly determines our cognitive abilities [1]. In this paper, we consider the extent to which perceptual abilities can be enhanced in young healthy individuals through training, with an eye toward cognitive fitness. A rich literature documents perceptual enhancements through perceptual learning [2], or in other words spending dozens of hours training on the very perceptual task to improve. Yet, such training typically results in highly specific improvements in the trained task; only little transfer is observed on related tasks [3]. This raises the issue of whether other forms of training may enhance perception in a way that would more gracefully transfer to varied contexts and contents. Training that enhances the fidelity, reliability and salience of perceptual and motor representations has been proposed to foster such transfer goals [4].

Over the past 10 years, action video game play have emerged as an intervention that may modify perceptual representations in such a way [5,6]. A growing literature has documented the beneficial impact of action video game play on perception [7••]. Below, we review in details the perceptual skills impacted by action video game in young healthy adults. We then discuss the hypothesized mechanism by which increased attentional control may mediate such an enhanced perception.

Perceptual skills rely on a collection of partially separate functions. One major distinction in perception exists between the 'where/how' dorsal pathway, which sustains localization and guides motor action, and the 'what' ventral pathway, which sustains object recognition [8]. This distinction has been best studied in the context of vision, but appears as a general organizational principle. Below we review separately the impact of action video games on tasks related to the dorsal and ventral pathways. Of note, we separate studies carried in the visual periphery at 10° or more, as peripheral processing has been suggested to be more plastic than central processing [9].

Importantly, we consider separately cross-sectional studies, comparing habitual action video gamers against non-gamers, and intervention studies. The latter compares two groups of non-gamers before and after training, with one group playing action video games versus the other playing control video games (e.g. social simulation game, Tetris, Balance). Cross-sectional studies address the rather societal question of what may be the pattern of perceptual strength and weaknesses of self-declared action video game players, a growing portion of the population. Indeed, action video games represented 26% of the video game sales in 2017 across the 2.6 billion worldwide players [10]. Intervention studies speak to the causal effect that action video game play exerts on perceptual skills, a fundamental point when considering application of this work to education or rehabilitation.

Ventral vision

There is mixed evidence that ventral vision is enhanced in action video game players, when compared to non-video game players. Tasks relying mostly on ventral vision include detections and discriminations of static low-level features (orientations, colors, lines) and high-level patterns (letters, textures, shapes).

Regarding low-level features, action video game players better discriminate the direction of a small indent on a shape [main effect of group on manual decision speed in 11 — Chapter 4, Experiment 2, and in 12], or the orientation of a grating [13••], than non-video game players. They also show less illusory conjunctions than non-gamers, suggesting more efficient feature binding [14]. Yet, they learn a texture discrimination task at the same rate as non-gamers [15•]. A 50-hours intervention study indicates a causal impact of action video game play in an orientation discrimination task [13••].

Regarding the processing of high-level pattern, mixed evidence exists for the perception of familiar forms like letters. Among studies testing acuity by asking participants to identify isolated letters, some report an advantage for action video game players compared to non-gamers [16,17] whereas others do not [18,19]. Yet, action video game players demonstrate better performance than non-gamers when discriminating shapes or spatially crowded letters in a single-task condition [16,20]. Thirty hours of action video games was enough to re-create this advantage in non-gamers for spatially crowded letters and for isolated letter acuity under dual-task conditions, but not for isolated letters in a single task condition [16,20]. Finally, action video game players are also better at detecting and discriminating masked stimuli than non-gamers, and globally quicker [21].

Together these effects are in line with higher resolution of visual processing along the 'what' pathway in action video game players, but especially so under attention-demanding conditions. Indeed, greater benefits of action video game play are generally observed in conditions that require distractor suppression (e.g. crowded versus isolated), cognitive flexibility (e.g. dual-task versus single task) or that involve masking [12,22–24].

Dorsal vision

Action video game play appears to enhance performance in dorsal vision in a reliable way. Tasks considered here use contrast-based low spatial frequency stimuli and require subjects to detect or discriminate motion, flicker or contrast differences. Action video game players outperform non-gamers when discriminating the direction of dots in kinematogram displays. Importantly, this enhancement can be attributed to higher rates of information integration in action gamers [25]. Motion discrimination is also improved for radial motion; yet not for translational or rotational motion [26]. Training studies indicate increased integration rates in non-video game players after 50 hours of action video game play [25], but not after 25 hours [27].

Contrast sensitivity is enhanced by action video gaming in both cross-sectional and intervention studies [28]. Beyond action video gamers, only radiologists have shown enhanced foveal contrast detection [29].

Action video gaming also results in reduced lateral masking during contrast detection tasks, in both a cross-sectional and a 50-hours intervention experiment [30]. These results are in line with a higher spatial and temporal resolution of dorsal visual functions in action video game players. This view was further supported by higher flicker fusion thresholds in action gamers when compared to non-gamers [31].

Peripheral vision

We consider here performance on any task conducted in the periphery (eccentricities $\geq 10°$), as action video games put rather high demands on peripheral perception. There is good evidence that action video game players show enhanced performance in peripheral vision, when compared to control participants.

Action video game players exhibit larger field of view than non-gamers, whether measured with a Goldmann perimeter [32] or the useful field of view paradigm [20]. A 30-hours training confirms larger useful field of view after action video gaming [20].

When considering feature discrimination tasks in the periphery, rather than target localization, a similar, albeit weaker pattern emerges. Peripheral color discrimination is more accurate in action video gamers than non-gamers [24], although a latter study only found a marginal effect [12 — main effect of group on saccade accuracy]. Action video game players also show quicker orientation discrimination than non-video game players [22 — main effect of group on correct saccade latency], as well as reduced crowding [17].

Finally, attention appeared to modulate group differences also for peripheral tasks. For example, crowding tasks and isolated letter identification require respectively more and less attention. Both were enhanced in action video game players, yet, the former, but not the latter, could be reproduced in a 30-hours intervention study [17].

Conflicting evidences exist for saccade latencies to peripheral targets. While latencies were shorter for action video gamers than non-gamers in a first study [23 — main effect of group on saccade latency], a latter study did not confirm that result [11 — Chapter 4, Experiment 2, main effect of group on saccade latency].

Audition

Most of the effects of action video games on audition come from one study [25] documenting larger rates of integration for auditory information in action video gamers than non-gamers. Participants were required to indicate which ear contained a tone, while noise was presented in both ears. The result was confirmed by a 50-hours intervention protocol [25]. This localization task, likely to engage the dorsal pathway, contrasts with a 20-hours training study [33] that did not find any changes when participants were asked to detect a tone, a task more likely to rely on the ventral pathway.

Other perceptual tasks

Action video gamers show an altered time perception, with a more accurate perception of audio-visual simultaneity than non-gamers, but not a better discrimination of event order [34]. Finally, the alternation rate in binocular rivalry did not differ between action gamers and non-gamers [35].

Cross-sectional versus intervention studies

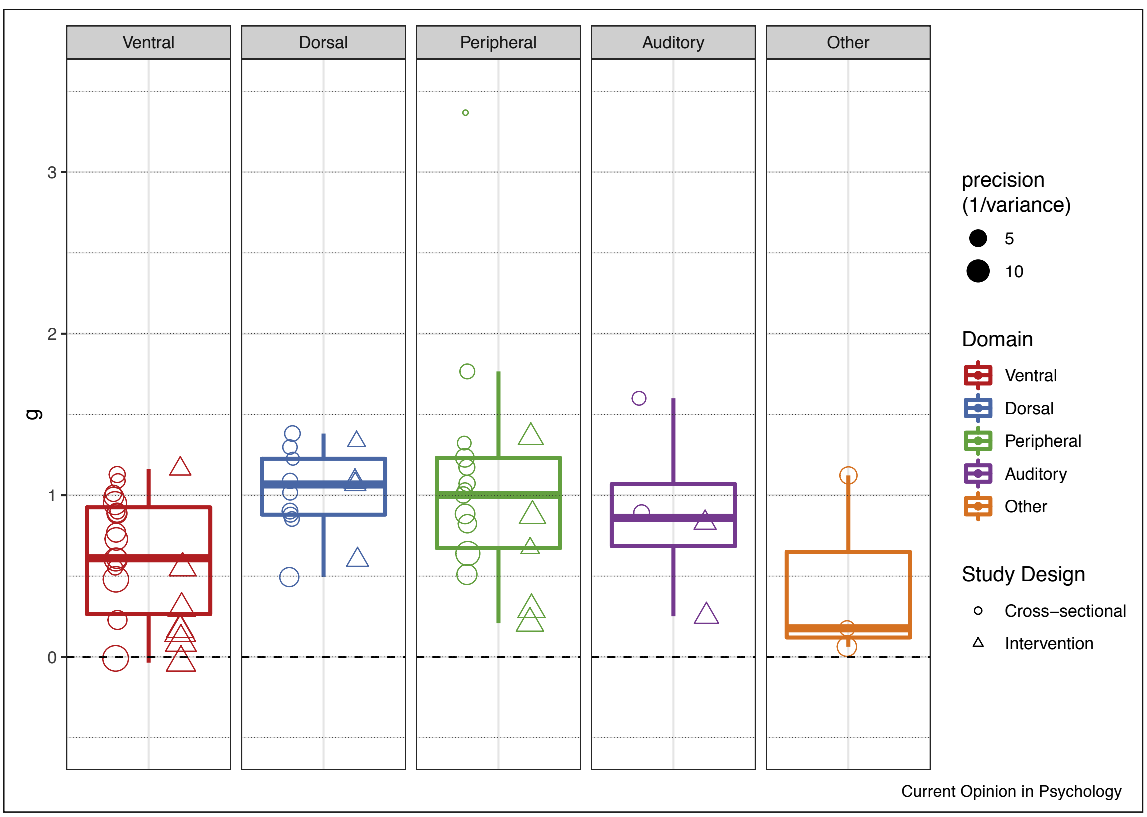
For each of the perceptual domains considered above, there is a clear impact of being an action video game player, but less consistent findings when it comes to intervention studies. Here, we have recomputed the overall effect of action video game play on perception from Bediou *et al.* [7••], taking into consideration the breakdown in different perceptual domains as listed above (Figure 1).

Cross-sectional studies indicate a medium-to-large effect of being an action video game player on perception ($g = 0.79$, $df = 16.6$, 95% $CI = [0.63, 0.96]$, $k = 42$, $m = 27$, $p < 0.001$). Intervention studies show a medium effect ($g = 0.53$, $df = 2.3$, 95% CI = $[-0.07, 1.12]$, $k = 18$, $m = 5$, $p = 0.065$), which needs to be cautiously interpreted given the low degrees of freedom. Nevertheless, intervention studies show a suggestive dose–response relationship (Figure 2). Effect sizes increase as training duration increase from 8 to 50 hours ($slope = 0.0177$; $p = 0.007$), with a minimum of 20 hours for significant training group differences to appear. The causal effect of action video game play may thus be masked by studies with training durations shorter than 20 hours.

Attentional control as a mechanism for perceptual changes

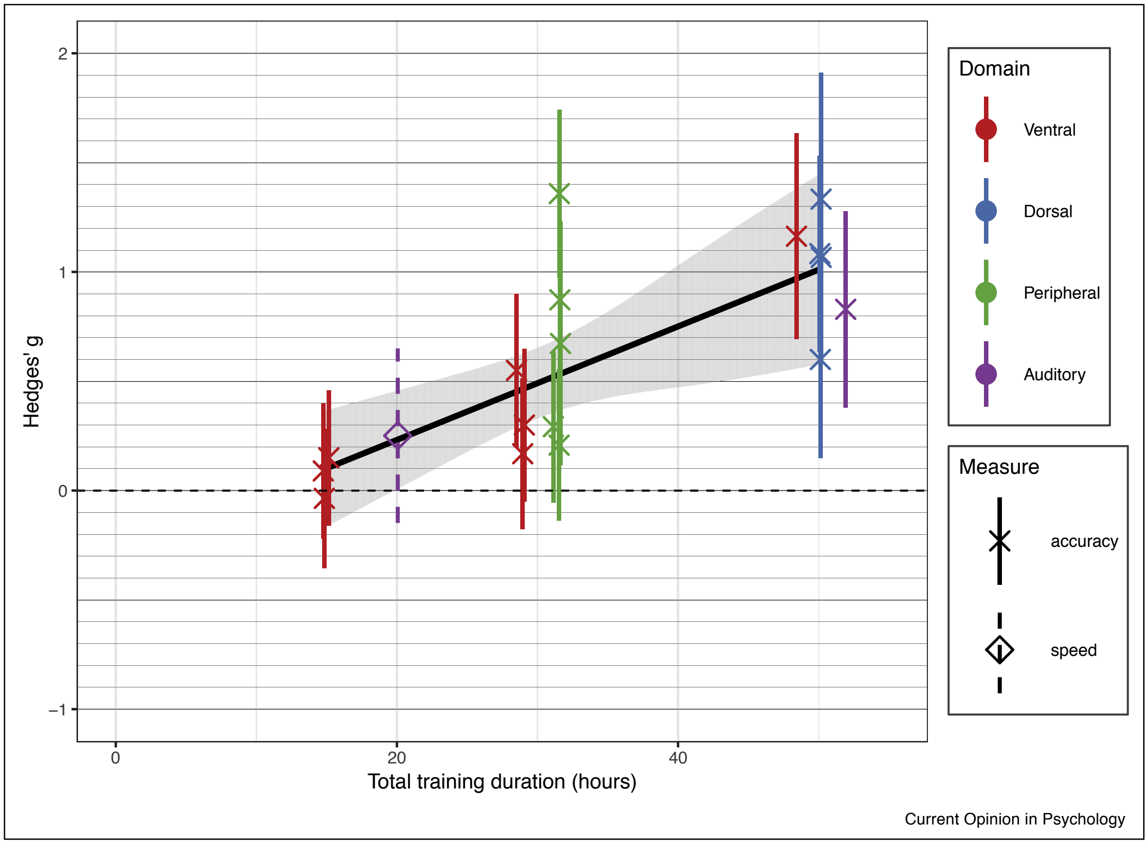
A key question concerns the source of these perceptual enhancements. We have made the proposal before that

Figure 1



Box plot of effect sizes (Hedge's g) from cross-sectional (circles) and intervention (triangles) studies by perceptual domains (studies considered according to the same inclusion/exclusion criteria as in Bediou *et al.* [7••]; different partitioning of the effects resulting in different clusters and thus slightly different effect sizes): Ventral vision, $g = 0.6$; Dorsal vision, $g = 1.1$; Peripheral vision, $g = 1.0$; Audition, $g = 0.9$. Others, $g = 0.18$. When considered together, the noted effect of action video game play on perception is moderate to large ($g = 0.79$). The size of symbols is proportional to the inverse of the variance.

Figure 2



Meta-regression of Hedge's *g* by training duration, showing a positive linear dose–response relationship. Confidence interval for the regression line were computed using the moving constant technique [52]. This analysis indicates that the effects become significant only after 20 hours of action video game training. Color indicates perceptual domain (red for ventral vision, blue for dorsal vision, green for peripheral vision, and purple for auditory for audition).

enhanced attentional control mediates perceptual benefits [36, for similar arguments, see 37,38]. Attentional control encompasses the ability to voluntary allocate attention to specific stimuli while ignoring sources of noise or distraction. Such control extends over the size, location and/or number of attentional foci [39••]. Critically, attentional control, or top-down/voluntary attention, is the one function most reliably improved by action video game play [7••,40, but see 41]. As reviewed below, there is good evidence [39••] that attentional control alters visual percepts and performance in a way consistent with many of the game-induced perceptual changes reviewed above.

In tasks related to ventral vision, voluntary attention improves discriminations of fine low-level features like orientations [42], or a small gap in a C [43]. Similarly, feature binding is a hallmark of voluntary attention [44].

Voluntary attention can also shape performance in tasks meditated by dorsal vision. It improves motion discriminations [45], contrast sensitivity, even for detections [46,47], through an increase of perceived contrast [42]. Decreasing attentional load increases flicker fusion thresholds [48].

Regarding peripheral tasks, voluntary attending to one peripheral location increases the spatial resolution in the focus of attention. According to the theory of the attention resolution [49], this could account for the higher crowding acuity of action video game players [17].

In sum, enhanced attentional control could allow action video game players to more efficiently focus on task-relevant dimensions, enabling them to accumulate more efficiently perceptual information in the service of decision making [36]. Furthermore, the resulting enhanced signal-to-noise ratio would facilitate the learning and consolidation of perceptual templates, creating in effect a virtuous processing loop. In line with this hypothesis are reports that action video game players benefit from more precise perceptual templates and learn faster an orientation discrimination task [13••] as well as display less memory interference when learning successive texture discriminations [16•]. Whether such changes in learning accompany action video game play remains to be tested.

Conclusion

Habitual action video game players benefit from enhanced perceptual skills, particularly for dorsal and peripheral vision. This review highlights a reliable dose–response effect in favor of a causal impact of action gaming on perception, but calls for new intervention studies of more than 20 hours. Of importance, we consider here only intervention studies focusing on young healthy adults at the peak of their performance, a population that by definition has little room to improve. Interestingly, action video games designed for clinical populations have been found to alter perception [50,51•], although too few studies exist at this time to draw firm conclusions. Yet, to the extent that changes in attentional control mediate perceptual enhancements, this would seem a promising avenue whether for rehabilitation or cognitive fitness.

Conflict of interest statement

Daphne Bavelier declares she is a member of the scientific advisory board of Akili Interactive, Boston and acts as a scientific advisor to RedBull, Los Angeles. There is no other interest to declare.

Acknowledgement

This research was funded by the National Eye InstituteEY020976 to DB.

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