Action video game training for cognitive enhancement

Green, C. Shawn; Bavelier, Daphné

Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Behavioral Sciences

Action video game training for cognitive enhancement

C. Shawn Green[1] and Daphne Bavelier[2,3]

Here we review the literature examining the perceptual, attentional, and cognitive benefits of playing one sub-type of video games known as 'action video games,' as well as the mechanistic underpinnings of these behavioral effects. We then outline evidence indicating the potential usefulness of these commercial off-the-shelf games for practical, real-world applications such as rehabilitation or the training of job-related skills. Finally, we discuss potential core characteristics of action video games that allow for wide learning generalization.

Addresses
[1] Department of Psychology, University of Wisconsin-Madison, Madison, WI 53706, USA
[2] Université de Genève, Faculté de Psychologie et Sciences de l'Education (FPSE), Genève, Switzerland
[3] Department of Brain and Cognitive Sciences, University of Rochester, Rochester, NY 14627, USA

Corresponding author: Green, C. Shawn (csgreen2@wisc.edu)

Current Opinion in Behavioral Sciences 2015, **4**:103–108

This review comes from a themed issue on **Cognitive enhancement**

Edited by **Barbara J Sahakian** and **Arthur F Kramer**

For a complete overview see the Issue and the Editorial

Available online 5th May 2015

http://dx.doi.org/10.1016/j.cobeha.2015.04.012

Introduction

For as long as there have been studies of human perceptual and cognitive capacities, there has been simultaneous interest in whether these capabilities can be improved [1,2]. And although it is true that nearly all humans will show clear improvements on an extensively practiced task, it is typically the case that little to no benefits of this training are seen on new tasks — even if the new tasks appear on the surface to be quite similar to the highly practiced task [3–5]. This general phenomenon has been observed across domains — from perception (where for instance, training to identify a target in one part of the screen may not transfer to a different part of the screen [6]), to cognition (where training on one working memory task may not transfer to a different working memory task [7]), to motor control (where learning to overcome one type of motor perturbation may not transfer to a different type of perturbation [8]). Such lack of generalization across tasks represents a significant obstacle to the goal of producing real-world training benefits.

Over the past decade though, instances of much broader training effects, often engendered by 'real-life activities' such as aerobic activity, participation in sports, meditation, music training, or, the focus of this review, playing certain types of video games, have begun to permeate the literature [9–12]. Indeed, there is now substantial evidence showing that playing one sub-genre of video games, so-called 'action video games', leads to improvements in a broad set of behavioral abilities that extend well beyond the confines of the games themselves [13,14]. Here we provide a brief review of this literature with a particular emphasis on the breadth of the benefits, the possible mechanistic underpinnings of the observed enhancements, the potential for such video games to be used in practical applications, and the critical characteristics of action video games that allow for such far-reaching effects to be realized.

What are action video games?

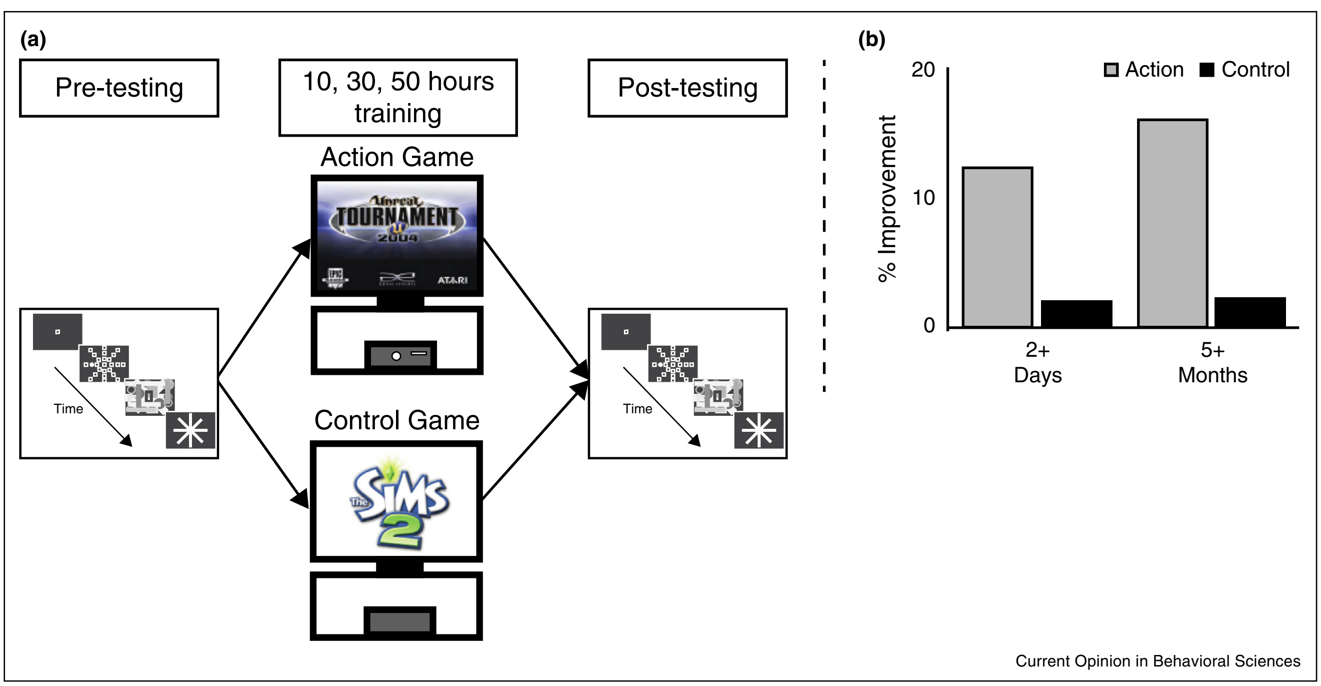
The superordinate category label 'video game' encompasses an incredibly wide variety of experiences — so much so that to some extent, the term has no predictive value at all. Little to nothing can be inferred by merely knowing that an individual plays 'video games,' as 'video games' can mean anything from simplistic matching of colored blocks on a mobile device up through navigating highly complex, laboriously designed virtual worlds on the newest consoles [15]. Researchers across psychology have thus typically focused their investigations at the level of specific game genres, wherein games are grouped by, among other things, commonalities in format, content, dynamics, and mechanics. In terms of the potential to alter basic perceptual, attentional, and cognitive abilities, the majority of the research has centered on the 'action video game' genre. Games within this genre are characterized by complex 3D settings, quickly moving and/or highly transient targets, strong peripheral processing demands, substantial amounts of clutter, and the need to consistently switch between highly focused and highly distributed attention all while making rapid, but accurate actions [16].

Studying the effects of action video games

Before outlining the actual effects of playing action video games, it is worth quickly discussing how studies in this domain are conducted and conclusions are reached [17]. As is true of the literature on music, aerobic activity, meditation and sports training — because it is the case that some individuals, as part of their daily life, choose to engage in substantial amounts of action video game play, while others totally refrain from video game play — it is thus possible for researchers to conduct cross-sectional ‘experiments of nature’ wherein the perceptual, attentional, or cognitive skills of avid action gamers are compared against those of their non-action game playing peers. However, while such studies can demonstrate an *association* between choosing to play action games and enhanced performance, they cannot establish that the relationship is *causal*. For this, intervention studies are conducted wherein individuals who do not naturally play video games are first pre-tested on measures of interest before being randomly assigned to play either an action video game or a control video game (a commercial game matched for general interest, flow, arousal, among others, but lacking all action components — see Figure 1). Participants then play their assigned game for a set period of time; work in the field has utilized training durations from 10 to 50 hours spaced over the course of weeks to months — as video game training, like all other forms of learning is far more effective when practice is distributed rather than massed [18,19]. Finally, at least 24 hours after the final play session (the delay ensures that any transient effects of game play are eliminated as potential concerns), the individuals are post-tested on the measures of interest with the critical question being whether the action trained group improves more from pre-test to post-test than the control video game trained group.

There are of course many challenges in evaluating the efficacy of any intervention where it is necessarily the case that the participants cannot be kept blind to the content of the intervention — something that is true of all behavioral interventions, whether the intervention is based on video games, aerobic exercise, meditation, athletics, or music. For instance, there is always the possibility that it is not the content of the intervention that leads to improvements per se, but it is instead the participants’ expectation that they should improve that causes improvements. And although in the case of action video games, the preponderance of the evidence to date has suggested that these confounds cannot explain the effects observed in the field (e.g. studies where participants are recruited in such a way that they do not know their gaming is of relevance tend to show the same effects as studies where participants are overtly recruited based on their gaming [20–25]), there is nonetheless always virtue in improving methodology to minimize the

Figure 1



Intervention studies to assess a causal relationship between action video gaming and improved behavioral abilities. **(a)** Participants with little to no action video game experience, and little overall video game experience, are first pre-tested on the psychological measures of interest (here the Useful Field of View task — left). The participants are then randomly assigned to play either an action entertainment video game (middle, top) or a control entertainment video game (middle, bottom) for a specified period of time (typically between 10 and 50 hours, with sessions properly spaced to avoid the deleterious effects of massed practice). Finally, at least 24 hours after the last gaming session, individuals take the same psychological measures again. **(b)** The critical measure is whether individuals in the action group improved more from pre-test to post-test than individuals in the control group. Here, in the case of the UFOV task, this is true not only a few days after the last video game training session (2+ days), as the effects persist for at least 5 months. *Data replotted from [28,30].

potential for confounds. The limitations associated with the current methodological approaches and potential avenues for improving the status quo have been the topic of a number of recent publications [26–28], and have been influential in fostering dialog related to best practices in behavioral interventions. A fuller discussion of some of the issues raised can be found in [17], but a general consensus is emerging around the need for behavioral training studies to be designed such that participants are randomly assigned to the experimental group and to control groups, with at least one control group being an active group following the same training schedule, degree of experimenter contact, and (as much as possible) expectations, as the experimental group. The use of measures that are not just based on faster reaction times or higher accuracy is also highly valuable. For example, some of the conclusions about attentional control in the action video game literature rest on differences in performance between conditions (i.e. interactions) and not just in main effects. Such interactions would be extremely difficult, if not impossible, for participants to intuit based on their expectations of performing better and thus concerns related to expectation effects are minimized. A fascinating question remains, however, given that participants cannot be kept blind to the content of their intervention. That question concerns the extent to which leading participants to believe that the training they will undergo will make them excel will indeed result in enhanced performance and which cognitive domains are/are not susceptible to such effects. Experiments that address the amount of variance explained solely by expectation effects would move the field forward by allowing the proper evidence-based assessment for placebo effects in the context of behavioral interventions.

Changes in perceptual, attentional, and cognitive skills

The enhancements associated with playing action video games range all the way from low-level perceptual skills up through high-level cognitive flexibility. This includes improvements in visual sensitivity [24,29], basic perimetry [20], perceptual decision making [30], speed of processing [31,32], perceptual simultaneity and temporal order judgments [21], in the capacity to select task relevant information across space [23,33•,34–36,37•,38] and time [23,33•,39,40], to overcome attentional capture [41,42] and utilize cognitive control [25], in the ability to track multiple moving objects [23,43,44], to mentally rotate complex shapes [36], to remember visually presented information [45,46], and to either rapidly switch between tasks [47•,48–52] or to perform multiple tasks concurrently [51,53] (although see [54–57] for failures to find such effects). The available research also strongly contradicts the popular conception of the 'trigger-happy' video game player who is willing to trade reductions in accuracy for increased speed. Instead, in tasks that measure both reaction time and accuracy, action gamers tend to show decreased reaction times as compared to non-gamers, but with equivalent levels of accuracy (and higher levels of accuracy in tasks that measure only percent correct — [31]). Finally, and critically, the sterile, lab-based tasks that have been utilized to assess behavioral functions have born little resemblance to action video games thus demonstrating a significant degree of learning transfer.

Mechanistic underpinnings of action video games: 'learning to learn'

The enhanced performance observed on various tasks following action video game experience has typically been framed in the literature as reflecting 'transfer effects,' wherein training on one task conveys an immediate benefit when confronted with a new task. However, recent work has suggested an alternative viewpoint wherein action video game experience, rather than producing immediate benefits on new tasks, conveys upon users the ability to more quickly and effectively learn to perform new tasks. In other words, action video game players have 'learned to learn.' Data consistent with this alternative framework has been observed in the perceptual and the motor domain [58•,59]. In both cases, no advantage was noted between avid action gamers and non-action gamers on the earliest trials of a new task (gabor identification or motor tracking learning). However, in both cases, action game player performance improved significantly more rapidly than non-action game player performance and also reached better asymptotic levels. Under this viewpoint, 'learning to learn' abilities emerge as a result of enhanced attentional control enabling more efficient suppression of sources of noise or distraction and, thus, faster and more faithful extraction of task-relevant information [60•,61,62].

Potential practical applications

Given the scope and scale of the observed action video game benefits, several research groups have examined the possibility of utilizing off-the-shelf action video games for practical purposes — either in rehabilitation or for job-related training. For example, in the area of rehabilitation, action video games have been shown to benefit both visual capabilities in adults with amblyopia (in some less severe cases even resulting in a return to normal acuity) [63•] and reading capabilities in children with dyslexia (presumably mediated by changes in visual attentional abilities, rather than changes in phonological or orthographic processing) [64]. And in the area of job-related training, there now exists a burgeoning literature examining the potential of utilizing action video games as training tools for laparoscopic surgeons [65–67] or pilots [68].

Critical features of video games to produce wide benefits

One significant disadvantage of studying the effect of media consumption on behavioral abilities is that the forms of media consumed do not remain static over time. This is certainly true of video games, where genres that previously were quite distinct in terms of content and mechanics now have considerable overlap. For instance, although a decade ago fantasy video games were typically rather slow and turn-based (i.e. the player had an unlimited amount of time to choose and execute a course of action), today games in the fantasy genre are often, at least at first glance, relatively indistinguishable from first-person shooter action games (the differences between the genres today having to do with storyline or player progression factors). This state of affairs calls strongly for replacing the genre-based approach to studying video game effects (e.g. action, real time strategy, among others) with an approach that focuses on the structural characteristics that drive behavioral enhancements (structural characteristics that might be present in games across many genres) [69,70].

In this endeavor it may be valuable to differentiate between those structural characteristics of video games that are common to nearly all effective learning platforms and those that may be uniquely responsible for the broad learning generalization discussed above. For example, all successful video games engender high levels of motivation and arousal, provide immediate informative feedback, are intrinsically rewarding, and utilize difficulty levels that are increased in a manner commensurate with player skill, with each of these characteristics being known to foster time-on-task and promote more effective learning [71•]. Because not all video games lead to the degree of learning generalization described above though, this suggests that there must be additional game features that foster such breadth and which are found only in a sub-set of video games. One possibility is the manner in which variety is incorporated into some games. In particular, while researchers have long noted the relationship between training variety and transfer [4], endless variety would actually dissuade learning (in that if every situation is brand new, there is little that can be learned). Instead, it is possible that there is a critical blend of variety at the level of stimuli, actions, and inferences, which will prevent automaticity and thus specificity [72], and structural regularities in the game, which will ensure there is always something to learn and that which can be learned is reasonably task independent [73,74]. Another prospect is the need to utilize attention in a highly flexible, but controlled manner. In particular, certain classes of video games require a heightened ability to adaptively switch attention to different task characteristics as they become goal relevant or to switch between a highly focused attentional state (e.g. as is essential when engaged with a particularly difficult enemy) and a more diffuse attentional state (e.g. when gathering information). By demanding that players' employ attention in this flexible manner across a wide variety of levels of resolution, the games may, in essence, teach the meta-skill of attentional control.

Conclusions

While standard perceptual or cognitive training paradigms often produce learning that is highly specific to the exact context of the trained task, the benefits of action video game play have been shown to extend well beyond the confines of the games. Clear enhancements in basic perceptual skills, in the ability to utilize selective attention, and in cognitive flexibility have been noted as a result of action video game play. Although more work on the real life implications of these effects is needed, the extent and size of the effects already appear sufficient for some real-world applications. Recent work suggests that this breadth is a result of 'learning to learn' — wherein action games teach skills and knowledge that allow new tasks to be more quickly learned. Current hypotheses suggest that the critical game characteristics driving this learning outcome include variety (of stimuli, actions, inferences, among others) and the need to flexibly utilize attention (either to switch between different characteristics as they become task relevant, or to switch between different states of attention). An important line of future work will be to test and further characterize those game characteristics that foster learning to learn.

Conflict of interest statement

DB is on the advisory board and a co-founder of Akili Interactive, and holds the following pending patents: Patent on Method and System for Treating Amblyopia (US Pat. Appln. No. 61/403 585); Patent on Method and System for Training 'Number Sense' (US Pat. Appln. No. 13/301 392).

Acknowledgements

This work was supported by an Office of Naval Research grant # N00014-14-1-0512.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest

1. Thorndike EL, Woodworth RS: **The influence of improvement in one mental function upon the efficiency of other functions**. *Psychol Rev* 1901, **8**:247-261.
2. James W: **The Principles of Psychology**. New York: Dover Publications Inc.; 1890.
3. Barnett SM, Ceci SJ: **When and where do we apply what we learn?.: A taxonomy for far transfer**. *Psychol Bull* 2002, **128**:612-637.
4. Schmidt RA, Bjork RA: **New conceptualizations of practice: common principles in three paradigms suggest new concepts for training**. *Psychol Sci* 1992, **3**:207-217.
5. Fahle M: **Perceptual learning: specificity versus generalization**. *Curr Opin Neurobiol* 2005, **15**:154-160.
6. Ahissar M, Hochstein S: **Task difficulty and the specificity of perceptual learning**. *Nature* 1997, **387**:401-406.
7. Melby-Lervag M, Hulme C: **Is working memory training effective? A meta-analytic review**. *Develop Psychol* 2013, **49**:270-291.

8. Tremblay S, Houle G, Ostry DJ: **Specificity of speech motor learning**. *J Neurosci* 2008, **28**:2426-2434.

9. Hillman CH, Erickson KI, Kramer AF: **Be smart, exercise your heart: exercise effects on brain and cognition**. *Nat Rev Neurosci* 2008, **9**:58-65.

10. Mann DT, Williams AM, Ward P, Janelle CM: **Perceptual-cognitive expertise in sport: a meta-analysis**. *J Sport Exerc Psychol* 2007, **29**:457-478.

11. Schellenberg EG: **Music lessions enhance IQ**. *Psychol Sci* 2004, **15**:511-514.

12. Davidson RJ, McEwen BS: **Social influences on neuroplasticity: stress and interventions to promote well-being**. *Nat Neurosci* 2012, **15**:689-695.

13. Green CS, Bavelier D: **Learning, attentional control and action video games**. *Curr Biol* 2012, **22**:R197-R206.

14. Bavelier D, Green CS, Pouget A, Schrater P: **Brain plasticity through the life span: learning to learn and action video games**. *Ann Rev Neurosci* 2012, **35**:391-416.

15. Apperley TH: **Genre and game studies: Toward a critical approach to video game genres**. *Simulation and Gaming* 2006, **37**:6-23.

16. Spence I, Feng J: **Video games and spatial cognition**. *Rev Gen Psychol* 2010, **14**:92-104.

17. Green CS, Strobach T, Schubert T: **On methodological standards in training and transfer experiments**. *Psychol Res* 2014, **78**:756-772.

18. Baddeley A, Longman D: **The influence of length and frequency of training sessions on the rate of learning to type**. *Ergonomics* 1978, **21**:627-635.

19. Stafford T, Dewar M: **Tracing the trajectory of skill learning with a very large sample of online game players**. *Psychol Sci* 2014, **25**:511-518.

20. Buckley D, Codina C, Bhardwaj P, Pascalis O: **Action video game players and deaf observers have larger Goldmann visual fields**. *Vis Res* 2010, **50**:548-556.

21. Donohue SE, Woldorff MG, Mitroff SR: **Video game players show more precise multisensory temporal processing abilities**. *Atten Percept Psychophys* 2010, **72**:1120-1129.

22. Hutchinson CV, Stocks R: **Selectively enhanced motion perception in core video gamers**. *Perception* 2013, **42**:675-677.

23. Dye MWG, Bavelier D: **Differential development of visual attention skills in school-age children**. *Vis Res* 2010, **50**:452-459.

24. Appelbaum LG, Cain MS, Darling EF, Mitroff SR: **Action video game playing is associated with improved visual sensitivity, but not alterations in visual sensory memory**. *Atten Percept Psychophys* 2013, **75**:1161-1167.

25. Colzato LS, van den Wildenberg WPM, Zmigrod S, Hommel B: **Action video gaming and cognitive control: playing first person shooter games is associated with improvement in working memory, but not action inhibition**. *Psychol Res* 2013, **77**:234-239.

26. Boot WR, Simons DJ, Stothart C, Stutts C: **The pervasive problem with placebos in psychology: why active control groups are not sufficient to rule out placebo effects**. *Perspect Psychol Sci* 2013, **8**:445-454.

27. Boot WR, Blakely DP, Simons DJ: **Do action video games improve perception and cognition**. *Front Cogn* 2011, **2**:226.

28. Kristjansson A: **The case for causal influences of action video game play upon vision and attention**. *Atten Percept Psychophys* 2013, **75**:667-672.

29. Li R, Polat U, Makous W, Bavelier D: **Enhancing the contrast sensitivity function through action video game training**. *Nat Neurosci* 2009, **12**:549-551.

30. Green CS, Pouget A, Bavelier D: **Improved probabilistic inference as a general mechanism for learning with action video games**. *Curr Biol* 2010, **23**:1573-1579.

31. Dye MWG, Green CS, Bavelier D: **Increasing speed of processing with action video games**. *Curr Dir Psychol Sci* 2009, **18**:321-326.

32. Dye MWG, Green CS, Bavelier D: **The development of attention skills in action video game players**. *Neuropsychologia* 2009, **47**:1780-1789.

33. • Green CS, Bavelier D: **Action video game modifies visual selective attention**. *Nature* 2003, **423**:534-537.
The first report to identify action video games as being particularly beneficial to visual and attentional processing.

34. Green CS, Bavelier D: **Effect of action video games on the spatial distribution of visuospatial attention**. *J Exp Psychol: Hum Percept Perform* 2006, **32**:1465-1478.

35. Green CS, Bavelier D: **Action-video-game experience alters the spatial resolution of vision**. *Psychol Sci* 2007, **18**:88-94.

36. Feng J, Spence I, Pratt J: **Playing an action video game reduces gender differences in spatial cognition**. *Psychol Sci* 2007, **18**:850-855.

37. • Wu S, Spence I: **Playing shooter and driving videogames improves top-down guidance in visual search**. *Atten Percept Psychophys* 2013, **75**:673-686.
Demonstrated that ‘action video games’ is not necessarily synonymous with ‘shooting’ or ‘violent’ video games. Similar behavioral benefits were induced by playing both a first-person shooter video game and an action car driving video games.

38. Castel AD, Pratt J, Drummond E: **The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search**. *Acta Psychol (Amst)* 2005, **119**:217-230.

39. Li R, Polat U, Scalzo F, Bavelier D: **Reducing backward masking through action game training**. *J Vis* 2010, **10**:1-33.

40. Pohl C, Kunde W, Ganz T, Conzelmann A, Pauli P, Kiesel A: **Gaming to see: action video gaming is associated with enhanced processing of masked stimuli**. *Front Psychol* 2014, **5**:70.

41. Chisholm JD, Kingstone A: **Improved top-down control reduces oculomotor capture: the case of action video game players**. *Atten Percept Psychophys* 2012, **74**:257-262.

42. Chisholm JD, Hickey C, Theeuwes J, Kingstone A: **Reduced attentional capture in action video game players**. *Atten Percept Psychophys* 2010, **72**:667-671.

43. Green CS, Bavelier D: **Enumeration versus multiple object tracking: the case of action video game players**. *Cognition* 2006, **101**:217-245.

44. Trick LM, Jaspers-Fayer F, Sethi N: **Multiple-object tracking in children: the ‘‘Catch the Spies’’ task**. *Cogn Dev* 2005, **20**:373-387.

45. Sungur H, Boduroglu A: **Action video game players form more detailed representation of objects**. *Acta Psychol (Amst)* 2012, **139**:327-334.

46. Blacker KJ, Curby KM: **Enhanced visual short-term memory in action video game players**. *Atten Percept Psychophys* 2013, **75**:1128-1136.

47. • Colzato LS, van den Wildenberg WP, Hommel B: **Cognitive control and the COMT Val(1)(5)(8)Met polymorphism: genetic modulation of videogame training and transfer to task-switching efficiency**. *Psychol Res* 2014, **78**:670-678.
Demonstrated that the beneficial effects of action video game training are modulated by individual differences in genotype — particularly genes related to dopamine pathways.

48. Karle JW, Watter S, Shedden JM: **Task switching in video game players: benefits of selective attention but not resistance to proactive interference**. *Acta Psychol (Amst)* 2010, **134**:70-78.

49. Colzato LS, van Leeuwen PJ, van den Wildenberg WPM, Hommel B: **DOOM'd to switch: superior cognitive flexibility in players of first person shooter games**. *Front Psychol* 2010, **1**:8.

50. Green CS, Sugarman MA, Medford K, Klobusicky E, Bavelier D: **The effect of action video games on task switching**. *Comput Hum Behav* 2012, **12**:984-994.

51. Strobach T, Frensch PA, Schubert T: **Video game practice optimizes executive control skills in dual-task and task switching situations**. *Acta Psychol* 2012, **140**:13-24.

52. Cain MS, Landau AN, Shimamura AP: **Action video game experience reduces the cost of switching tasks**. *Atten Percept Psychophys* 2012, **74**:641-647.

53. Chiappe D, Conger M, Liao J, Caldwell JL, Vu KL: **Improving multi-tasking ability through action videogames**. *Appl Ergon* 2013, **44**:278-284.

54. Boot WR, Kramer AF, Simons DJ, Fabiani M, Gratton G: **The effects of video game playing on attention, memory, and executive control**. *Acta Psychol* 2008, **129**:387-398.

55. Gaspar JG, Neider MB, Crowell JA, Lutz A, Kaczmarski H, Kramer AF: **Are gamers better crossers? An examination of action video game experience and dual task effects in a simulated street crossing task**. *Hum Factors* 2014, **56**:443-452.

56. van Ravenzwaaij D, Boekel W, Forstmann BU, Ratcliff R, Wagenmakers EJ: **Action video games do not improve the speed of information processing in simple perceptual tasks**. *J Exp Psychol Gen* 2014, **143**:1794-1805.

57. Murphy K, Spencer A: **Playing video games does not make for better visual attention skills**. *J Art Support Null Hypoth* 2009, **6**:1-20.

58. • Bejjanki VR, Zhang R, Li R, Pouget A, Green CS, Lu ZL, Bavelier D: **Action video game play facilitates the development of better perceptual templates**. *Proc Natl Acad Sci USA* 2014, **111**:16961-16966.

Demonstrated that the benefits of action video game play are consistent with a 'learning to learn' account. Action gamers and non-action gamers performed similarly on the earliest trials of a new task, but action gamers showed steeper learning functions.

59. Gozli DG, Bavelier D, Pratt J: **The effect of action video game playing on sensorimotor learning: evidence from a movement tracking task**. *Hum Mov Sci* 2014, **38C**:152-162.

60. • Mishra J, Zinni M, Bavelier D, Hillyard SA: **Neural basis of superior performance of action videogame players in an attention-demanding task**. *J Neurosci* 2011, **31**:992-998.

Found enhanced neural suppression of task irrelevant items in action video game players as compared to non-action video game players, the degree of which was correlated with enhancements in behavioral performance.

61. Krishnan L, Kang A, Sperling G, Srinivasan R: **Neural strategies for selective attention distinguish fast-action video game players**. *Brain Topogr* 2013, **26**:83-97.

62. Wu S, Cheng CK, Feng J, D'Angelo L, Alain C, Spence I: **Playing a first-person shooter video game induces neuroplastic change**. *J Cogn Neurosci* 2012, **24**:1286-1293.

63. • Li RW, Ngo C, Nguyen J, Levi DM: **Video-game play induces plasticity in the visual system of adults with amblyopia**. *PLoS Biol* 2011, **9**:e1001135.

Showed improved visual performance in adults with amblyopia following action video game training.

64. Franceschini S, Gori S, Ruffino M, Viola S, Molteni M, Facoetti A: **Action video games make dyslexic children read better**. *Curr Biol* 2013, **23**:462-466.

65. Schlickum MK, Hedman L, Enochsson L, Kjellin A, Fellander-Tsai L: **Systematic video game training in surgical novices improves performance in virtual reality endoscopic surgical simulators: a prospective randomized study**. *World J Surg* 2009, **33**:2360-2367.

66. Kolga Schlickum M, Hedman L, Enochsson L, Kjellin A, Fellander-Tsai L: **Transfer of systematic computer game training in surgical novices on performance in virtual reality image guided surgical simulators**. *Stud Health Technol Inform* 2008, **132**:210-215.

67. Rosser JC Jr, Lynch PJ, Cuddihy L, Gentile DA, Klonsky J, Merrell R: **The impact of video games on training surgeons in the 21st century**. *Arch Surg* 2007, **142**:181-186.

68. McKinley RA, McIntire LK, Funke MA: **Operator selection for unmanned aerial systems: comparing video game players and pilots**. *Aviat Space Environ Med* 2011, **82**:635-642.

69. King D, Delfabbro P, Griffiths M: **Video game structural characteristics: a new psychological taxonomy**. *Int J Ment Health Addiction* 2010, **8**:90-106.

70. Clearwater DA: **What defines video game genre? Thinking about genre study after the great divide**. *Loading... J Can Game Studies Assoc* 2011, **5**:29-49.

71. • Gentile DA, Gentile JR: **Violent video games as exemplary teachers: a conceptual analysis**. *J Youth Adolesc* 2008, **37**:127-141.

Outlines the ways in which video games naturally instantiate many of the known best practices to induce learning and neuroplasticity.

72. Fulvio JM, Green CS, Schrater PR: **Task-specific response strategy selection on the basis of recent training experience**. *PLoS Comput Biol* 2014, **10**:e1003425.

73. Tenenbaum JB, Kemp C, Griffiths TL, Goodman ND: **How to grow a mind: statistics, structure, and abstraction**. *Science* 2011, **331**:1279-1285.

74. Kemp C, Goodman ND, Tenenbaum JB: **Learning to learn causal models**. *Cogn Sci* 2010, **34**:1185-1243.