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

Video games, cognitive exercises, and the enhancement of cognitive abilities

Joaquin A Anguera[1,2] and Adam Gazzaley[1,2,3]

In this review we explore the emerging field of cognitive training via distinct types of interactive digital media: those designed primarily for entertainment ('video games') and those created for the purpose of cognitive enhancement ('cognitive exercises'). Here we consider how specific design factors associated with each tool (e.g., fun, motivation, adaptive mechanics) and the study itself (e.g., participant expectancy, dose effects) can influence cognitive enhancement effects. We finally describe how the development of hybrid interventions that capitalize on strengths of each type of interactive digital media are anticipated to emerge as this field matures.

Addresses
[1] Department of Neurology, University of California, San Francisco, United States
[2] Department of Psychiatry, University of California, San Francisco, United States
[3] Department of Physiology, University of California, San Francisco, United States

Corresponding authors: Anguera, Joaquin A (joaquin.anguera@ucsf.edu) and Gazzaley, Adam (adam.gazzaley@ucsf.edu)

Current Opinion in Behavioral Sciences 2015, **4**:160–165

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 24th June 2015

http://dx.doi.org/10.1016/j.cobeha.2015.06.002

2352-1546/Published by Elsevier Ltd.

There are a number of interventions that have demonstrated the potential to enhance cognitive abilities, ranging from the more traditional (e.g., nutrition, exercise) to the more technological (e.g., pharmaceuticals, genetic therapies, neurostimulation). One approach, although still controversial [1], that has been gaining momentum is the use of interactive digital media to augment cognition, typically referred to as cognitive training. Over the last decade, there has been a surge in the number of interactive software programs created with claims of their ability to improve fundamental aspects of cognition known as cognitive control (i.e., attention, working memory, and goal management (multi-tasking/task-switching)). Although there have been promising results, few studies have successfully demonstrated clear improvements on untrained cognitive tasks (what we refer to as cognitive enhancement, generalized benefits or transfer [2•,3]), and often not even for abilities that are highly related to training itself (i.e., near transfer [3–6]). In this review we differentiate between two types of interactive digital media: those designed primarily for entertainment [7•] ('video games') and those created for the purpose of cognitive enhancement ('cognitive exercises'). Exploring this dichotomy, we will consider how certain factors associated with each type of intervention and corresponding study designs may influence the potential for cognitive enhancement and for validating it experimentally.

Video games and cognitive exercises

In general, video games are designed with two primary goals: enjoyment and sustained player engagement. Many of today's most popular video games involve high levels of art, captivating music, and intricate storylines to create immersive environments for an enhanced player experience. Such video games typically involve carefully designed game mechanics that drive game play to be both challenging and fun, with careful considerations of reward cycles that deliver positive and negative feedback at appropriate times. Cognitive exercises share many, but not all, of these elements: these tools are more focused at challenging underlying neural systems or specific cognitive abilities due to their targeted approach, but often without the immersive elements that are core to entertainment video games. The dichotomy between video games and cognitive exercises can perhaps best be appreciated from the perspective of their physical analogies: a running-based treadmill program is a physical exercise targeting clear health outcomes, but is often laborious and not fun, despite anticipated benefits. Alternatively, playing a running-based sport (e.g., soccer) is often quite fun, but not inherently designed as a training tool to engender specific health benefits. Of course, there is subjectivity in assigning examples of interactive digital media into these categories, but this division provides a starting point for the following discussion.

One of the first examples of interactive digital media being used as a tool (in this case, for understanding training-related strategies) was Space Fortress [8], developed in 1983. It was carefully designed to intensely challenge several cognitive abilities through repetitive interactions, with the direct goal of examining different training strategies to accelerate learning. This approach, along with the state of video game industry at the time, explains why there were minimal elements directly promoting fun or engagement compared to modern video games. Cognitive training using Space Fortress has shown some positive effects on aspects of cognition [9,10], but transfer has not been attained consistently [11–13]. Since then, a plethora of cognitive training studies have emerged using this type of approach, several of them demonstrating positive training effects involving attention [14–16], working memory [17–19], and even intelligence [20,21•] (although see [22•,23]). Some, although not all, of these approaches have attempted to 'gamify' the training platforms via the inclusion of low-level reward mechanisms like points and colorful environments to increase participant engagement. The popularity of this gamification approach suggests that design factors typically found in entertainment-based video games are widely thought of as beneficial for cognitive enhancement.

There have also been notable reports of enhancements in the cognitive control abilities being induced by entertainment-designed video games. Starting with the seminal work of Green and Bavalier [24], positive effects have been found in those playing first-person shooter video games, such as heightened cognitive control compared to non-video game players and individuals training on other types of video games [24,25]. Along the same lines, recent work by Oei and Patterson demonstrated that video game training (primarily 'action' games, although effects were found with non-action games) with games downloaded from iTunes to an iPhone/iPod led to positive effects on attention and working memory abilities [26•,27]. While these results are encouraging, there have also been a number of video games training studies that have not observed beneficial effects beyond improvements on the game itself, including for action-based games [28]. For example, work by Boot and colleagues failed to show evidence of transfer to any test of cognitive control abilities following ~20 h of game play in young adults on *Medal of Honor* (a first-person shooter game) or *Rise of Nations* (a real-time strategy game [29]; however, see [30]). Similar lack of effects were shown with younger adults after 15 h of playing web-based 'casual' games (e.g., puzzle or reasoning-based games [31]). Perhaps the most compelling data on this topic for older adults involves recent meta-analyses detailing a range of observed effects (both positive and negative) following video game training studies [32•,33]. These results remind us that the use of these platforms is not a 'sure thing' with respect to evidencing cognitive enhancement [34•], and that not all types of entertainment-based video games ('action' versus 'strategy' versus 'casual' games) lead to similar effects.

Intervention design factors

A broad view of the data generated by cognitive training studies suggests that the repetitive use of interactive media that requires rapid decisions in demanding environments leads to the best chance of engendering cognitive enhancement effects [35]. However, there are a number of factors related to qualities of the cognitive training intervention that are worth considering, such as fun, motivation to play, and underlying game mechanics in the form of adaptivity. The role of fun is one that is often touted, but is notably difficult to properly assess given the inherent intrinsic evaluation of fun by each individual. Both educators and the video game industry have recognized for years the importance of incorporating fun into their respective workspaces to achieve optimal outcomes [36–39], making a clear case for its importance in cognitive training studies. However, it is still unclear exactly how fun factors into cognitive training given that training participants often report similar levels of engagement as individuals playing control games [40•,41,42], yet they show distinctly different levels of improvement. These types of results warrant future work in which the active ingredients of a training intervention are the same (e.g., motivation, game mechanics, etc.), but the amount of fun differs.

Highly related to this concept is the factor of motivation, an important extrinsic quality deeply embedded in video games through carefully crafted reward structures that engender player engagement. Video games are inherently designed to have high motivation levels thanks to their immersive game elements, in contrast to many cognitive exercises. A recent study by Dorrenbacher *et al.* suggested that the motivational setting can have a positive effect on near-transfer benefits, but does not appear to contribute to abilities outside of those trained directly (e.g., far transfer [43]). These findings are interesting when considering work by Prins *et al.* [44], who examined motivational effects within a working memory cognitive exercise. These authors reported that high motivation led to individuals voluntarily training more and subsequently outperforming a low-motivation group in terms of in-game performance and transfer effects. However, recent work by Katz *et al.* [45] suggests that specific types of motivational elements like real-time scoring can actually hinder cognitive training effects, a broad implication for both researchers and game designers that warrants further investigation. These findings suggest that motivational biases may aid individuals playing video games in reaching greater outcomes versus those engaged in cognitive exercises.

Another factor frequently employed in video games to enhance the playing experience is the titration of game difficulty to encourage subsequent play. This is known as adaptivity, and is defined as the modification of stimuli or responding characteristics of the challenge as determined by an individual's performance. This tool is also commonly used in the development of cognitive exercises, where it is often assumed to be core for an optimal training experience. A recent example of the selective benefits of adaptivity with a cognitive exercise was demonstrated by Mishra and colleagues in an inter-species training study involving both older rats and humans [46]. They showed that adaptively modifying distracting stimuli in response to participant improvement led to selective plasticity in how each species processed distracting information. These effects, and the presence of similar outcomes in other studies using adaptivity (including seminal work by Merzenich and colleagues [14,46–51]) suggest that it can be a powerful mechanic for cognitive enhancement via either approach (however, see [52]).

Study design factors

Equally important as intervention-based factors in realizing the goal of cognitive enhancement are factors associated with the study design itself. There are a number of factors that could be discussed here (for an excellent summary of these, see [2•]). However, when considering both video games and cognitive exercises there are two study-based factors that each appear to contribute to the potential effects: expectancy (e.g., an individual's anticipated cognitive gains from game play), and dose effects (e.g., the amount of time needed to induce cognitive changes). As elegantly explained elsewhere [2•,53•], expectancy can have a profound influence through placebo effects on subsequent training outcomes. It is not hard to image that a naïve individual would have greater expectancy with respect to the use of cognitive exercise designed for cognitive enhancement compared to a video game designed for entertainment. For example, Boot and colleagues [54] demonstrated that absent training effects were associated with the belief that playing a given video game would not lead to cognitive enhancement. This point dovetails with dose effects, as some researchers have suggested that video game training requires greater doses (e.g., hours of play) to evidence cognitive enhancement [30,55], which may be related to expectancy factors in these studies that assess tools not originally designed for this purpose. However, recent meta-analyses involving each type of intervention in older adults actually suggest that shorter training periods (3×/week or less) often have greater effects than longer training periods [32•,33]. This result may reflect overtraining-related cognitive fatigue (cf. [56,57]) associated with improperly spaced training schedules [58,59], a loss of motivation as anticipated rewards are smaller than the immediate cost of training [60•,61], or other unaccounted factors. In any case, these findings suggest that dose is not well understood with respect to cognitive enhancement.

This discussion raises another interesting question to be considered when designing a study: does training on several different modules within a given type of interactive digital media lead to more beneficial cognitive effects than playing one type repetitively and intensively? This approach is akin to variable priority training [62], where training requires participants to intentionally vary their task priorities amongst one (or more) dimensions. This approach inherently forces participants to consider information about the underlying relationships amongst tasks being performed, which theoretically leading to greater generalizability (e.g., see [10,63,64]). However, the data suggests that the 'multi-game' approach has not regularly been shown to be effective at achieving transfer effects beyond a control group [65], regardless of the amount of time invested in training. For example, neither 5 + h of training using the Nintendo *Brain Age* 'multi-game' platform [66], nor 20 h of training using the Wii *Big Brain Academy* 'multi-game' platform [67] led to meaningful transfer effects involving cognitive control. Even more intriguing is recent work by Shute and colleagues [68] demonstrating that playing a single first-person spatial puzzle video game *Portal 2* led to more positive effects in spatial abilities (and other non-cognitive skills) than training on a battery of cognitive exercises using the *Lumosity* platform. These findings, in conjunction with a recent meta-analysis testing this concept across several training studies [32•], supports the idea that training on fewer tasks may be more beneficial in terms of yielding transfer effects than training on a multitude of tasks (however, see [48,49]), although dose effects considerations are also warranted.

A hybrid approach

We recently attempted to leverage the strengths associated with video games and cognitive exercises by developing a hybrid platform with assistance from video game professionals from *Lucas Arts* to characterize and remediate deficient cognitive control abilities in older adults. This game, *NeuroRacer* [40•], incorporated key design factors from the entertainment video game world (e.g., engaging visual elements, timely rewards, motivating feedback) and the cognitive exercise field (e.g., targeted training at a deficient neural deficit and rapid adaptivity) with the aim of achieving an optimal training experience. Game play involved participants performing a perceptual discrimination task (e.g., responding with a button-press only when a green circle appeared) while simultaneously performing a visuomotor tracking task (i.e., maintaining a car in the center of a winding road with a joystick). Performance feedback for each task was presented at the end of each 3-min run. Two adaptive algorithms independently manipulated difficulty for each task, such that if a participant performed above an approximate 80% criterion on either task, game play would become more difficult on said task (and vice versa for performance below this criterion). To ensure equivalent engagement of each component task, rewards were only given when performance on both component tasks improved beyond the 80% criterion. We hypothesized that by challenging goal management (e.g., multi-tasking) abilities we would observe improvements in attention and working memory given common mechanistic underpinnings of these cognitive control abilities.

Following 12 h of video game play over the course of the month, the older adult participants training on a the multitasking version of the game showed enhanced performance on untrained cognitive tests of sustained attention and working memory. These improvements were shown to be driven by the goal management aspects of training, as a control group that trained on the individual tasks in isolation (single-tasking) did not show any type of improvement. Multitasking-training participants also showed evidence of augmented midline frontal theta activity as well as frontal–parietal theta coherence, neural signatures obtained by using EEG during game play that reflects the engagement of the prefrontal cortex and long-range neural networks involved in cognitive control, respectively [40•]. This work should be considered a first step in validating the presence and function of cognitive neurotherapeutics, as future research with larger numbers of participants that replicates the present findings is warranted. Although further experimentation is required to validate the role of all the elements, we hypothesize that the unique hybrid design of *NeuroRacer* contributed the observed effects, providing a template for future collaboration between the video game industry professionals and cognitive neuroscientists to create the next generation of cognitive training tools.

Conclusions

There are numerous factors to be considered when designing cognitive training interventions and then validating the benefits. This field is still in its infancy in terms of understanding why any given approach leads to a positive or negative outcome. The proliferation of cognitive enhancement tools aimed at populations who would benefit most from remediation (e.g., children and older adults with cognitive impairments) recently led to a strong declaration by a group of researchers in a consensus statement [69]. The statement provided several valid critiques of this burgeoning field, such as limited evidence in supporting the idea that interactive digital media has beneficial effects on real-world activities. This statement underscores the responsibility of researchers in academia and industry to provide rigorous scientific evidence to support claims that these tools can enhance cognition. Looking toward the future, these concerns can be best assuaged through a deeper understanding of intervention design elements and how they serve as active ingredients that are most capable of leading to meaningful and sustainable changes in brain and behavior.

Conflicts of interest statement

AG is co-founder and chief science advisor of Akili Interactive Labs, a newly formed company that develops cognitive training software. AG has a patent pending for a game-based cognitive training intervention, 'Enhancing cognition in the presence of distraction and/or interruption', which was inspired by the research presented here. JAA has no conflicts of interest.

Acknowledgements

This work was supported by the National Institute of Health Grants 5R01AG040333 (AG). We would like to thank Jyoti Mishra for her feedback on earlier versions of this manuscript.

References

1. Ferguson B: **Videogames: the good, the bad, and the ugly**. *Games Health J* 2013, **2**:1-2.

2. • Green CS, Strobach T, Schubert T: **On methodological standards in training and transfer experiments**. *Psychol Res* 2014, **78**:756-772.
An elegant overview on methodological aspects of cognitive training that include expectation, test–retest effects, control groups selection, interpreting null results, and more.

3. Zelinski EM: **Far transfer in cognitive training of older adults**. *Restor Neurol Neurosci* 2009, **27**:455-471.

4. Karbach J, Kray J: **How useful is executive control training? Age differences in near and far transfer of task-switching training**. *Dev Sci* 2009, **12**:978-990.

5. Lustig C *et al.*: **Aging, training, and the brain: a review and future directions**. *Neuropsychol Rev* 2009, **19**:504-522.

6. Noack H, Lovden M, Schmiedek F: **On the validity and generality of transfer effects in cognitive training research**. *Psychol Res* 2014, **78**:773-789.

7. • Bisoglio J *et al.*: **Cognitive enhancement through action video game training: great expectations require greater evidence**. *Front Psychol* 2014, **5**:136.
A review of studies that provides a balanced perspective regarding the efficacy of video game training, with care given to describe why the magnitude and specificity of these types of effects are not often observed.

8. Mané A, Donchin E: **The Space Fortress game**. *Acta Psychol* 1989, **71**:17-22.

9. Nikolaidis A *et al.*: **Parietal plasticity after training with a complex video game is associated with individual differences in improvements in an untrained working memory task**. *Front Hum Neurosci* 2014, **8**:169.

10. Voss MW *et al.*: **Effects of training strategies implemented in a complex videogame on functional connectivity of attentional networks**. *Neuroimage* 2012, **59**:138-148.

11. Boot WR *et al.*: **Transfer of skill engendered by complex task training under conditions of variable priority**. *Acta Psychol (Amst)* 2010, **135**:349-357.

12. Lee H *et al.*: **Performance gains from directed training do not transfer to untrained tasks**. *Acta Psychol (Amst)* 2012, **139**: 146-158.

13. Gopher D, Well M, Bareket T: **Transfer of skill from a computer game trainer to flight**. *Hum Factors* 1994, **36**:387-405.

14. Montani V, Grazia MDFD, Zorzi M: **A new adaptive videogame for training attention and executive functions: design principles and initial validation**. *Front Psychol* 2014, **5**:1-12.

15. Bherer L *et al.*: **Testing the limits of cognitive plasticity in older adults: application to attentional control**. *Acta Psychol (Amst)* 2006, **123**:261-278.

16. Bherer L *et al.*: **Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood**. *Exp Aging Res* 2008, **34**:188-219.

17. Buschkuehl M *et al.*: **Neural effects of short-term training on working memory**. *Cogn Affect Behav Neurosci* 2014, **14**:147-160.

18. Buschkuehl M *et al.*: **Impact of working memory training on memory performance in old–old adults**. *Psychol Aging* 2008, **23**:743-753.

19. Berry AS *et al.*: **The influence of perceptual training on working memory in older adults**. *PLoS One* 2010, **5**:e11537.

20. Jaeggi SM *et al.*: **Improving fluid intelligence with training on working memory**. *Proc Natl Acad Sci U S A* 2008, **105**:6829-6833.

21. • Au J *et al.*: **Improving fluid intelligence with training on working memory: a meta-analysis**. *Psychon Bull Rev* 2015, **22**:366-377.
One (somewhat controversial; see next citation for an alternative view) perspective on the generalization of working memory training potentially leading to far transfer effects in the domain of intellegence.

22. • Redick TS *et al.*: **No evidence of intelligence improvement after working memory training: a randomized, placebo-controlled study**. *J Exp Psychol Gen* 2013, **142**:359-379.
One (somewhat controversial; see previous citation for an alternative view) perspective describing the inability to replicate previous gains in intellegence following working memory training.

23. Shipstead Z, Redick TS, Engle RW: **Is working memory training effective?** *Psychol Bull* 2012, **138**:628-654.

24. Green CS, Bavelier D: **Action video game modifies visual selective attention**. *Nature* 2003, **423**:534-537.

25. Wu S *et al.*: **Playing a first-person shooter video game induces neuroplastic change**. *J Cogn Neurosci* 2012, **24**:1286-1293.

26. • Oei AC, Patterson MD: **Enhancing cognition with video games: a multiple game training study**. *PLoS One* 2013, **8**:e58546.
A very 'real-world' approach to cognitive training using apps from the iTunes store, showing evidence of near-transfer effects that were specific to the type of app participants trained with.

27. Oei AC, Patterson MD: **Enhancing perceptual and attentional skills requires common demands between action video games and transfer tasks**. *Front Psychol Cogn* 2015, **6**:1-11.

28. van Ravenzwaaij D *et al.*: **Action video games do not improve the speed of information processing in simple perceptual tasks**. *J Exp Psychol Gen* 2014, **143**:1794-1805.

29. Boot WR *et al.*: **The effects of video game playing on attention, memory, and executive control**. *Acta Psychol (Amst)* 2008, **129**:387-398.

30. Basak C *et al.*: **Can training in a real-time strategy video game attenuate cognitive decline in older adults?** *Psychol Aging* 2008, **23**:765-777.

31. Baniqued PL *et al.*: **Cognitive training with casual video games: points to consider**. *Front Psychol* 2014, **4**:1010.

32. • Toril P, Reales JM, Ballesteros S: **Video game training enhances cognition of older adults: a meta-analytic study**. *Psychol Aging* 2014, **29**:706-716.
Similar to the Lampit meta-analysis below, a well-organized view providing effect sizes and other insights to highlight positive (and null) findings in a population that is especially vulnerable to cognitive declines.

33. Lampit A, Hallock H, Valenzuela M: **Computerized cognitive training in cognitively healthy older adults: a systematic review and meta-analysis of effect modifiers**. *PLoS Med* 2014, **11**:e1001756.

34. • Unsworth N *et al.*: **Is playing video games related to cognitive abilities?** *Psychol Sci* 2015, **26**:759-774.
An interesting paper describing how focusing on extreme group analyses in the video game space can lead to distinct findings compared to the general population with respect to cognitive abilities.

35. Green CS, Bavelier D: **Exercising your brain: a review of human brain plasticity and training-induced learning**. *Psychol Aging* 2008, **23**:692-701.

36. Smith L, Mann S: **Playing the game: a model for gameness in interactive game based learning**. In *Proceedings of the 15th Annual NACCQ*; *Hamilton, New Zealand: 2002*.

37. Mathers BG: **Students' perceptions of "fun" suggest possibilities for literacy learning: "you can be entertained and informed"**. *Reading Horizons* 2008, **49** p. Article 6.

38. Newmann F: *Student Engagement and Achievement in American Secondary Schools*. New York, NY: Teachers College Press; 1992.

39. Singer R: **Are we having fun yet?** In *Rethinking Childhood.* Edited by Pufall PB, Unsworth RP. Rutgers University Press; 2004: 207-228.

40. • Anguera JA *et al.*: **Video game training enhances cognitive control in older adults**. *Nature* 2013, **501**:97-101.
An example of a video game training study with multiple control groups, evidence of both near & far transfer, neural correlates of training, and persisting beneficial effects that persisted beyond the training period without any booster training.

41. Bejjanki VR *et al.*: **Action video game play facilitates the development of better perceptual templates**. *Proc Natl Acad Sci U S A* 2014, **111**:16961-16966.

42. Belchior P *et al.*: **Older adults' engagement with a video game training program**. *Act Adapt Aging* 2012, **36**:269-279.

43. Dorrenbacher S *et al.*: **Dissociable effects of game elements on motivation and cognition in a task-switching training in middle childhood**. *Front Psychol* 2014, **5**:1275.

44. Prins PJ *et al.*: **Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD?** *Cyberpsychol Behav Soc Netw* 2011, **14**:115-122.

45. Katz B *et al.*: **Differential effect of motivational features on training improvements in school-based cognitive training**. *Front Hum Neurosci* 2014, **8**:242.

46. Mishra J *et al.*: **Adaptive training diminishes distractibility in aging across species**. *Neuron* 2014, **84**:1091-1103.

47. Brehmer Y, Westerberg H, Bäckman L: **Working-memory training in younger and older adults: training gains, transfer, and maintenance**. *Front Hum Neurosci* 2012, **6**:1-7.

48. Smith GE *et al.*: **A cognitive training program based on principles of brain plasticity: results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study**. *J Am Geriatr Soc* 2009, **57**:594-603.

49. Mahncke HW *et al.*: **Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study**. *Proc Natl Acad Sci U S A* 2006, **103**:12523-12528.

50. Ball K, Edwards JD, Ross La: **The impact of speed of processing training on cognitive and everyday functions**. *J Gerontol B Psychol Sci Soc Sci* 2007, **62**:19-31.

51. Merzenich MM *et al.*: **Temporal processing deficits of language-learning impaired children ameliorated by training**. *Science* 1996, **271**:77-81.

52. von Bastian CC, Eschen A: **Does working memory training have to be adaptive?** *Psychol Res* 2015:1-14.

53. • Boot WR *et al.*: **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.
An insightful paper describing an important and often overlooked factor in cognitive training studies (expectancy) that can (and should) be properly assessed before launching any training study.

54. Boot WR *et al.*: **Video games as a means to reduce age-related cognitive decline: attitudes, compliance, and effectiveness**. *Front Psychol* 2013, **4**:31.

55. Belchior P *et al.*: **Video game training to improve selective visual attention in older adults**. *Comput Hum Behav* 2013, **29**:1318-1324.

56. Persson J *et al.*: **Cognitive fatigue of executive processes: interaction between interference resolution tasks**. *Neuropsychologia* 2007, **45**:1571-1579.

57. Anguera JA *et al.*: **The effects of working memory resource depletion and training on sensorimotor adaptation**. *Behav Brain Res* 2012, **228**:107-115.

58. Wang Z, Zhou R, Shah P: **Spaced cognitive training promotes training transfer**. *Front Hum Neurosci* 2014, **8**:217.

59. Penner IK *et al.*: **Computerised working memory training in healthy adults: a comparison of two different training schedules**. *Neuropsychol Rehabil* 2012, **22**:716-733.

60. • Mayas J *et al.*: **Plasticity of attentional functions in older adults after non-action video game training: a randomized controlled trial**. *PLoS One* 2014, **9**:e92269.

61. Green L, Fristoe N, Myerson J: **Temporal discounting and preference reversals in choice between delayed outcomes**. *Psychon Bull Rev* 1994, **1**:383-389.

62. Schmidt RA, Bjork RA: **New conceptualizations of practice: common principles in three paradigms suggest new concepts for training**. *Psychol Sci* 1992, **3**:207-217.

63. Kramer AF *et al.*: **Training for executive control: task coordination strategies and aging**. In *Attention and Performance XVII*. Edited by Gopher D, Koriat A. Cambridge, MA: MIT Press; 1999:617-652.

64. Kramer AF, Larish JF, Strayer DL: **Training for attentional control in dual-task settings — a comparison of young and old adults**. *J Exp Psychol Appl* 1995, **1**:50-76.

65. Owen AM *et al.*: **Putting brain training to the test**. *Nature* 2010, **465**:775-778.

66. Nouchi R *et al.*: **Brain training game improves executive functions and processing speed in the elderly: a randomized controlled trial**. *PLoS One* 2012, **7**:e29676.

67. Ackerman PL, Kanfer R, Calderwood C: **Use it or lose it? Wii brain exercise practice and reading for domain knowledge**. *Psychol Aging* 2010, **25**:753-766.

68. Shute VJ, Ventura M, Ke F: **The power of play: the effects of Portal 2 and Lumosity on cognitive and noncognitive skills**. *Comput Educ* 2015, **80**:58-67.

69. • Longevity MPIfHDaSCo: *A Consensus on the Brain Training Industry from the Scientific Community*. 2014:. Available from: http://longevity3.stanford.edu/blog/2014/10/15/the-consensus-on-the-brain-training-industry-from-the-scientific-community/.

An important perspective piece by a number of leaders in the cognitive training field describing how there is insufficient evidence at present to substantiate claims that ‘brain games’ have any beneficial effect in cognitive impacted individuals.