

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)

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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 dem-

onstrated 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 imagine 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.

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- 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.