Video game play, attention, and learning: how to shape the development of attention and influence learning?

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Purpose of review
The notion that play may facilitate learning has long been touted. Here, we review how video game play may be leveraged for enhancing attentional control, allowing greater cognitive flexibility and learning and in turn new routes to better address developmental disorders.

Recent findings
Video games, initially developed for entertainment, appear to enhance the behavior in domains as varied as perception, attention, task switching, or mental rotation. This surprisingly wide transfer may be mediated by enhanced attentional control, allowing increased signal-to-noise ratio and thus more informed decisions.

Summary
The possibility of enhancing attentional control through targeted interventions, be it computerized training or self-regulation techniques, is now well established. Embedding such training in video game play is appealing, given the astounding amount of time spent by children and adults worldwide with this media. It holds the promise of increasing compliance in patients and motivation in school children, and of enhancing the use of positive impact games. Yet for all the promises, existing research indicates that not all games are created equal: a better understanding of the game play elements that foster attention and learning as well as of the strategies developed by the players is needed. Computational models from machine learning or developmental robotics provide a rich theoretical framework to develop this work further and address its impact on developmental disorders.

Keywords
attention, child development, computerized training, learning, learning disabilities, play, video games

INTRODUCTION
La plus utile règle de toute l’éducation ce n’est pas de gagner du temps, c’est d’en perdre.
Jean-Jacques Rousseau, Émile ou De l’Éducation.

From ethologists to psychologists, it has long been recognized that play time presents key opportunities for learning [1,2]. All mammals engage in playful activities during which instinctive behaviors seem to be shaped – as during rough-and-tumble play – or new strategies developed – as during play pretend. During play, the individual is typically highly engaged, faced with complex sequences of events, and challenged to respond appropriately, all the while in a fail-safe environment, conducive to exploration – setting ideal conditions to promoting learning. In addition, play is typically social, adding a key motivational component. As illustrated by the computational approaches to learning, these are ideal conditions to foster more flexible behaviors and promote adaptability to new situations – a form of learning to learn [3**]. At the same time, play can also be conceived of as a natural outcome of development that can then be leveraged to assess the performance in a more engaging and natural way [4].

Here, we focus on a very specific form of play: that mediated through new media and, in particular, video games. We will consider the current knowledge of these effects on behavior, with a special emphasis on attention and learning. To this...
Developmental disorders

KEY POINTS

- Action video game play improves top-down attention.
- Top-down attention is seen to facilitate learning.
- Not all video games promote learning and brain plasticity.
- Need to take into account the player: interventions should not be applied blindly to any population.

aim, we will first review the developmental time course of attention before considering the impact of various forms of media use on attentional control. We will discuss other interventions – in school and after-school programs – that appear promising in improving attentional control as well as the possible consequences of this research on clinical populations.

At first sight, the focus on attentional control may seem to be a departure from our central topic: play and learning. Yet, one of the dominant assumptions – both in education and developmental robotics – is that learning relies on a fundamental skill: the ability to focus on task-relevant features, while ignoring potential sources of distractions. Increased signal-to-noise promotes not only processing efficiency but also learning as the nature of the task at hand becomes easier to apprehend and distractions are better ignored [5*].

THE DEVELOPMENT OF ATTENTION: VARIETIES OF ATTENTION AND MILESTONES

Attention is critical to guide information processing, given limited resources. It can be exogenous or stimulus-driven, automatically capturing resources for the immediate processing of salient or unpredicted stimuli, as when startled by a sudden alarm. Alternatively, attention can be endogenous or top down, engaged voluntarily and oriented toward a desired goal as when reading on a crowded bus [6]. This form of attention can be expressed in the temporal and spatial domains as well as toward objects. For example, the temporal resolution of attention can be assessed using the attentional blink task, in which individuals are to report the presence of target stimuli presented within a stream of mostly nontarget stimuli. The attentional blink phenomenon refers to the observation that detecting a first target reduces the ability to detect a subsequent target if it is presented shortly thereafter, as if attention had blinked.

These different forms of attention rely on partially different neural networks and follow different developmental trajectories [7]. Orienting toward abrupt onsets seems present at birth and mediated by subcortical structures, whereas other forms of exogenous attention are under cortical control and reach adult levels only by ages 10–11 years [8]. Top-down attention on the other hand relies on the development of a fronto-parietal network and improves at least until adolescence, as exemplified by the attentional blink task [9,10]. Top-down spatial attention appears to mature faster, reaching asymptotic levels around age 7, when assessed with simple tasks, but can be shown to mature beyond puberty with more complex tasks. The developmental milestones of top-down attention are typically measured through the visual modality; yet, an important variant uses dichotic listening, whereby participants listen to two simultaneously presented stories, one in each ear. Through instructions, participants are told which ear to attend to and are then questioned about the stories. Importantly, while the stories are played, target sounds are presented to either ear, making it possible to assess the event-related potentials (ERPs) to these irrelevant stimuli and how they are affected by attention [11]. Using this paradigm, markers of top-down attention could be characterized in children as early as preschool up to adulthood, tracking separately not only enhancement of the to-be-attended stream, but also suppression of the irrelevant, distracting stream.

When it comes to learning, two forms of attention are essential: top-down attention – because it controls the allocation of processing resources to the task at hand, a prerequisite for any form of declarative learning and a facilitator of most skilled learning, even if some learning is certainly possible without attention [12] – and sustained attention, the ability to hold focus from seconds to minutes [13–15], a key skill for school and yet understudied, especially when it comes to ways to enhance it. We regroup below the mechanisms that subsume these two forms of attention under the term ‘attentional control’. These mechanisms are at play in attention disorders [attention deficit disorder (ADD) and attention deficit hyperactivity disorder (ADHD)], with their compromise being associated with impulsivity and various forms of inattentiveness.

VIDEO GAME PLAY AND ATTENTIONAL CONTROL: COUNTER-INTUITIVE FINDINGS

How can attentional control be improved? Does play have a special status when it comes to fostering attentional control? Games can be used to develop attention, a fact that the French psychologist Alfred Binet exploited to help children acquire the attentional skills needed in school. In a telling example, Binet documents the game of ‘statue’, in which
children are to take a pose and hold it for as long as possible. Although laughter and chatting initially dominate the classroom, over time children get into the game, trying their best to outperform their peers! The use of such games, Binet [16] surmises, was key in allowing students who had failed the school system to catch up two academic years in one! More recently, in another surprising twist, playing commercially fast paced, action packed such as first or third shooter video games has been shown to improve attentional control across many of its manifestations [17] and has led to investigating whether action video game play may positively affect attention in the developing brain [10,18,19].

Dye and Bavelier [10] tested top-down attentional skills of 7–22 year olds focusing on top-down attention in space (Visual Search), in time (attentional blink paradigm), or over objects as in the multiple object tracking (MOT) paradigm, in which participants are presented a set of identical objects moving in space and asked to keep track of a subset of them. For all of these tasks, children who reported playing action video games systematically outperformed those who did not. This group difference emerged between 7 and 10 years of age, and kept increasing thereafter. Notably, action video gaming children reached adult nonplayer levels of performance for attention in time (attentional blink) by ages 7–10 and for attention to objects (MOT) by ages 11–13 years (see also [19]). Clearly, the developmental time-course of attention is being modified by the technology use. Here, we see it accelerated by a certain type of video game play, but technology use has certainly been associated with worse, rather than better, attentional control, with many reporting an increase in ADD and ADHD and other wellbeing issues among pediatric populations [20,21]. The source of this rise remains an active topic of studies.

Although video game play is often blamed, the Test of Variables of Attention (TOVA) which focuses on impulsivity and sustained attention – functions typically hindered in ADD and ADHD – shows that action video game play is not the culprit. When tested on the TOVA, action video game players were faster, but not less accurate, than nonaction game players, suggesting a notable ability at making more correct decisions per unit of time ([22], see Fig. 1).

Finally, it is important to note that various components of attention are not all equally affected by action video game play. Whereas attentional control is seen to improve, exogenous attention or the automatic pull on attention created by abrupt onsets is unchanged by action video games [18,23–25]. This is the case despite the profusion of abrupt onsets that these video games contain. Such results highlight the need to go beyond intuitive analyses of the impact of technology use on the brain and call for more controlled laboratory studies distinguishing among the many technology uses. Only by doing so can we achieve the needed level of granularity to understand how various technology uses affect brain and behavior.

In adults, many of the studies have gone beyond contrasting groups based on their reported action video game play experience (>5 h/week for at least 6 weeks vs. <1 h per week). In training studies, nonvideo game players asked to play action video games for about 0.5–1 h per day, 5 days a week for 2–10 weeks, show improved attentional abilities above and beyond a control group asked to play other genres of commercial video games [26–33], establishing a direct link between action game play and attention enhancement. In children, because of the typical violence in action videos, training studies would be unethical, calling for the development of age-appropriate action video games.

This work should not be taken as an excuse to binge on video games. Short daily sessions over multiple weeks suffice to induce long-lasting positive changes, in line with the importance of distributed practice in learning. In some studies, the effects of action video game training were still visible months to years after the end of training. It should be recognized that video game play affects the brain at multiple time-scales. Some effects occur after small amounts of training, whereas others require extensive practice. The potential of video game play to induce neuroplastic changes is highlighted by reports of changes in both gray [34] and white matter [35] after only 2 h of playing an action-video car-racing game. Interestingly, these changes were observed only when participants raced the same track repeatedly, and thus could learn its spatial layout, but not when the track changed continuously, implying that in addition to the time on task, the specific way in which a game is played critically determines its effects on the brain.

The existing training studies in children have all used specially designed computer software (e.g., [36–39]). For example, Rueda et al. [38] assigned 4 and 6 year olds to five sessions of either an attention training game – originally designed by the National Aeronautics and Space Administration (NASA) to prepare monkeys for space travel – or of video watching. Both groups were pretrained and posttested on an attention task while recording ERPs. In the game but not the movie-watch group, the brain markers of attention after training resembled those observed in the adult brain. Interestingly, no effect was observed at the behavioral level (see also
This observation fits well with the notion of ‘preparation for future learning’, which states that games produce latent effects that facilitate future learning [40]. Computerized games have also been developed to train executive functions of preschool children [41,42]. Although not directly targeting attention, some of these studies reported transfer effects from working memory training to attentional control tasks [43].

Top-down attention appears, therefore, highly plastic, especially during development, making it both vulnerable and also a powerful target for intervention.

**OTHER APPROACHES TO RETRAINING ATTENTIONAL CONTROL**

Other interventions exist in addition to computer and video games. Contemplative training such as mindfulness meditation [44] or compassion meditation [45,46] also improves the abilities to regulate one’s behavior, be it through enhanced attentional control or better emotional regulation [47]. Yet, applications of these approaches on children and adolescents remain limited, calling for further studies [48].

Physical exercise, especially in sedentary individuals, results in both physical and cognitive improvements. After exercising regularly for several weeks, older adults display not only improved physical health, but also enhanced cognitive functions, including faster reaction times, enhanced attentional control, and executive processes, and spatial cognition [49]. Although exercise training studies on children are rare, the sharp rise in obesity and the all-too common attention problems that affect this age group, combined with the fact that exercise can easily be gamified (as illustrated by the recent surge in

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**FIGURE 1.** The Test of Variables of Attention (TOVA) assesses impulsivity and sustained attention. In this test, participants are seated in front of a computer screen and required to press a key as fast as possible in response to a target (black square in upper position) and to withhold responding to nontarget stimuli (black square presented in lower position). (a) In one condition, the targets are rare and the nontargets appear frequently. The extent to which participants are able to stay on task and respond quickly to rare targets is a measure of sustained attention. (b) In a different set of trials, targets appeared frequently, whereas nontargets were rare. The extent to which participants are able to withhold responding to nontargets is a measure of impulsivity. Dye et al. [22] used the TOVA to assess differences in impulsivity and sustained attention between young adults who were either nonvideo game players (NVGPs) or habitual action video game players (VGPs). (c) Their results show that VGPs were overall faster than NVGPs and that held true in both the sustained attention and the impulsivity condition. (d) This increased speed did not come at the expense of accuracy as both groups did not differ on this measure, indicating overall enhanced attentional control in VGPs. Error bars are standard errors of the mean. Of note is the fact that the TOVA software automatically considers response times shorter than 200 ms as anticipatory responses and classifies them as incorrect. Because VGPs have many response times below 200 ms, VGPs would have been found to have worse attention than NVGPs despite being correct on these trials. The plotted data did not use the 200-ms cutoff for anticipation. An important lesson is the importance of revising clinical tests and their criteria for use as new generations may not match previous norms. In this case, ample research documents faster response times in the users of technology. Reproduced with permission [22].
exergames [50]), suggest that such interventions might be especially promising [51,52].

The possibility of re-introducing within the school system some of the best practices suggested by the studies of attention and its underlying brain systems has recently caught some traction. An example is ‘Tools of the Mind’ – a program based on Vygotsky’s insights on the factors that promote learning, including use of aids and strategies to facilitate focus, use of private speech to regulate one’s thoughts as well as acting of short scenarios. All these activities require self-regulation and concentration; in turn, such interventions markedly improve executive functions and attentional control in school-age populations [53].

Finally, an often-forgotten catalyst of cognitive development is children’s home environment. In a recent thought-provoking study, Neville et al. [54] contrasted two forms of intervention: one focusing mainly on child classroom training with reduced parent-directed training, and the other both on children’s attention and parent-directed training. Increase in attentional control was assessed both behaviorally and through ERP markers of selective attention, demonstrating an enhancement of brain responses to attended stimuli in the group who received most parent training. This study is all the more important in that it focused on children from low socio-economic background, in which the neural underpinnings of selective attention are compromised. The key role of family members in fostering positive conduct in children is receiving more and more attention and has led to the development of family video games, specially designed for children to play with adults [55]. Although this game genre is developing fast, controlled studies are needed to quantify their impact on cognition, social, and affective skills.

**IMPLICATIONS FOR CLINICAL POPULATIONS**

The possibility of retraining attentional control and stimulating learning makes this work particularly relevant to children with learning disabilities and attention disorders (ADD and ADHD). Yet not all interventions that boost attention in normal children may apply to clinical populations. This point is probably best illustrated by asking whether ADD and ADHD individuals, who suffer from low attentional and executive control, should be advised to play action video games. Probably not! First, a number of studies point to the time spent playing video games as a risk factor for ADD and ADHD and pathological gaming, calling for caution [56,57]. Second, enhancing attentional control in individuals with intact regulatory brain systems is a different proposition than doing so in individuals in whom these systems are dysfunctional. Finally, to appeal to a wide audience, video games allow for many types of game play and thus strategies. This means that the same game can be played not only proactively – with the player seeking to predict next moves and events – but also reactively, with the player jumping in the middle of the action and indiscriminately pushing the buttons. These two types of game play are unlikely to have the same effect on attention, and may explain the apparent discrepancy between action video game playing enhancing performance in TOVA (see Fig. 1), whereas being a risk factor for ADD and ADHD. In the ADD and ADHD population, a series of mini-games targeting both attentional control and executive functions have shown some promising results [58]. Yet, at present, neurofeedback whereby the patient is trained to control his or her brain states appears one of the most promising technology-based interventions for attention disorders [59,60,61]. Of course, neurofeedback could be naturally integrated into video game play, facilitating treatment compliance [62].

Surprisingly, some commercial video games have been found to positively impact health. Low vision patients, such as amblyopic patients, can enhance their visual acuity by playing the Sims, Tetris, or Unreal Tournament. This was shown in adult amblyopes typically thought to be past the ‘critical period’ for visual plasticity and thus untreatable [63,64].

Children with language impairment often exhibit attentional problems and seem to benefit from retraining attentional control. In one study, Italian dyslexic children played either action mini-games or nonaction mini-games for 12 h over 9 days. The action mini-game trainees exhibited increased attentional skills and faster reading speed than the nonaction trainees [65]. Of note, both forms of mini-games were part of the same commercial video game ‘Rayman’s Raving Rabbids’. Action mini-games emphasized visuo-motor control, precise aiming, and proper timing of action, as well as divided attention and planning, whereas the control mini-games emphasized very fast motor execution with little need for control on behalf of the player. That different parts within a game can have such different impact tellingly illustrates the key role of processing demands inherent to the game play in shaping the game impact, and call for further cognitive task analyses of game play. And indeed, not all games seem to equally foster performance improvement and transfer, as shown by a large-scale study of ‘brain games’ in adults which reported gains on the trained mini-games, with little transfer to different assessments testing the same cognitive functions [66].
Together, such studies suggest that enhanced attentional control may be key in unlocking brain plasticity and learning; however, a causal role for attentional enhancement in rehabilitating language or visual deficiencies remains to be firmly established.

**CONCLUSION**

Children are faced with incredibly complex learning problems in open-ended environments that they have to solve autonomously. In this context, human play is thought to be an ingenious trick invented by evolution to help solve those problems. Two major insights in understanding human play have recently emerged in machine learning and developmental robotics [67**]. First, gaining information is valuable to the individual and might by itself be rewarding. Play may, therefore, provide the right time windows to express such intrinsically motivated actions. Second, information or novelty seeking per se is not sufficient to drive efficient learning in the multidimensional space faced by the learning child. Indeed, completely unpredictable events, such as white noise on a television screen, will forever remain both novel and unlearnable; yet children rarely get stuck trying to learn them. The dominant view is that cognitive mechanisms, such as attentional control, are specifically designed to maximize learning, which would explain the many positive consequences of fostering the development of attentional control. Combined together, these two insights identify play as a key activity that can be leveraged to better engage patients with their prescribed therapy, enhance treatment compliance and its learning impact as well as to continuously monitor performance in a seamless way facilitating diagnosis and treatment titration to a patient’s need. It is with these goals in sight that video game play is seen as a promising avenue for the diagnosis and treatment of developmental disorders at the turn of the 21st century.

**Acknowledgements**

This study was conducted with partial support by the grants from the National Science Foundation (1227168) and the Swiss National Foundation (100014_140676) to D.B.

**Conflicts of interest**

D.B. has patents pending for action video-game-based intervention to promote learning and brain plasticity in the domains of mathematics and visual rehabilitation. D.B. is a consultant for PureTech Ventures, a company that develops approaches for various health areas, including cognition.

**REFERENCES AND RECOMMENDED READING**

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

- of special interest
- of outstanding interest

6. This article reviews the effects of action video game play on vision, attention and cognition as well as presents a conceptual framework grounded around notions developed in reinforcement learning and machine learning.
41. This book presents novel ideas, backed up by experimental results, on how to use games to improve learning in and for schools. Of particular relevance are the concepts of preparation for future learning, of ego- protection mechanisms (protect- • ing the learner from the adverse consequences of failure) and the necessity to measure learning, not after the fact in an artificial test, but rather while it unfolds.
55. These authors present a comprehensive review and meta-analysis on the effectiveness on using neurofeedback in treating ADHD and discuss directions for future research.
62. This work demonstrates that an attentional control training coupled with parent-training can lead to a large range of benefits for children from low socio-economic backgrounds. These include improved social skills, less frequent problem behav- iors at school and at home, increased non-verbal IQ and enhanced attentional control.
67. This short review paper presents the most recent advances in training children to better exert attentional control and self-regulate. It also exemplifies the progress made by science in this domain since the pioneering ideas of Binet.