VIEWPOINT

Brains on video games

Daphne Bavelier, C. Shawn Green, Doug Hyun Han, Perry F. Renshaw, Michael M. Merzenich and Douglas A. Gentile

Abstract | The popular press is replete with stories about the effects of video and computer games on the brain. Sensationalist headlines claiming that video games 'damage the brain' or 'boost brain power' do not do justice to the complexities and limitations of the studies involved, and create a confusing overall picture about the effects of gaming on the brain. Here, six experts in the field shed light on our current understanding of the positive and negative ways in which playing video games can affect cognition and behaviour, and explain how this knowledge can be harnessed for educational and rehabilitation purposes. As research in this area is still in its early days, the contributors of this Viewpoint also discuss several issues and challenges that should be addressed to move the field forward.

Q *Does playing video or computer games have beneficial effects on brain and behaviour? If so, does the evidence point to general improvements in cognitive function?*

Daphne Bavelier & C. Shawn Green. Although the popular media has a strong tendency to produce breathless headlines about the effects (or lack of effects) of video games, it is worth noting that the term 'video games' is far from a single construct and thus, has almost no scientific predictive power. One can no more say what the effects of video games are, than one can say what the effects of food are. There are millions of individual games, hundreds of distinct genres and sub-genres, and they can be played on computers, consoles, hand-held devices and cell phones. Simply put, if one wants to know what the effects of video games are, the devil is in the details.

Studies that have examined perception and spatial cognition (from our lab and many others) have focused on one specific genre of games — the so-called 'action' video games. Indeed, playing this type of game results in a wide range of behavioural benefits, including enhancements in low-level vision, visual attention, speed of processing and statistical inference, among others. Furthermore, properly controlled training studies have repeatedly demonstrated a causal link between video game playing and enhanced abilities. Hence, it is not just that people who naturally choose to play games have better perceptual skills. The ability to improve one's abilities through practice has obvious practical ramifications, from rehabilitation of visual skills in individuals with amblyopia (also known as a 'lazy eye') to the training of surgeons.

Doug Hyun Han & Perry F. Renshaw. The extent to which playing video and on-line games affects the brain and behaviour is uncertain. It is likely that the specific beneficial or harmful effects are determined by the characteristics of both the individual and of the game. Several studies have reported that video and on-line game play may improve visuo-spatial capacity, visual acuity, task switching, decision making and object tracking in healthy individuals. However, methodological limitations to these studies have also been noted. For example, cross-sectional comparisons of gamers and non-gamers may reflect baseline differences in cognitive abilities rather than the effects of game playing. Moreover, video game training studies that involve the recruitment of non-gamers and that provide game experience have not generally shown that gaming enhances performance on higher level reasoning and problem solving tasks.

Michael M. Merzenich. The potential benefits that can be achieved through video-game play are, of course, a function of the specific task requirements, and of the cognitive and social demands and values represented by the game(s) in play. Games that require progressively more accurate and more challenging judgments and actions at higher speeds, that require focused attention and the suppression of progressively stronger distracting lures, that increase working memory spans, that provide pro-social training contexts, and that offer increasingly harder cognitive challenges — among many other possible game dimensions — can be expected to drive positive neurological changes in the brain systems that support these behaviours.

There is growing direct evidence that intensive use of video games results in significant generalized improvements in cognitive function. Video games are controlled training regimens delivered in highly motivating behavioural contexts. The documented gains in processing speed, attentional control, memory, and cognitive and social control that result from playing specific games are expected. Because behavioural changes arise from brain changes, it is also no surprise that performance improvements are paralleled by enduring physical and functional neurological remodelling.

At the same time, it should be noted that the daily time spent playing video games in school-age children has been shown to be inversely correlated with academic achievement, arguably because time spent playing video games is time stolen from reading and curriculum-related academic study.

We and others have used video-game design strategies to create training exercises that drive targeted changes in perception, cognition, and cognitive and social control more efficiently and more effectively. We have shown that these game-like exercises drive positive changes in perceptual, cognitive and action control abilities paralleled by 'corrective' neurological changes in the brains of trainees. Importantly, in these trained populations, intensive exercise results in generalized benefits and, in the case of student populations, predicts future academic success.

Douglas A. Gentile. Several lines of research demonstrate that video games can have beneficial effects. One excellent programme of research has been conducted by Daphne Bavelier and C. Shawn Green, examining the effects of playing what they call 'action' video games — in practice, these are usually highly violent first-person shooting games such as *Unreal Tournament*. Besides including violent content, action games include high speed, high perceptual and motor load, unpredictability and an emphasis on peripheral processing. In several training studies, these games have been found to influence various aspects of perceptual processing, including multiple object tracking spatial resolution and central and peripheral attention skills. In other words, when you constantly need to scan the screen to detect little differences (because they may signal an enemy) and then orient attention to and target that area, you become better at those perceptual and attentional skills. These are probably not so much general improvements in cognitive functioning as they are specific skills that can be transferred only to other similar tasks (such as the perceptual skills needed by air traffic controllers). One recent study, for example, found that although experienced video gamers were better at spatial navigation in computer-mediated tasks than non-experienced players, they were not better at the same type of navigation in a real-world environment. So, what is learned may not be a broad, general improvement in skill.

Although there are fewer studies that have examined the positive effects of video gaming on social behaviour, there are now a couple by Tobias Greitemeyer and also by my lab. We conducted experimental studies in the US, Japan and Singapore and found a causal short-term effect, namely that playing pro-social games led to more 'helping' behaviour, whereas playing a violent game led to more 'harming' behaviour. In a longitudinal study, we found that children who played more pro-social games early in a school year demonstrated increased helpful behaviours later in the school year.

***Q** Does playing video or computer games have negative effects on brain and behaviour?*

D.B & C.S.G. There is no question that the same characteristics that make many games effective teachers of perceptual and cognitive skills can also be harnessed to produce maladaptive effects on brain and behaviour. There is an extremely large body of research demonstrating a relationship between playing certain types of violent video games and increases in measures of aggressive thoughts. However, the subtleties regarding the size of the effects reported in published research are often sorely lacking in popular treatments of the topic. Violent video games alone are unlikely to turn a child with no other risk factors into a maniacal killer. However, in children with many risk factors, the size of the effect may be sufficient to have practical negative consequences.

In terms of the possibility of video games potentially causing 'reduced attention', we have yet another concept that means different things to different people. If one means the ability to rapidly and efficiently filter visual distractors that are quickly presented (that is, visual attention), then clearly playing action games greatly enhances this ability. However, if one means the ability to sustain focus on a slowly evolving stream of information, such as paying attention in class, there is recent work that suggests that total screen time, and video game playing time in particular, may have negative effects.

Thus, although parents and politicians typically want to view the world as black or white (and seek yes or no answers to questions such as 'Should I let my child play video games?'), there is simply no getting around the fact that any complex training regimen is likely to produce a myriad of behavioural effects. Simply put, the world really is grey, and the answer to the above question is always 'It depends'.

D.H.H & P.F.R. Early studies on internet addiction (involving game playing) reported altered social behaviour, increased aggression, loneliness, reduced attention and depressed mood in patients with internet addiction. Recent studies have also reported relatively high rates of co-morbid psychiatric illness in people with internet addiction, including major depressive disorder, bipolar disorder, attention deficit hyperactivity disorder (ADHD) and anxiety spectrum disorders. In addition, dysfunctional family structures are thought to constitute an important risk factor for internet and on-line game addiction. Tragically, several horrific cases of family collapse due to internet addiction have been reported in Taiwan and Korea. For example, a mother with an on-line gambling addiction throttled her two-year old son who had annoyed her by asking for a meal. Similarly, a thirteen year-old son beat his mother to death because she accused him of spending too much time playing on-line games. Further, a couple who were immersed in an on-line game ignored their 30 month old daughter to the point where she starved to death. We believe that there is strong evidence in support of the view that excessive internet use or game play is associated with adverse consequences on behaviour in some individuals.

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M.M.M. Intensive game-play practices have been shown to have several negative effects on cognition. First, exposure to fast action games, on a play level that applies to the average regular gamer, has been shown to contribute to an increase in ADHD-related behaviours, and — it has been argued — can lead to listlessness and discontent in slower-paced and less stimulating academic, work or social environments.

Second, time spent playing such games is time spent away from other school- (or work-) related, social or outdoor activities. As noted earlier, despite the cognitive gains that are potentially attributable to it, heavy game play, especially to a level of addiction, is inversely correlated with academic, occupational and social success.

Third, action games with anti-social (violent) content — which are particularly addictive and provide particularly strong motivational bases for driving positive cognitive changes — have been shown to reduce empathy, to reduce stress associated with observing or initiating anti-social actions, and to increase confrontational and disruptive behaviours in the real world. These effects can be expected to increase as the images and scenarios in action games become more realistic. The increasingly heavy use of video games and related virtual-reality simulation environments for training combat military personnel provides clear testimony of their effectiveness for inuring the 'player' against the social challenges and stresses associated with observing or voluntarily initiating aggressive and violent behaviours. Although we can appreciate the value of such training for soldiers, policemen or emergency room technicians, there is a serious question as to whether or not intensive exposures to such scenarios contribute positively to empathy and human understanding in the greater society.

Fourth, as discussed below, games can be addictive. Addiction generates its own special destructive class of neurological and social burdens.

D.A.G. There is evidence that games can have negative effects, which makes sense when one considers that most of the effects reported are learning effects at their core. As stated by Donald Hebb in 1940, neurons that fire together wire together. Whatever we practice repeatedly affects the brain, and if we practice aggressive ways of thinking, feeling and reacting, then we will get better at those. This is not to say that violent games necessarily cause violent behaviours, because human aggression is complex and multicausal. But it does suggest that when we practice being vigilant for enemies and then reacting quickly to potentially aggressive threats, we are rehearsing this script. In fact, this is what has been shown in several studies: playing violent video games increases what is called a 'hostile attribution bias', a perceptual and cognitive bias to attribute hostile intentions to others' actions. When people with such a bias are bumped into in the hallway, they assume that it was done with hostile intent rather than by accident, and the most automatic response is to retaliate in some way. The most comprehensive meta-analysis conducted to date included 136 papers detailing 381 independent tests of association conducted on 130,296 research participants. The analyses found that violent game play led to significant increases in desensitization, physiological arousal, aggressive cognition and aggressive behaviour. By contrast, pro-social behaviour was decreased.

This is not to say that there isn't some disagreement about this question in the scientific community, for example over how to interpret the size of the effect and whether it is of sufficient practical significance. On which side of the debate an investigator falls seems, in my opinion, to depend on whether they care most about criminal level violence or low-level aggression. The evidence that playing video games induces criminal or serious physical violence is much weaker than the evidence that games increase the types of aggression that happen every day in school hallways. As a developmental psychologist, I care deeply about this everyday aggression (verbal, relational and physical), whereas critics of the research seem to be mostly interested in criminal violence.

With regard to attention, there are not many studies into the effect of playing video games on the types of directed and sustained attention that is needed in the classroom, but those that exist seem to suggest that there is a relationship between video gaming and attention problems in school. My current interpretation is that the same attentional skills that are learned by playing action games (such as a wider field of view and attention to the periphery) are part of the problem. Although these are good skills in a computer-mediated environment, they are a liability in school when the child is supposed to ignore the kid fidgeting in the chair next to him and focus on only one thing.

Q ***How strong is the evidence that gaming can be addictive?***

D.B & C.S.G. Although the lack of firmly established standards has definitely hindered research in this field (for example, the American Medical Association does not currently recognize video-game or internet addiction as a psychiatric disorder), there does seem to be an emerging scientific consensus that video-game play has the potential to become pathologically addictive. At present, the best research uses scales adapted from those developed to diagnose pathological gambling. It is important to note that 'pathologically addicted' implies more than simply spending a considerable amount of time playing games. Being pathologically addicted means, among other things, an actual reduction in the ability to function normally in society. Thus, an individual who plays video games forty hours per week may not meet the criteria for being a pathological user, whereas others may exhibit pathological signs despite substantially less total usage.

A key issue for future research concerns the characterisation of the neural pathways underlying this pathological use of technology. We know that the frontostriatal pathway, which strongly mediates both drug addiction and behavioural disorders such as pathological gambling, is also activated by some video games. Unfortunately, relatively little is known about the developmental time course of the relevant neural pathways, and even less about how their development is affected by the use of technology.

D.H.H & P.F.R. Several recent studies have suggested that internet addiction may be harmful enough to be categorized as a psychiatric disorder. Internet addiction is sometimes classified as a 'behavioural addiction' in light of its natural course, clinical symptoms, tolerance, comorbidities and neurobiology. In other studies, internet addiction has been regarded as a subtype of impulse-control disorder.

Possible genetic vulnerability to on-line game addiction has been reported in studies on the genes encoding the dopamine D2 receptor, catecholamine-o-methyltransferase and the serotonin transporter, and is consistent with the view that individuals with internet addiction have high novelty seeking and exhibit high reward dependence behaviour. Similarly, some games seem to have much more of an addictive potential than others.

Neuroimaging studies have documented changes in brain activity during on-line game play. There is now evidence that brain areas that respond to game stimuli in patients with on-line game addiction are similar to those that respond to drug cue-induced craving in patients with substance dependence. These brain regions include the dorsolateral prefrontal cortex, orbitofrontal cortex, parahippocampal gyrus, nucleus accumbens, thalamus and caudate nucleus.

The functional impairments observed in individuals with on-line game addiction are also thought to be similar to the impairments observed in other addictions. For example, video- or on-line game play has been associated with dysfunction in five domains: academic, social, occupational, developmental and behavioural. Subjects who are typically recruited for research studies engage in on-line game play for more than 4 hours per day or 30 hours per week. These subjects reported a persistent desire for online gaming and unsuccessful efforts to cut down or control on-line game playing. School grades and work performance decreased. They also showed disruption of their daily routines (sleeping during the day and gaming at night, irregular meals and poor hygiene) and were irritable, aggressive, and violent when family members asked them to stop playing. Some patients borrowed enormous amounts of money ($30,000 over three months) to support their on-line game play. Other patients reported on-line game play after finishing school and that this prevented them from obtaining a job or participating in significant social roles.

M.M.M. About 1 in 5 regular gamers (4-10% of school-age children and young adults) seem to meet the medical criteria that would define them as 'addicted'. Recent studies have revealed alterations in the orbitofrontal and anterior cingulate

cortices of dependent gamers that parallel those recorded in alcoholics and individuals addicted to other substances of abuse. It should be noted that addiction-related distortions in reward systems involved in learning processes contribute to broad-ranging cognitive deficits in every other studied form of addiction.

Our younger-age population is strongly attached to screen-delivered media in a variety of forms. Most regular video-game players are also heavy consumers of other media; on average they are engaged with screens for more than 10 hours per day (projecting forward, over 20 years of their life by age 60). There is thus a massive and unprecedented difference in how their brains are plastically engaged in life compared with those of average individuals from earlier generations, and there is little question that the operational characteristics of the average modern brain substantially differ from that of our ancestors. A better understanding of the consequences of these differences in brain use for societal and individual brain health should be high on our research agenda.

D.A.G. I began studying the issue of video-game 'addiction' because I was highly sceptical of it. I believed that people were misusing the expression to mean 'spends a lot of time gaming', because addictions are not defined by how much one engages in an action (for example, drinking), but by how much it damages one's life. I began studying gaming from this more clinical approach, using criteria adapted from those for pathological gambling. Based on this much stricter set of criteria — which assess dysfunction in multiple areas of life (school, social, family, psychological and emotional functioning) — about 8% of US gamers between 8 and 18 years of age could be considered pathological or 'addicted'. There are now scores of studies showing that the pattern of problems that pathological gamers face are very similar to the problems that people with substance or gambling addictions have. Thus, the problem seems to have some construct validity.

There are only two published longitudinal studies on this topic to date. One focused on 881 Chinese adolescents between 13 and 16, using Young's 20-item Internet Addiction Scale. Adolescents were surveyed twice, nine months apart. Pathological internet use predicted increased risk of depression (but not general anxiety) nine months later, after controlling for several potential confounding factors such as sex, age, family dissatisfaction and illness, among others. A larger study of 3,034 Singaporean children and adolescents followed over two years gave some of the first clear evidence of whether variables such as depression and poor school performance are predictors of or are predicted by pathological video gaming. Because of the large sample size, this study was able to classify gamers into four types: those who never exhibited pathological behaviour over the two years, those who became pathological gamers, those who were pathological at the start but stopped being pathological, and those who were and stayed pathological gamers. As in the first study with Chinese adolescents, depression became worse if adolescents became pathological gamers. Anxiety, social phobia and school performance also became worse in adolescents who became pathological gamers. Interestingly, if they stopped being pathological gamers, their depression, anxiety, social phobia decreased and school performance improved. These findings suggest that these variables may be outcomes of pathological technology use rather than predictors of it. At a minimum, they suggest that these variables are co-morbid with pathological gaming, such that they can influence each other.

To my knowledge, however, there haven't been any published studies looking at the effects of gaming addiction on the brain, although there are some demonstrating that dopamine is released and that brain reward centres are activated during video-game playing.

***Q** Is there a place for using video or computer games in education and rehabilitation?*

D.B & C.S.G. Some of the recent successes using off-the-shelf games (which were designed with no particular outcome in mind, other than being a fun game) in the rehabilitation of, for instance, amblyopia, are certainly a cause for optimism. However, although the idea of using video games in educational and rehabilitative settings has been around for decades, as a field we're probably still only in the very early stages of learning how to effectively harness the power of video games while simultaneously attempting to produce a desired outcome. For instance, many of the earliest educational video games were little more than slightly dressed up flashcards — full of sounds and interesting looking graphics, but lacking most of the characteristics that truly define a video game. Too often those developing the games were individuals who knew a lot about the content they wanted to teach, but very little about how make a game compelling and fun. As more true game developers turn their attention to educational and/or clinical applications, new fields are emerging in which educational and medical practitioners are collaborating with game designers to develop fun and attractive activities that will guarantee time on task and at the same time have the educational or rehabilitation impact that experts in the field are seeking.

D.H.H & P.F.R. There have been several trials of video games in educational and rehabilitation settings. In the rehabilitation of patients with post-traumatic stress disorder following motor vehicle accidents, the virtual-reality experience (through a computer game) of driving or riding in a car may improve clinical symptoms and promote recovery. In addition, several games have been developed for screening or rehabilitation of people with dementia. Furthermore, we have reported that eight weeks of internet-game play reduced delusional thinking and extra-pyramidal symptoms in patients with schizophrenia. In addition, pro-social video games have been associated with increased empathy and decreased reported pleasure at another's misfortune, compared with the effects of neutral games in healthy subjects. In a pilot study in adolescents with autism spectrum disorders, we noted increased social behaviour and increases in fusiform gyrus activity in response to emotional words and emoticons during a six week, pro-social on-line game playing period. Although existing research is limited, we believe that a growing number of clinical applications for video-game play will emerge over time.

M.M.M. Video games *per se* don't have a special role to play in these arenas. Video games exploit well-established principles of motivation and learning that have been established by experimental psychology and neuroscience research. Those same principles have also been applied by us and by others in designing 'brain training' exercises to drive targeted, positively empowering and, if necessary, 'corrective' behavioural and neurological changes in the brains of children and adults who are in need of help. These forms of game-like training have already strengthened or recovered the abilities and improved the prospects and quality of life of millions of individuals. There is, of course, a convergence in the design of successful

video games and effective plasticity-based brain training exercises, because enthusiastic engagement by a gamer or trainee is a key goal in both arenas. However, because education- or rehabilitation-directed training is necessarily designed to address neurological impairments that apply to specific learning problems or for specific clinical indications, there are inevitably practical constraints on such exercise designs. It should also be noted that the educational and medical applications of brain training are most effectively deployed by using internet-based strategies, so that trainee compliance and progress can be monitored, and by applying internet-delivered assessment tools to assure that generalized, targeted benefits are being achieved. Video games do not implement these monitoring and outcome-assessment methods.

These game-like computer-based training programmes represent the first wave in an impending revolution for brain training in schools, medicine and in the broader society. In the future, such computer-guided brain training may be employed to substantially improve the performance of almost every child in school. In parallel, using this approach to drive strengthening, ameliorative or corrective changes that increase resilience in people who are at risk for certain illnesses, or to treat patients whose brain function is impaired by illness, is rapidly emerging as an important new dimension of psychiatric and neurological medicine.

We must remember that the application of this technology in humans has a potentially destructive side. It is easy to impair human abilities by training, even while other abilities are being improved or refined. Furthermore, video games shall continue to evolve in forms that are increasingly addictive. Time spent on screen-delivered media can be expected to steal more time away from real life. Video game attraction strategies that have been empirically developed to capture the hearts and minds of the player are already being more extensively applied by the persuaders than by the educators or the medical practitioners. The Genie (neuroscience-guided brain plasticity) is out of the bottle, for good and — if we let it loose without more guidance and restraint — almost certainly, for ill.

D.A.G. Games offer significant promise for education. They use many of the techniques that a truly exceptional teacher uses. For example, they have clear objectives that are set at multiple difficulty levels to adapt to the prior knowledge and pace of each learner; they require learning to be active, with immediate feedback and sufficient practice to the point of mastery; practice on a game continues until much of what is learned becomes automatic; mastery of a game is reinforced extrinsically, by points and levels, and intrinsically, by a feeling of accomplishment and social status; levels of progress are well-sequenced, such that success at later levels is contingent upon mastering earlier levels; games encourage distributed practice across time; and games enable the gamer to practice the same concepts in different contexts, therefore encouraging transfer of skills. Unfortunately, games have yet to find a way to live up to their promise. Authors such as James Gee have documented the theoretical value of games for education. Studies of educational software demonstrate that children do learn from playing educational games. Nonetheless, the amount of money spent on educational games is a tiny fraction of the amount spent on a commercial entertainment game. Therefore, most educational games aren't as interesting, fun or good as even a mediocre commercial game.

Q ***What are the challenges and future directions for neuroscience research in this field?***

D.B & C.S.G. The mechanisms by which video-game play triggers such widespread brain plasticity remain to be elucidated. And because behavioural and non-invasive brain imaging methods can only take us so far towards this goal, pharmacological studies in humans and complementary studies in animal models (yes, rats playing *Call of Duty* — or at least the animal equivalent) may move the field forward. Beyond the clear theoretical interest, findings from such studies will be of great practical benefit when attempting to design games that result in transferable learning, be it for rehabilitation purposes, education or training.

One of the remaining challenges is to better understand which game components are crucial for promoting a given skill in a particular individual. Although our current knowledge is at the group level — for example, some overarching game components, such as the need to constantly predict when and where events of interest may occur, are crucial in training attention and executive functions — the most efficient learning regimens are unlikely to be one-size fits-all. Games in the future will have the ability to gather data about the player while simultaneously building the exact game needed in real time. A handful of pilot training schools are already exploring this type of highly personalized tutoring.

> "Studies of educational software demonstrate that children do learn from playing educational games."

D.H.H & P.F.R. First of all, objective diagnostic criteria for gaming addiction should be established. In addition, we need to better understand the differences between pure on-line gaming addiction and on-line gaming addiction that is co-morbid with other psychiatric disorders. This is important as some investigators have argued that internet addiction does not exist but is merely a symptom of psychiatric illnesses such as major depressive disorder or ADHD. Second, the vulnerabilities to on-line gaming addiction, including genetic and cognitive factors, need to be more clearly defined. Third, standard and effective treatments need to be developed and validated. Several pilot studies have suggested that the antidepressant drugs citalopram and bupropion may be effective for the treatment of on-line gaming addiction. Similarly, cognitive behavioural therapy (CBT) has been reported to be effective for reducing internet use time and improving daily life patterns and family coherence. However, future studies on on-line gaming addiction treatment will require larger populations and longer follow-up periods. In addition, the relationship between clinical symptoms and changes in brain activity needs to be more clearly defined. Finally, studies of internet-game play are currently somewhat polarized and this area of research is likely to be improved if investigators acknowledged both the potential beneficial and harmful effects of video games.

M.M.M. Scientists and technologists have now developed practical strategies that strongly engage a large proportion of people from all over the world (especially those of younger ages) at a level of positive motivation that can progress to addiction in many of them. Modern societies have come to be massively media-engaged and media-dependent, over an incredibly short time-span in our history. The application of motivationally-powerful strategies to help children and adults change their behaviours (and brains) for the better has already begun

in earnest. Because of their great didactic efficiencies, and because brain plasticity-based exercises can improve the performance characteristics of the brain of almost every child, these new game-like tools shall be at the core of a schooling revolution. They might also be widely deployed to treat the specific neurological problems that characterize psychiatric and neurological illnesses, and the normal ageing process.

How can we intelligently control this development? First, we should work to further integrate cognitive neuroscience with educational science and clinical medicine. Our understanding of the differences between the operational brains of normal versus developmentally, neurologically or psychiatrically impaired individuals is rapidly increasing, as is our understanding of the neural bases of human intelligence and ability. This knowledge will provide the foundation for both designing and confirming the effectiveness of targeted training tools. Second, the entry of new game-like training programmes into schools and clinics must be based on controlled, high-standard trials. The scientific community and the public should insist that any medical claims about training programmes are based on formal review processes (by the US Food and Drug Administration or equivalent). Third, the public would benefit from standards organizations that objectively quantify the positive and negative consequences of the intensive use of specific video games. Finally, we should intensify our efforts to determine how our growing screen dependence in our everyday lives is changing us in ways that both strengthen and weaken us, as individuals and as a society.

D.A.G. Perhaps the greatest challenge facing us right now is the trap of biased and dichotomous thinking. Most people (including many scientists) are either critics or proponents of games and gaming research. This has a detrimental effect on the field, and serves to increase rhetoric and to limit research. I have proposed that there are at least five dimensions along which video games can have effects on brain and behaviour — the content, context, structure and mechanics of games, and the time spent game playing. When all these dimensions are taken into account it is often possible to explain how research findings that initially seem to be contradictory are actually congruent.

The amount of time that people spend on recreational games can have effects on them, regardless of specific game features. Some studies have demonstrated that the amount of time spent playing games predicts poorer school performance. This effect is likely to be due to displacement of other academically beneficial activities. Other studies have demonstrated a relationship between the amount of sedentary gaming and obesity, repetitive strain disorders and video-game addiction.

Most of the research on video game effects has focused on the content dimension. In short, people learn the content of whatever games they play. If they play educational games, they learn the educational content and can apply it in school; if they play games designed to teach health content, they learn those concepts and apply them to their lives; if they play violent games, they learn the violent content and may apply it to their lives.

The context of game play may produce differential effects, and this is the least researched dimension at this time. Context can be defined within the game or outside of the game. One type of within-game context can be seen in violent games that allow for either team-based or 'free-for-all' modes of play. Both may be equally violent, but playing in an 'everyone-for-oneself mode' might lead to more aggressive thoughts, lower empathy and greater desensitization. If the in-game context requires players to cooperate to achieve goals, this might also teach teamwork and social coordination skills. Furthermore, the social context outside of the game may matter. Playing a violent game in a room (virtual or real) with other individuals might increase the effects on aggression because players are giving each other social support for aggression. However, it might actually reduce these effect if one's motivations are pro-social (that is, to help your friends in the game). No studies have yet tested these hypotheses.

The way in which the game is structured and displayed on the screen can also have effects. Screen structure provides information that is learned, similar to how we learn to perceive visual information in general. Some studies have demonstrated that gaming improves visual attention skills, including the ability to acquire three-dimensional information from flat screens. Playing games that require those skills has also been shown to improve mental rotation skills.

Finally, the mechanics dimension refers to what can be learned from playing a game with different types of game controllers. Depending on the type of controller, different fine and gross motor skills and balance skills can be improved and these effects could be harnessed for therapeutic purposes. The intersection of structure and mechanics is the continuous feedback loop that is often referred to as 'hand–eye coordination'.

Considering these different dimensions when analysing the effects of video games should, hopefully, reduce dichotomous thinking in the field. Playing video games is neither good nor bad — existing research shows that they are powerful teaching tools and therefore we need to harness that potential, aiming to maximize the benefits while minimizing the potential harms.

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