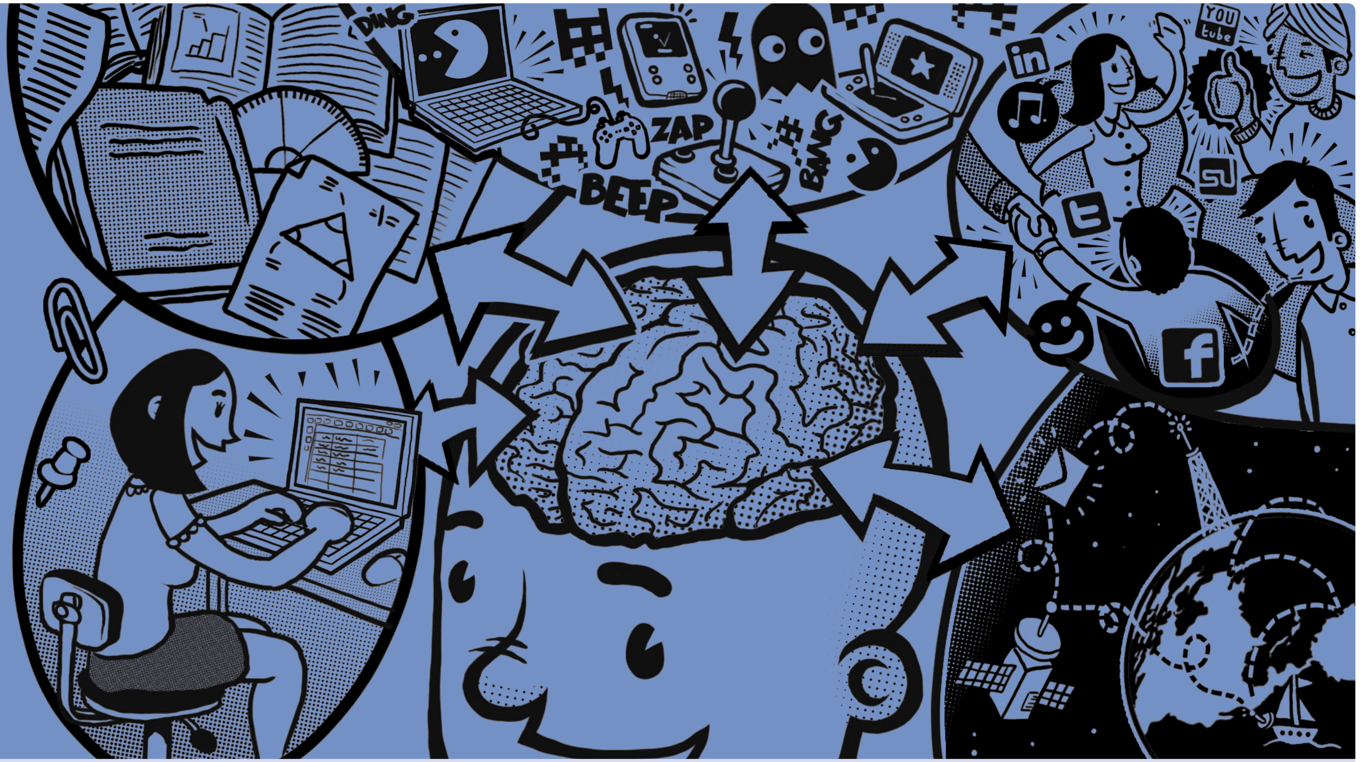
nominettrust

The impact of digital technologies on human wellbeing

EVIDENCE FROM THE SCIENCES OF MIND AND BRAIN



A STATE OF THE ART REVIEW written for Nominet Trust by Dr Paul Howard-Jones

Foreword

Exploring what it means to use the internet safely is more than understanding online privacy and personal security. It is important to understand the implications of our online life for our offline well-being - that is, to explore the implications of using interactive technologies on the ways in which we behave, on our values and on our mental and physical health. At Nominet Trust, we are committed to supporting initiatives and organisations that work towards a safer, more accessible internet, used for social good. In doing so, we need to be aware of safe internet use in its broadest sense.

This publication aims to highlight what the field of neuroscience can tell us about the implications of using interactive technologies on young people's brains, behaviours and attitudes. It brings together the latest research from this emerging area, not only to understand its implications, but to recognize the limitations of the existing evidence. By doing so, we hope to highlight what is known about 'safe uses' of interactive technologies, but also what is not known, i.e. what cannot be claimed or needs to be researched in more detail. If we are to develop effective and safe practices that use digital technologies, we need to be clear about the evidence that we build upon and ask more nuanced questions to determine where future research should be focused.

Dan Sutch
Head of Development Research
Nominet Trust - July 2011

About the series

Nominet Trust State of the Art Reviews are undertaken by leading academics to collate and analyse the latest research at the intersection of the internet and society. Drawing on national and international work, these reviews aim to share the latest research to inform the work of the Trust, those applying to the Trust for support and our wider partner organisations.

We value your comments and suggestions for how to act on the recommendations in these Reviews, and how we can build the series, so that it is more useful to us all as we work towards a safer, more accessible internet, used for social good.

We look forward to your comments and suggestions at:

DevelopmentResearch@nominettrust.org.uk

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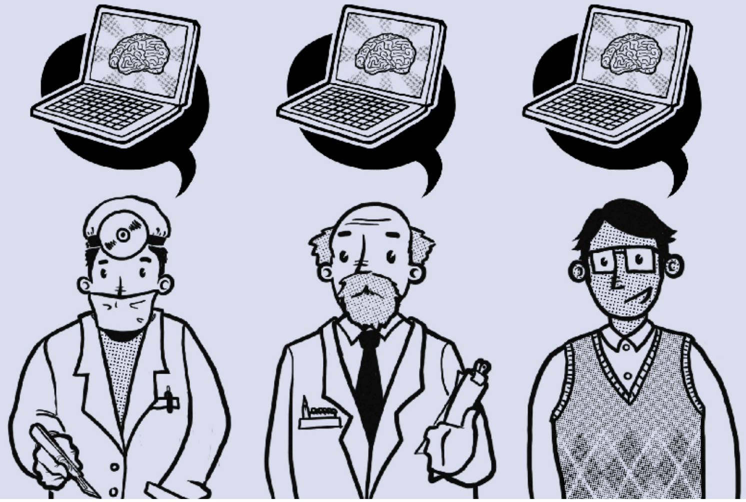
Written by **Paul Howard-Jones** for Nominet Trust



Designed by **Ben Carruthers**

Illustrated by **Sam Bevington**

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Introduction

Our lives have become increasingly immersed in technology. Much of our communication is now online, much of our leisure and entertainment is provided by the internet and video games, and many of us find our mobile phones have become an essential part of our connectivity and everyday organisation. With these changes in lifestyle, questions are arising about what technology may be doing to us.

Some of these questions revolve around potential detrimental effects, which have been the frequent focus of alarming press articles. Some commentators have suggested that we are facing an 'unprecedented crisis' in which 'the human brain … is under threat from the modern world'[A], that 'our love of the latest technology could be turning into a 21st-century addiction'[B], that Facebook is 'infantilizing' us[C] and Google is degrading our intelligence[D].

The vanguard of our advance into this new world is our children, and especially our teenagers. We know that the developing brain of a child is more plastic, and responds more malleably to experience than an adult's brain. This provides some justification for the especially strong concerns around the emerging 24/7 technology lifestyle of our children, and we are wise to ask what this will mean for their development and education. Therefore, although this review includes research on adults, there is a particular emphasis on research with children and adolescents. Additionally, amongst the types of technology considered, video games will enjoy greater attention. This reflects their accumulating status in the research literature as a special case of environmental influence on the mind and brain.

Some commentators have suggested that we are facing an 'unprecedented crisis' in which 'the human brain … is under threat from the modern world', that 'our love of the latest technology could be turning into a 21st-century addiction'

A
Greenfield, S. in Daily Mail (2009).

B
Roberts, D. in The Telegraph (2010).

C
Wintour, P. in Guardian (London, 2009).

D
Carr, N. in The Atlantic Vol. July/August (2008).

The burgeoning literature in this area makes it impossible to reference in full all the research that might be considered relevant. Instead, the understanding that is emerging on individual topics is illustrated by considering those studies that appear most relevant and valid. The recency of the research has also been a factor in weighting its significance, since the technology itself, and the manner and extent to which it is used, are rapidly changing year by year.

Paul Howard-Jones
July 2011

Executive Summary

- Rather than label any type of technology as being good or bad for our brain, it is how specific applications are created and used (by who, when and what for) that determine their impact.

- Existing forms of online communication for supporting existing friendships are generally beneficial for their users, with little basis for considering that social network sites and online communication, in themselves, are a source of special risk to children. Internet-related abuse (eg inappropriate sexual solicitation, cyberbullying) appears related to issues beyond the use of the internet.

- Internet use (including online gaming) is problematic when it regularly interferes with normal daily living and is difficult to control, although internet/gaming addictions have not been established as psychiatric disorders. No particular threshold has been identified that can be defined as excessive use, but research supports a guideline of maximum two hours total screen-based entertainment per day for children. Problematic internet usage is associated with a range of psychosocial difficulties, but the internet can also support mental health through online therapeutic treatment for a range of mental health disorders.

- The internet is a valuable learning resource and all learning involves changes in the brain. Some technology-based types of training can improve working memory, and others can provide mental stimulation that helps slow cognitive decline.

- Some types of gaming (whether on-line or off line) can improve visual processing and motor response skills, prompting suggestions that games may represent a particularly effective way to enhance brain plasticity across the lifespan. The mechanisms involved are still not understood, but may help explain the effectiveness of such games to also influence affective response. Playing violent and prosocial video games generally shifts behavioural tendencies towards aggressiveness and empathy respectively. Gaming can strongly engage the brain's reward system, and this may also help explain their attractiveness.

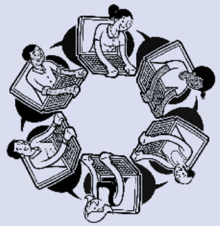
- Although technology can helpfully support learning, some applications can be a distraction, suggesting parental monitoring of younger students' use of technology may benefit learning outcomes. For example, adult students who make substantial use of instant messaging consider they are distracted by it, and such heavy "multitasking" does not appear to improve the ability to switch attention between applications.

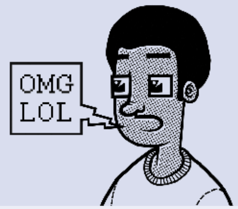
- Evidence linking technology-based activity to a reduction in physical exercise is mixed, but how and when technology is used does appear to influence sleep. In particular, late night technology use is linked to reduction in sleep and sleep quality, and teenagers who use their mobile phones after "lights out" are considerably more likely to suffer daytime sleepiness. Again, games may be different from most other types of technology in their influence on neurobiological processes, with some evidence that they can disrupt children's sleep and learning even when played early in the evening.

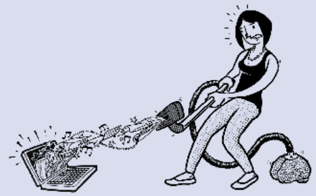
- Parents and their children would benefit from clearer independent information about where a significant body of research indicates potential risks from a particular technology application. They would also benefit from support in assessing and acting upon these risks. Academic achievement and student wellbeing would benefit from schools having access to curriculum and teaching resources aimed at delivering skills to students that enable their 'hygienic' use of internet and digital technology. These resources would help schools equip students with the knowledge and understanding required to guide their own use of technology.

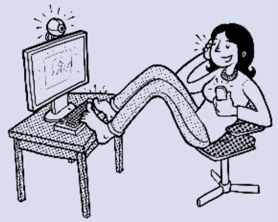
- More research is needed in a number of areas, to help evaluate the risks and potential benefits for healthy development presented by the new technologies and their applications. Some types of games have been identified as having a particularly strong influence upon brain function, suggesting the need for further research aimed at understanding more about the processes involved, and the issues and opportunities that such games may provide.

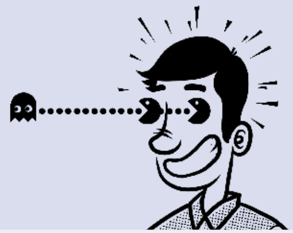
Technology and the sciences of mind and brain

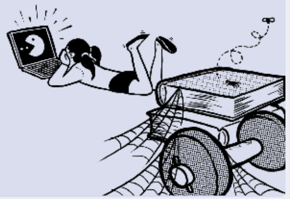


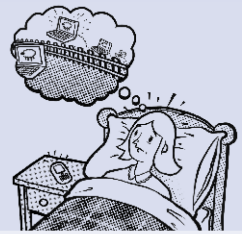






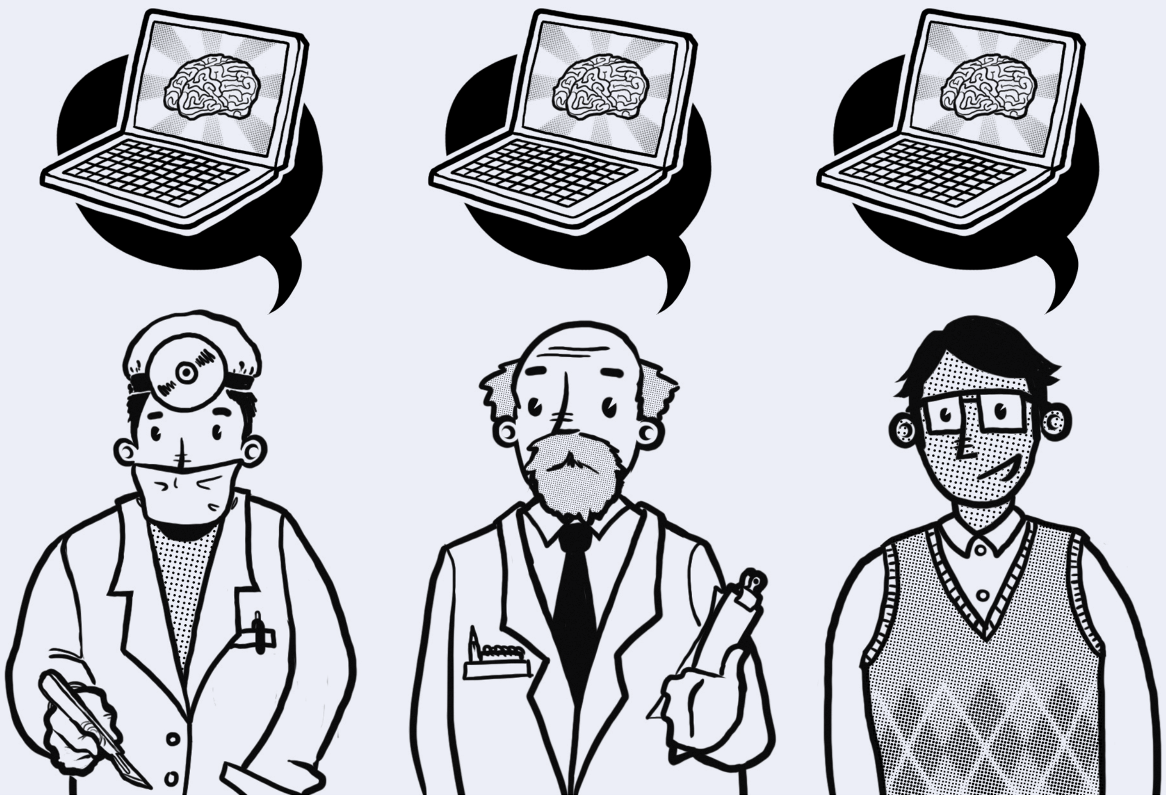






Introduction to technology and the sciences of mind and brain

What can, and can't, evidence from neuroscience tell us? What do I need to know about neuroscience to read this report?



Neuroscience is now providing a new source of insight into understanding human behaviour, with its novel methods of generating images of how our brains are functioning. These methods and images are invaluable tools with which to understand ourselves, including how we interact with technology, but they can also be a source of popular misunderstanding. For example, headlines that the internet is 'rewiring' our brains might appear alarming[1] – as if the internet is changing the connectivity of our otherwise 'hard-wired' brains. From neuroscience, however, we know even the adult brain retains a level of plasticity such that a vast array of 'everyday' experiences can change its connectivity, function and even structure[2,3]. Any experience that leaves a memory, since that memory must have a biological substrate, must have modified our brain. Observable changes at the level of the brain, therefore, do not imply irreversible outcomes. Instead, they provide a source of evidence that should be considered alongside psychological and behavioural data to address specific questions. When all these sources of evidence 'match up', we can be more sure about the findings and recommendations that they individually and collectively help generate.

To help constrain interpretation of the existing evidence, each section of this review will be summarised in terms of 'what we know' and 'what we do not know'. Unless otherwise stated, 'what we know' will be restricted to findings supported by converging studies published in high-quality peer-reviewed journals. When it comes to concluding that technology has been the cause of a particular outcome, we need to be particularly careful. There is very rarely a single cause of anything in human behaviour and development[4]. We can, however, be most sure we have determined that technology is a significant contributory factor when research of three different types points in the same direction[5]. These three types are a) well-designed experimental research (eg testing for a difference in the behaviour after a short period of technology use compared with another activity) b) correlational research (testing for an association between a use of technology and the extent of the behaviour) and c) longitudinal studies (testing whether the amount of technology use between two or more times can be used to predict changes in the behaviour).

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A further difficulty in considering the evidence is the specialist language and terms that are sometimes used to express it. No expert knowledge of neuroscience or psychology is required to understand the findings of this review, but some basic facts about neuroanatomy might be helpful for two reasons:

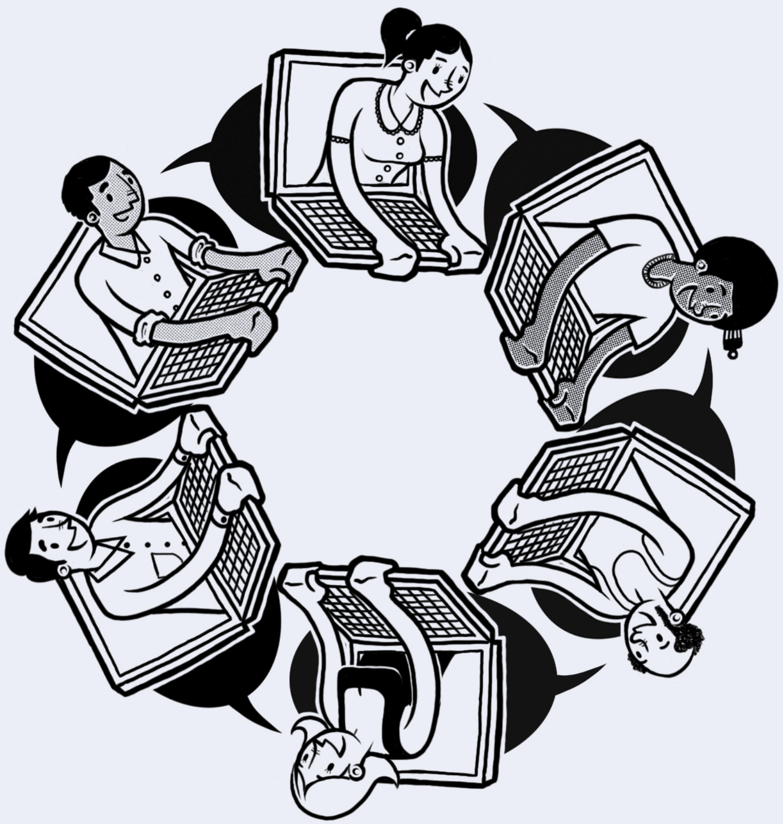
- they will help you visualize some of the brain regions you may encounter in the text later, and help you understand and remember the principles discussed
- they are a good first defence against neuromyth in this and other areas.

Therefore, some readers might like to read the brief notes in the About the brain section (page 86) and the related Glossary (page 94).

About the brain section ›

Social networking

Are social network sites helping or hindering our children's social skills? What are the risks?



Teenagers are by far the most avid users of the new social media. In the UK, just over one fifth (22%) of adult internet users aged 16+ and almost half (49%) of children aged 8-17 who use the internet have profiled themselves on a social networking site[6]. This may be due to the opportunities offered by online communication for selectively presenting and revealing oneself to others (self-presentation and self-disclosure)[7]. However, the very features of online communication that make it controllable and attractive to teenagers can also expose them to risks. For example, its potential accessibility and anonymity can expose them to cyberbullying or sexual solicitation, or simply deter the development of offline friendships and face-to-face social skills. Valkenburg and Peter identified three key aspects of psycho-social development that online communication can influence: identity, intimacy and sexuality[7]. Following Valkenburg and Peter, the potential positive and negative effects of social communication across the internet in terms of each of these aspects will be briefly considered here.

With respect to identity, recent research suggests a beneficial effect of online communication on self-esteem, associated with positive responses to profiles and a sense of mastery and control over blogs and homepages[8,9]. However, there is also clear and well-documented evidence of problematic over-use of the internet, which impacts negatively on wellbeing (see section on Excessive internet use).

With respect to developing intimacy and friendships, the second half of the 1990s generated several studies that showed greater internet use amongst teenagers was associated with reduced social connectedness and wellbeing[10-12]. However, at this stage in the adoption of the internet, less teenagers had internet access, making it more difficult to maintain existing social networks online. Additionally, more recent technologies (Facebook, instant messaging, etc) have since been developed to encourage communication with existing friends. Over the last decade, the effects reported in the research literature have been positive rather than negative[13], with most recent studies showing that online communication stimulates teenagers' social connectedness and wellbeing[14,15]. An important caveat, however, is that these results only hold for using the internet to maintain existing relationships. Using the internet to make new friends has been linked to lower levels of wellbeing[16]. Furthermore, cyberbullying remains an under-

Over the last decade, the effects reported in the research literature have been positive rather than negative, with most recent studies showing that online communication stimulates teenagers' social connectedness and wellbeing

researched and apparently prevalent problem[17], with most surveys reporting that 10-35%[18] of children have received a cyberbullying experience. In a recent study in Belgium, it was noted that children whose parents are less involved with their internet use have a higher chance of becoming perpetrators, and children who take more online risks are more likely to become victims[19]. However, the research also found that both the victims and perpetrators of cyberbullying tend to experience these roles offline as well, with another study also suggesting victims may be experiencing broader problems than simply internet naivety[20]. The authors of the latter study conclude that interventions, which have often lacked effectiveness[18], may benefit from broadening their focus beyond how the internet is used.

With respect to sexual development, teenagers frequently turn to the internet for information and discussion about emotional, moral and social issues regarding sex. In particular, many gay and lesbian adolescents find online communication a safer way (in terms of maintaining privacy) to discuss problems surrounding their sexual orientation and its public acknowledgement. On the downside, unwanted sexual solicitation continues to be a risk. Given the paucity of UK statistics in this area, data from the US will be used to provide some perspective on the potential size and nature of the problem[21]. This shows the numbers of young internet users reporting such experiences had dropped between 2000 (19%) and 2005 (13%), and, compared to other sex crimes, internet-related sex crimes against children are rare. For example, in the US in 2006, about 2% of sex crimes against teenagers were internet-related and a recent survey of US law enforcement agencies concluded that young people are not at particular risk when interacting on social network sites[22]. Furthermore, perpetrators of those sex crimes involving the internet do not fit the popular notion of 'predators' who use trickery and violence to engage in forcible sexual assault or paedophilic child molesting. Instead, crimes involving adults and juveniles more often fit a model of statutory rape, ie adult offenders who meet, develop relationships with, and openly seduce underage teenagers. This has brought calls for younger adolescents to be armed with greater awareness and avoidance skills, rather than targeting the social network sites themselves[22]. Posting personal profiles has been indicated as a potential risk of social networking sites[23], but a study of bloggers (aged 10-17) revealed no increased risk for

The victims and perpetrators of cyberbullying tend to experience these roles offline as well, with another study also suggesting victims may be experiencing broader problems than simply internet naivety

youths who set up personal profiles[24]. Those youths who do receive unwanted sexual solicitations do so more via instant messages or in chatrooms than through social networking sites[25], supporting the idea that young people need to be supported in developing general skills of awareness and avoidance, rather than kept away from social network sites. A history of offline sexual or physical abuse appears to be a strong risk factor for receiving online aggressive sexual solicitations[20], and so it may be particularly important for these young people to receive guidance in developing such skills[21].

Social networking

We know that...

online communication that supports existing friendships can benefit self-esteem and social connectedness

there is little basis for considering that existing forms of popular social network sites and online communication, in themselves, are a source of special risk to children

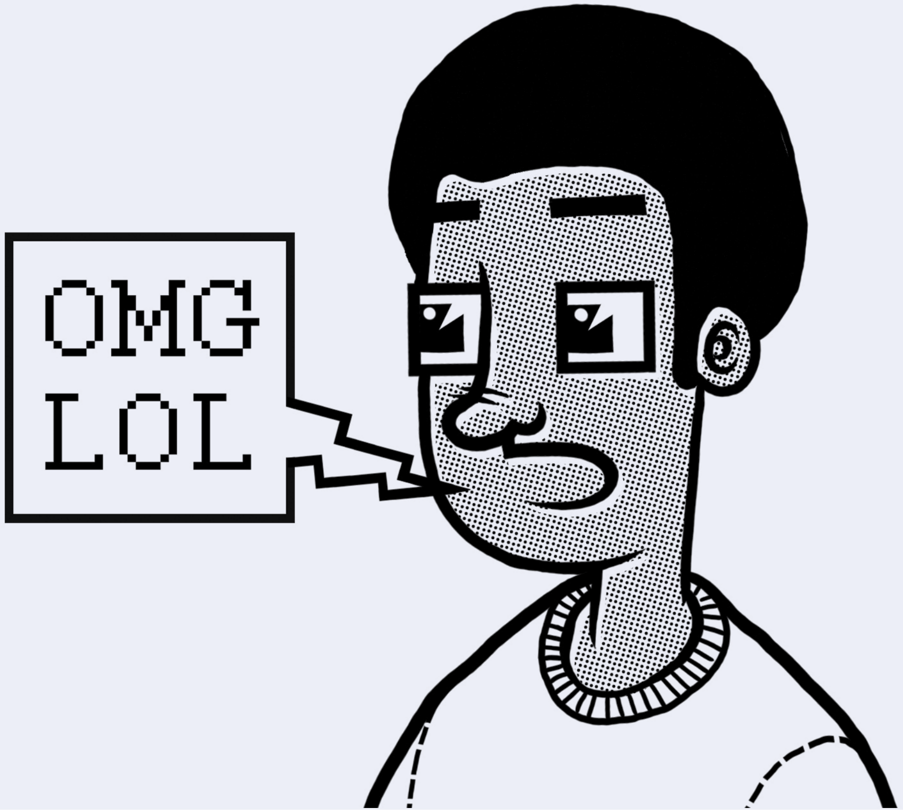
children with histories of offline victimisation are more vulnerable to risks from cyberbullying and sexual solicitation.

We do not know...

how the design and use of social network sites and other forms of online communication may develop in the future.

Excessive internet use

Is it possible to use the internet too much? What types of activity are usually involved with excessive internet?



While moderate use of online communication can benefit wellbeing, concerns have been raised about internet 'addiction'. Rather than exceeding some daily threshold, internet access is considered as problematic when it becomes compulsive, interferes with the normal activities of daily living, and when the person can no longer control it[26]. This type of problem is often accompanied by withdrawal (including feelings of anger, tension, and/or depression when access is unavailable), tolerance to excess usage (including seeking better equipment and more hours usage) and adverse consequences (arguments, poor achievement, isolation and fatigue)[27]. Spending more than three hours a day on the internet has also been linked to poor vision in children[28].

Surveys in the US and Europe indicate around 1.5%-8.2% prevalence of excessive internet use in the general population[27]. Many discussions of internet addiction, however, fail to discriminate between what the internet is being used for, despite over-use of the internet being associated with one or more specific types of problematic behaviour. In a study of mental health practitioners, adults seeking help for excessive use of the internet focused on excessive access of pornography or online communication related to infidelity, while issues of excessive use by young people focused chiefly on gaming[29]. Online communication has been suggested as a significant variant of this putative disorder[30], but even heavy usage of the internet for communicating with family and friends appears to have little impact on the likelihood of internet usage becoming problematic[15,26]. Instead, the significant predictors of problematic usage appear to be low self-esteem, anxiety and the use of the internet for sensation-seeking activities that the user considers to be important[26,31].

It is worth noting, however, that some researchers maintain that internet addiction is not a true addiction, but may be the product of other existing disorders such as depression, or a 'phase of life problem'[32]. Also, some of the chief hazards of internet addiction (marital, academic and professional problems, together with sleep deprivation) might be the cause rather than the effect of excessive internet use. The issue of problematic video gaming, which appears most prevalent amongst the young, is dealt with in more detail in the About the brain section (page 86).

Rather than exceeding some daily threshold, internet access is considered as problematic when it becomes compulsive, interferes with the normal activities of daily living, and when the person can no longer control it

While excessive use of the internet can become associated with depression and anxiety, the internet is also being developed as an effective tool to treat such mental health issues. For example, a recent review of 22 studies of computerized Cognitive Behavioural Therapy (CBT) aimed at ameliorating anxiety and depressive disorders concluded that this approach, especially via the internet, can provide effective, acceptable and practical health care for those who might otherwise remain untreated[33]. Similarly, a review of nine randomly controlled trials of internet-based therapy for the treatment of addictions concluded that, although more research was required to understand relative differences in their outcomes, such an approach was effective in achieving positive behavioural changes[34]. Although it remains debatable whether such approaches are likely to replace face-to-face treatment with a professional, the internet clearly provides a durable, workable environment for services to remote or disabled populations, as well as to people who prefer not to be visible and exposed[35].

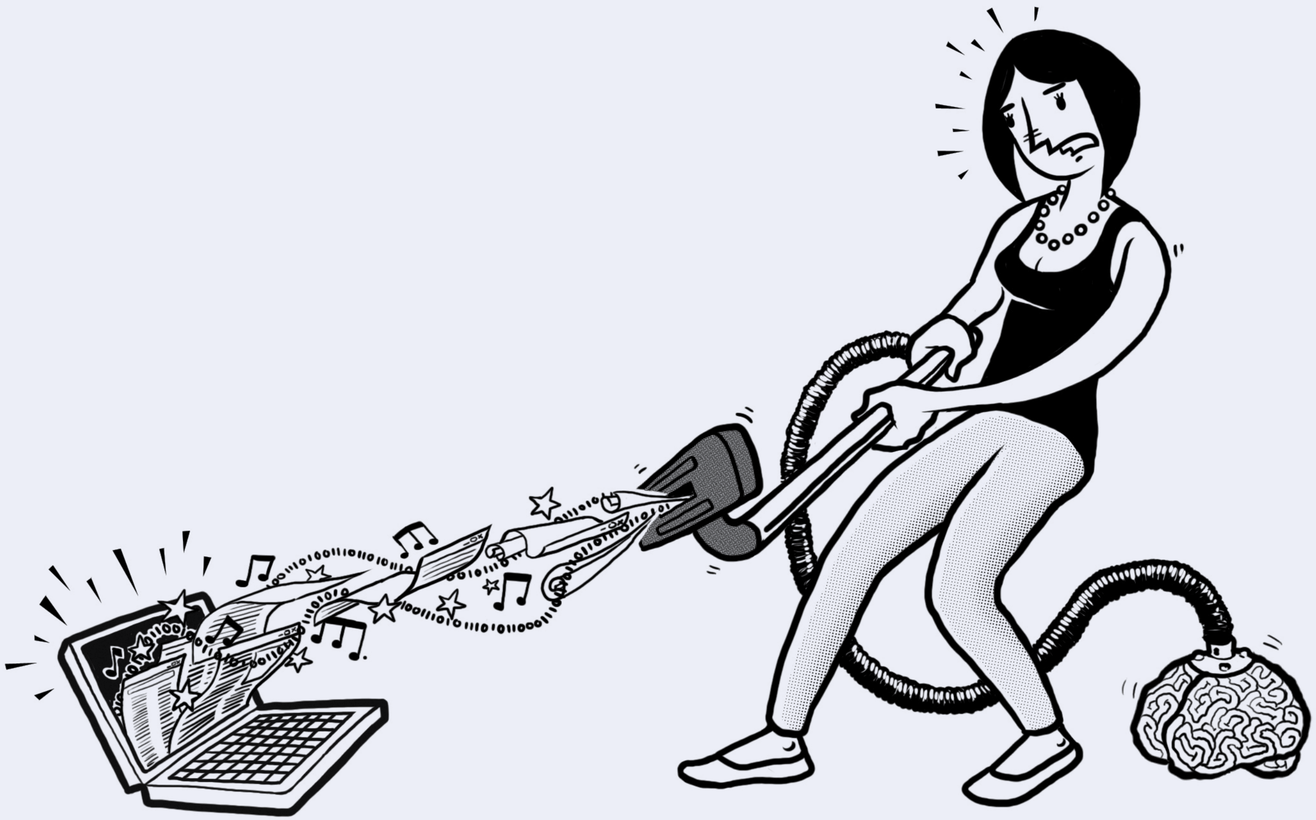
While excessive use of the internet can become associated with depression and anxiety, the internet is also being developed as an effective tool to treat such mental health issues

Excessive internet use

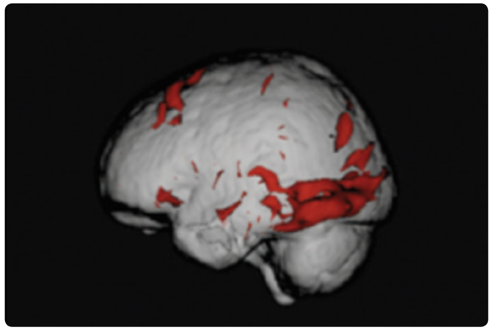
We know that...	We do not know...
internet use can be considered problematic when it regularly interferes with normal daily living and is difficult to control	a particular threshold exists (in terms of hours spent accessing the internet) that can be defined as problematic
online communication with family and existing friends is not likely to lead to problematic usage	excessive use of the internet is a psychiatric disorder.
risk factors for problematic internet usage include low self-esteem, anxiety and the use of the internet for sensation-seeking activities that the user considers to be important	
the internet can also support mental health, by providing online therapeutic treatment for a range of mental health disorders including depression, anxiety and addiction.	

Information gathering

Is the internet rewiring our brains and should we be concerned?



Gary Small and colleagues carried out a novel study of how the brains of middle-aged and older participants respond when using an internet search engine[36]. Compared with reading text, they found that internet searching increased activation in several regions of the brain, but only amongst those participants with internet experience (see Fig 1). Based on the regions involved, the researchers suggested that internet searching alters the brain's responsiveness in neural circuits controlling decision making and complex reasoning (in frontal regions, anterior cingulate and hippocampus). However, because an uncontrolled task was used, it is difficult to know what cognitive processes the participants were carrying out. This is a problem when attempting to draw conclusions about neural differences. It is possible that, even when they were supposed to be searching, less experienced users were spending more time reading text while their 'savvy' users who had learnt how to use search engines were using sophisticated search strategies. After five days of training for an hour a day, the internet-naïve participants were producing similar activations as their more experienced counterparts. In a later book[37], Small and Vorgan use this result to raise a concern that if the naïve subjects had 'already rewired their brains' after just five hours on the internet, what might happen to the more malleable brains of children, when they spend their 'average eight hours daily with their high-tech toys…'? It can be hypothesised that children would also show changes in neural activity associated with learning to use a search engine, although the basis for anticipating changes beyond this is not made clear. Changes in neural activation in different regions can be expected when learning any task for the first time. For example, after adults learned to carry out complex multiplication[38], the brain activity produced by carrying out this task shifted from frontal to posterior regions (suggesting less working memory load and more automatic processing – see Fig 2).



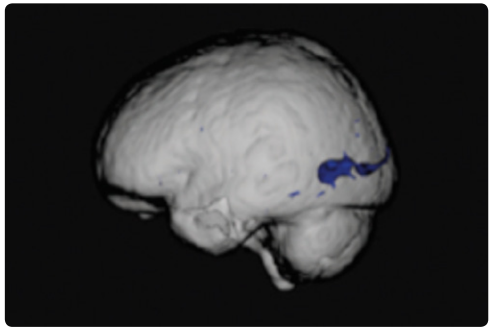


Fig 1
Regions of brain that were activated more by internet searching than reading for individuals a) without prior internet experience and b) with prior internet experience (with additional activity in regions associated with decision making and complex reasoning). These individuals may have learnt to use the internet, and so were more involved with mental processes involving, for example, search strategies. These images are from research by Small et al.[36].

All learning brings about changes in the brain, and the internet allows access to an effectively infinite educational resource. One outstanding characteristic of this resource is that its multimodality exceeds that of books (ie, it provides information in many forms: auditory, images, video, textual, etc). Such multimodality is regarded of considerable educational benefit since, for example, adding pictures to text can enhance memory for the text[39]. This enhancement of memory may be linked to the additional brain activity produced by multimodal stimulus over and above that produced by each mode separately[40]. However, multimodality alone does not, of course, guarantee improvement in long-term memory or even the ability of the resource to engage those wishing to learn from it. Internet-based learning resources require judicious design, with multimodality enhancing learning when it encourages in-depth processing that relates to the learning[41].

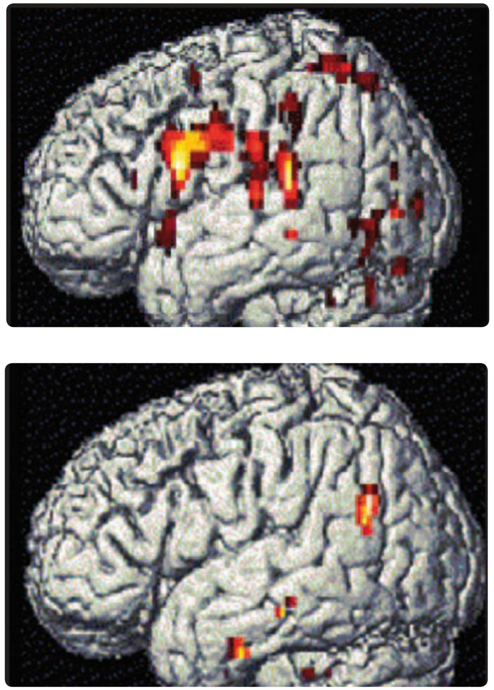


Fig 2
It is not just learning how to use the internet that can "rewire" our brains. Gaining mastery of any task can result in a shift in the brain activity generated when we carry it out. These images are from a study that required adults to practise complex multiplication: a) hotspots show regions of the brain where activity decreased; b) regions of the brain where activity increased after training (Delazer et al.[38]).

Information gathering

We know that...	We do not know...
the internet is a valuable learning resource and all learning involves changes in the brain.	search engines are more effective at 'rewiring our brains' than other environmental influences.

Multitasking

Do online multitaskers develop special skills?

The phrase 'multitasking' refers to attending to two or more parallel tasks (as might be envisaged when browsing products online and discussing them with friend(s) via instant messaging). Despite popular perceptions, high frequencies of this type of behaviour appear restricted to a minority of users, even amongst the 'net generation'[42]. In the strictest sense, engagement with two tasks simultaneously is extremely difficult, and so it can be assumed that online multitasking is chiefly about switching between two or more activities. When dealing with competing tasks (eg alternating our focus between different 'windows' on a screen), higher order (or top-down) processes are important in orienting and switching our attention efficiently. Andrews and Murphy[43] investigated the task-switching abilities of video gamers by presenting them with stimuli consisting of a number and letter, with a cue that sometimes asked them to make consonant/vowel judgements and sometimes odd/even judgements. They found video-gamers were better at task-switching, a finding also reached in a more recent study[44]. This performance may be aided by gamers' enhanced ability to suppress distracting visual information[45,46] while having sufficient attentional resources left over to allocate these beyond the current target.

These results contrast with a report that extensive media multitaskers are more susceptible to interference from irrelevant environmental stimuli and irrelevant memories[47]. However, there is a clear difference between playing an action game in which rewards are provided for efficient attention switching, and the practice of willingly increasing the number of distracting influences. Those who choose to simultaneously view multiple windows and browsers, chat and enjoy portable media all at once may be seeking distraction rather than rehearsing their attentional skills. Alternatively, it has been proposed[48] that heavy media multitaskers may benefit from their practice by partially attending to more than one stream of information simultaneously, rather than rehearsing the ability assessed by Ophir et al., ie switching between streams while ignoring the others[49]. This might provide an argument for media multitaskers to continue their practice in the face of the study by Ophir et al., but the suggestion remains that media multitasking does not develop the same set of attentional skills as playing video games.

However, there is a clear difference between playing an action game in which rewards are provided for efficient attention switching, and the practice of willingly increasing the number of distracting influences (such as choosing) to simultaneously view multiple windows and browsers, chat and enjoy portable media all at once

Multitasking

We know that...	We do not know...
video gamers develop executive attentional skills that may support them in allocating their visual attention (ie in task switching and suppressing distracting information)	if enhancement of executive attentional skills from video gaming translate into benefits for everyday online multitasking
extensive media multitaskers do not appear more skilful in these respects.	the cognitive advantages, disadvantages or the processes that characterise typical media multitasking.

Brain training

What types of brain training appear to work?

There have been some commercial attempts focused on developing cognitive function, including online training programmes that can be pursued over the internet. Disappointingly, there is a dearth of convincing evidence for the effectiveness of these commercial products. Indeed, computer-based cognitive training (or so called 'brain training') has chiefly been found to improve performance on the training itself, rather than transferring to everyday application[50]. One important exception, however, is the training of working memory. Working memory describes our ability to hold information in our attention, and it is a major constraint on our ability to learn new concepts. When young adults undertook a 19-day computer-based training program that focused on developing working memory for 30 minutes a day, it was found that not only their working memory, but also their fluid intelligence improved (ie their ability to solve problems in new situations)[51]. A convincing range of such results have led scientists to conclude that working memory can be trained[52], with such training shown to increase activations in frontal and parietal cortices associated with working memory[53] (see Fig 3). This bodes well for those wishing to develop more effective 'brain training' games – but so far the commercial response to these exciting developments has been slow.

Although other types of training, beyond working memory, have been disappointing in their ability to enhance cognitive function, we know that cognitive stimulation (eg reading and socialising) is healthy and can help protect our mental faculties[54]. This can include computer-based training, which has been shown as effective in slowing the rates of cognitive decline in adults[55], including sufferers of Alzheimers[56].

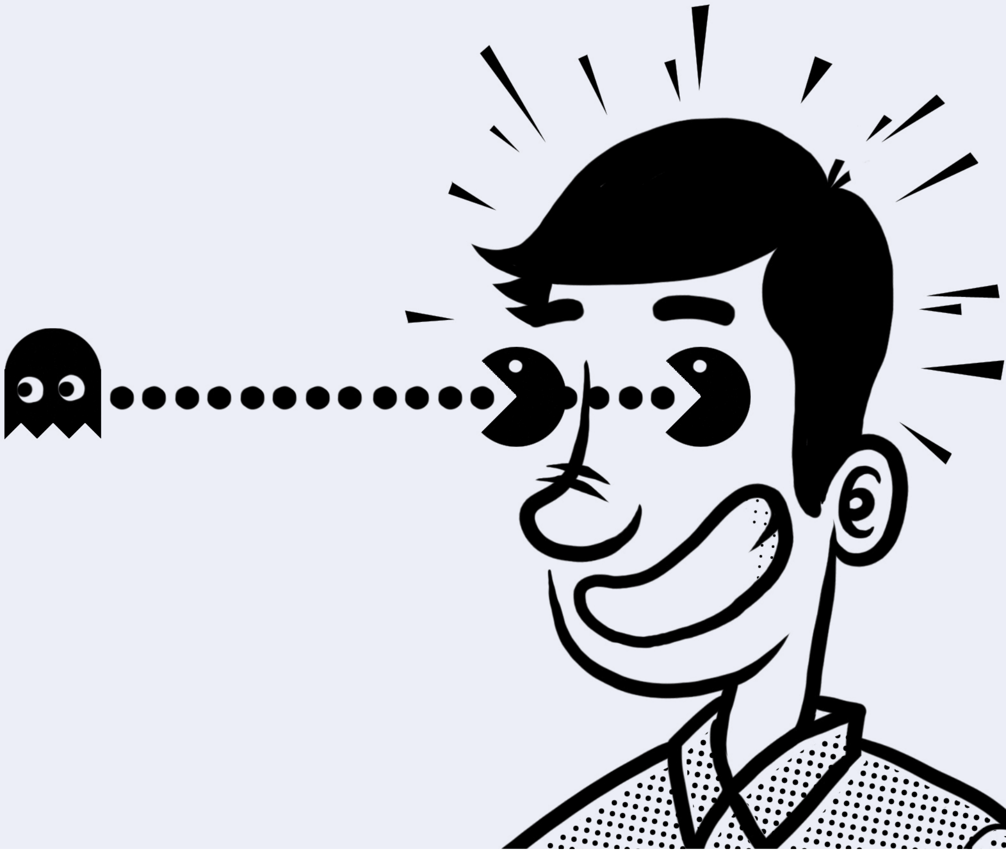
Fig 3
Computer-based brain-training can improve working memory function. The image shows the location of increased prefrontal and parietal brain activity related to such improvements (Olesen et al.[53])

Brain training

We know that...	We do not know...
working memory can be trained	existing commercial 'brain-training' games can provide transferable benefits in terms of developing cognitive function amongst healthy adults.
mental stimulation helps slow rates of cognitive decline, and this can include computer-based activity.	

The attraction of video games

Can you become addicted to video games and what's a safe limit? Why are video games so attractive and how may they affect the brain?



Video games can be played on- or offline, but internet games are one of the most popular pastimes for young internet users[57,58]. A simple observation about video games is their capacity to engage their players. However, the attraction of video games can become problematic for some children and this appears, at least, to be a very real and prevalent phenomenon. Playing internet video games has been implicated as a popular pastime of problematic internet users[59]. Video game addiction has been rejected from inclusion in the Diagnostic and Statistical Manual of Mental Disorders (DSM) but, when its criteria for pathological gambling were applied to adolescent UK gamers, researchers found one in five teenagers met the criteria for pathological addiction[60]. Similar results have been obtained in a study in Norway, with 3% of children aged 12-18 having a 'pathology', and 10% at risk[61]. In Germany, 10% of children aged 11-14 were found to be indulging in excessive computer and game use [62] and, in the US, 8.5% of youths aged 8-18. In Singapore, between 7.6% and 9.9% of a sample of more than 3,000 8-14 year-olds would be classified as pathological gamers[63]. All these studies report that such behaviour is more prevalent amongst boys.

Obsessive game players are generally distinguished by a set of personal traits and behaviours. Some of these might also be a cause (rather than an effect) of intense gaming, and these include loneliness, low self-esteem and lower satisfaction with daily life[64,65]. The profile of potential pathological gamers is not all negative, however. One study of 127 children and adults who were self-reported gaming addicts were characterised as generally highly intelligent, motivated and achievement orientated (though often misunderstood), and a follow up study five years later showed the younger group had performed well in higher education and worked in high ranking jobs[66]. However, the bulk of the evidence suggests intense game playing can create further social anxiety, poorer social relationships[67] and increased levels of depression[68].
The fact that it is so prevalent during adolescence is concerning, since poor psychosocial wellbeing at this stage can lead to further psychiatric conditions later in life[69]. The intensity of play may provide an early warning. In a two-year longitudinal study led by Douglas Gentile, researchers were able to show that youths who became pathological gamers began with an average of 31 hours per week, whereas those who never become pathological players began with an average of 19 hours per week (ie an

Video game addiction has been rejected from inclusion in the Diagnostic and Statistical Manual of Mental Disorders (DSM) but, when its criteria for pathological gambling were applied to adolescent UK gamers, researchers found one in five teenagers met the criteria for pathological addiction average of two to three hours per day)[63]. Those who continued to be pathological gamers displayed increased levels of depression, anxiety and social phobia, while those able to give up pathological gaming displayed less of these behaviours. This study also linked pathological gaming to increased aggression, likelihood of being a victim of aggression, and poorer academic grades. This evidence, together with the data on attentional problems discussed above, tends to support current guidelines from the American Academy of Pediatrics (AAP) for a maximum of two hours total screen time per day for children[70,71].

Neuroscience research provides some insight into why games are so engaging and why this can become a problem. Along with many other rewarding pleasures such as food, drugs, gambling and music, studies have suggested midbrain dopamine is released when we play video games[72] (but see constraints on interpretation published elsewhere[73]). Efforts to understand how persistent drug use influences the brain have focused on mechanisms underlying long-term associative memories in the frontal lobes and striatum which receive input from dopamine neurons in the midbrain[74]. Video gaming provides many instances of reward per unit of time relative to most 'real world' experiences, and a recent study suggests it can release amounts of dopamine comparable to the effects of psycho-stimulant drugs on the brain[68]. Further studies have sought to compare the neural responses to video games and drugs likely to induce dependency. For example, when regular video game players encounter images from their game, the response of their brain resembles that observed when drug addicts encounter cues reminding them of their drug[75,76] (see Fig 4) and changes in the brain over a six-week period of playing video games is comparable to those observed in the early stages of drug addiction[73].

Fig 4
In a transverse (horizontal) slice of the brain, the image shows where brain activity was greater for excessive video game players (compared with non game players) when they viewed images from a video game(Ko et al.[76]). The brain regions activated (including nucleus accumbens, anterior cingulate and dorsolateral prefrontal cortex) are also activated when substance abusers experience craving.

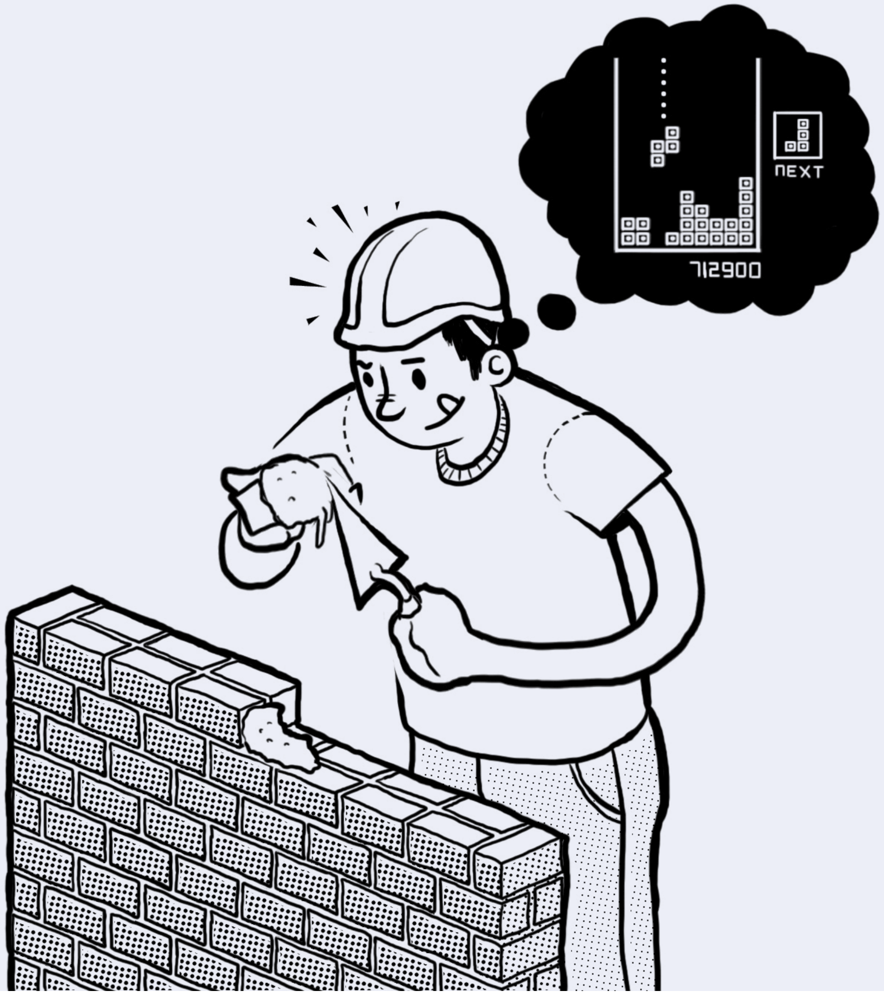
However, there is presently no consensus about the diagnostic criteria that should be used for pathological gaming and, more broadly, addiction to using the internet. It should be borne in mind that there are many other types of excessive behaviour (such as eating too much chocolate, shopping and working too hard) that can have very unhealthy consequences, but are not considered psychiatric disorders in themselves. There is, therefore, cause to question whether difficulty in controlling use of video games and/or the internet should be considered as 'true' addictions[78]. The time course of such putative pathologies might help indicate their seriousness, but here there is also a lack of consensus. The Gentile study[63] suggested pathological gaming usually continues for more than two years and so cannot be considered just a 'phase', while other work showed half of those diagnosed using similar criteria were no longer 'addicted' a year later[79].

The attraction of video games

We know that…	We do not know…
excessive use of video games is common and can be unhealthy. (Research supports a guideline of maximum two hours total screen-based entertainment per day for children.)	video gaming should be considered as an 'addiction' alongside drug dependency, although studies of drugs and drug addiction may help shed light on the attractiveness of gaming.

Visuomotor skill learning

Can video games have beneficial effects on their players?



Problematic gaming may be a serious downside of the ability of video games to capture their players' attention, but there can be significant benefits as well. The ability of such technology to strongly stimulate their player's reward system may also contribute to their potential as teachers. Increases in midbrain dopamine are also associated with improved ability to store and to explicitly recall information (declarative memory), possibly due to the enhanced plasticity that dopamine can provide[80-82]. When models are used to estimate changes in midbrain dopamine during an educational game, these can predict when, during the game, a player can recall newly-learnt educational content[83]. A study of working memory training has also shown individual improvements in working memory are correlated with changes in cortical dopamine receptor density (see Fig 5), supporting the notion that working memory training may help dopamine-based transmission of information in the brain[84]. These join another set of findings about the potential benefits of computer games regarding the ability of video games to teach a range of visuomotor skills, and these will now be reviewed.

Although often characterised in the popular press as mindless activities, it seems that video games can influence the development of abilities that psychologists call 'skills'. These skills include very basic visual perceptual and motor (movement) response abilities rather than higher-order reasoning skills or the 'thinking skills' taught in schools. They can, however, contribute to the efficiency with which many everyday tasks are carried out including, as we shall see, tasks that are critical to some professions and fields of learning.

In 2003, Green and Bavelier[85] studied visual processing skills of gamers compared with non-gamers (18-23 years-old) and found that playing video games was associated with enhanced visual attention capacity, superior allocation of spatial attention over the visual field and improved temporal processing of visual information (ie gamers were less likely to suffer 'bottlenecks' of attention when many events occurred in quick succession). Murphy and Spencer[86] failed to replicate these findings with a larger sample, although this may have been due to the types of video game experienced by their participants. Green and Bavelier considered participants who only played action video games, whereas Spencer and Murphy's participants either only played action video games or

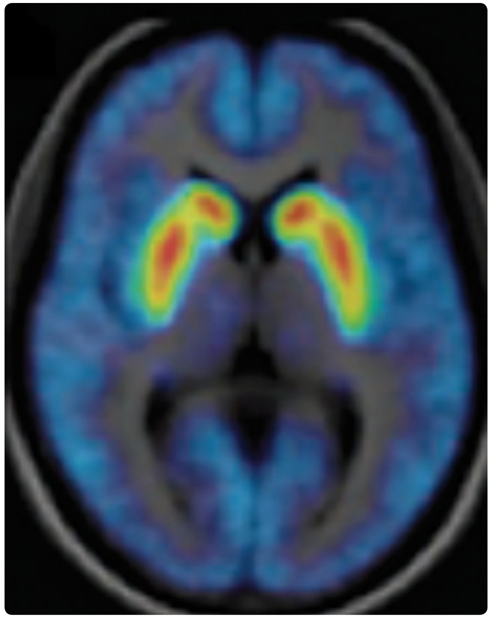


Fig 5
Hotspots show availability of cortical dopamine receptors in the brain. Improvements in working memory that arise from computer-based training are correlated with changes in the density of these receptors, suggesting dopamine is involved in the underlying processes (McNab et al.[84]).

a combination of action and strategy video games. The importance of video game type has been noted in other studies (see page 41 for research on contrast sensitivity).

Dye and colleagues[87] studied visual attention in gamers and non-gamers in four different age groups (aged 7-10,11-13,14-17,18-22 years old). Their results suggested that action video game players of all ages had enhanced attentional skills which allowed them to make accurate responses more rapidly, with additional attentional resources to help process distractions. This approach was extended to assess visual attention with three types of task[88]. Researchers tested child and adult participants in a simple visual search task (locating a simple target shape amongst a field of distracters), and a multiple object tracking task (requiring multiple moving objects to be tracked simultaneously). They also tested their participants' ability to reallocate attentional resources once they had been allocated, using an attentional blink task. In this task, the participant must report a particular aspect of a visual stimulus (eg whether it points up or down) appearing unexpectedly in a stream of distracters. They concluded that young action game players perform faster in these tasks than non-gamers, achieving scores that non-gamers may achieve only as adults, if ever. Castel and colleagues[89] studied visual attention in a group of gamers aged 18-34 who had, on average, played for 12.9 hours per week over the previous six months. Again, gamers produced faster response times relative to non-gamers.

The rapid response of gamers in these tasks should not, however, be confused for 'trigger-happy' behaviour, since the accuracy of the response was not diminished[90]. However, the tasks to which video game effects are shown to transfer are usually computer-based. Indeed, a study led by Richardson[91] found that video game experience predicted navigation performance in a virtual environment, but did not appear related to navigation ability in real environments. This suggests video games may not offer a general enhancement of spatial abilities, but may improve tasks combining rapid motor responses and visual processing (visuomotor skills) in small scale environments.
Other studies have also found differences between those who play video games and those who do not. For example, Green and Bavelier investigated the ability of video game players to track independently moving objects[92]. Participants were young adults

This suggests video games may not offer a general enhancement of spatial abilities, but may improve tasks combining rapid motor responses and visual processing(visuomotor skills) in small scale environments

who had played an action video game at least three to four days a week in the previous six months. These gamers kept track of objects moving randomly about a screen more accurately than non-gamers . Other researchers[93] have reported similar correlations amongst children and young adults of video game experience with improved ability to track multiple objects.

However, such effects might not be caused by the game itself. For example, it is possible that those with good tracking abilities are better at video action games, and so are more likely to spend their time playing them. Such self-selection may even have some biological basis since recent research[94] shows the rate at which individuals improve on a video game can be predicted by the pre-existing size of their dorsal striatum, a region associated with cognitive flexibility, as measured by task-switching and the ability to transfer learning to new tasks. To address issues of self-selection, experimental studies can be devised in which the effects of playing games on non-gamers are examined. Green and Bavelier[95] divided their non-playing participants into two groups, one of which experienced 30 hours on action video games and the other (their control group) did not. Performance on their multiple object tracking task was then reassessed. The training improved their performance, whereas the control group of non-players who received no training did not show any improvement. Rather than simply finding enhancements amongst established game players, this type of training study provides more convincing evidence that the game is producing the skill, rather than those with skills choosing to game. In their earlier research, Green and Bavelier[85] also asked non-players to engage with an action video game for one hour per day for ten consecutive days. After action-game training, scores were significantly improved on all three measures of visual processing tested: enumeration (reporting how many squares are presented in a briefly flashed display), a useful field-of-view task (measuring participants' ability to locate a target amongst distractors) and an attentional-blink task (measuring temporal processing).

Studies involving controlled programmes of training have now been carried out by other researchers. In a study of adults, it was found ten hours of training on an action video game improved spatial attention and mental rotation, with women benefiting more than

However, such effects might not be caused by the game itself. For example, it is possible that those with good tracking abilities are better at video action games, and so are more likely to spend their time playing them

men – implying that playing action video games can help close gender difference in spatial cognition[100]. The effects of action game training have also been studied in respect to contrast sensitivity, which is the primary limiting factor in how well one is able to see[97]. It is defined as the ability to detect small increments in shades of gray on a uniform background. As well as finding improved sensitivity amongst regular video game players, these researchers trained non-game players for 50 hours over nine weeks using action games, and a control condition of playing a non-action game for the same duration. A large percentage improvement in contrast sensitivity was found for action-game training, and this effect was extremely robust across the sample of participants, raising hopes for complementary clinical procedures aimed at improving eyesight[98].

There is, however, evidence of training with video games failing to demonstrate effects. A team led by Boot[99] found 23.5 hours of video game training over four to five weeks did not improve performance on a battery of cognitive tests that included those used by Green and Bavelier[89], with the exception of some improvement in mental rotation skills. Rather than challenge the notion that video game training can improve skills, Boot's team concluded there may be boundary conditions on the effectiveness of video games to enhance skills in a transferable manner. They point to small differences in their assessment tasks but raise the issue that, if such small procedural differences did have an effect on outcomes, then possibly video game training may not always transfer to complex tasks outside the laboratory. The content of the video game should be considered an important factor in predicting outcomes, and it is video gaming based around action that is most consistently linked to improvements in visuomotor skills.

Although the identification of mediating factors deserves further research, the evidence appears strongly supportive of video games enhancing skills. It is not, of course, unusual to find that training can improve performance. For example, practise at luggage screening can improve detection rates[100], but these effects are limited to the task itself. However, the training effects of video games appear to transfer beyond video games. The significance of this finding is emphasised by the many failed efforts to develop training programmes[E] that can achieve transferable cognitive enhancement[50,101,102]. It should also be noted that the training periods used by experimenters with video

In a study of adults, it was found ten hours of training on an action video game improved spatial attention and mental rotation, with women benefiting more than men – implying that playing action video games can help close gender difference in spatial cognition

E
The exception to this general failure appears to be in the area of training working memory discussed above, see Klingberg, T. (2010). Training and plasticity of working memory, Trends in Cognitive Sciences, 14(7), 317-324

games are relatively modest compared with the several thousands of hours per year spent gaming by many regular players.

This makes video games a special case of scientific interest and there are now serious efforts underway to understand why they have such influence on our cognitive abilities. In a recent study[103], non-game players were trained with either 50 hours of action video game or the same amount of a non-action video game as a control. Participants were then asked to carry out a test of visual motion direction and a test of auditory tone location, indicating left and right in both tests by pressing a button. By fitting models to the data derived from these tests, researchers were able to rule out the possibility that decreased response times in the group trained with action video games was due to improved motor response. Instead, they were able to implicate improved probabilistic inference as the causal mechanism. That is, action video games appear to train participants in making better decisions about the likelihood of outcomes based on previous history. This is not, of course, an improvement in the ability to consciously weigh up and reflect upon evidence, but an improved ability to automatically assess a sensory environment. Action video games rarely repeat exactly the same situation so, as pointed out by the team undertaking this study, learning in this context encourages an improvement in rapidly and accurately 'learning the statistics on the fly and how to accumulate this evidence more efficiently'. They speculate three possible candidate explanations for why this learning can transfer to other tasks: it may be linked to development of neural regions that are shared across modalities; and/or the development of the fronto-parietal circuits that control these regions; and/or the global release of neuromodulators such as noradrenalin that can improve such probabilistic inference across a wide range of circuits.

Evidence for the transfer of skills is further bolstered by some convincing examples of where action-game training has contributed to real-world expertise. An early study by Gopher[104] showed ten hours of video game experience using Space Fortress (designed specifically to study cognitive training[105]) improved the subsequent flight performance of cadets. Following this work, video game training was incorporated into the regular training programme of the Israeli Air Force. An echo of this finding can be found in recent

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informal reports that gamers make better drone pilots[106]. In a study of laporoscopic surgery, Rosser et al.[105] found that, compared with non-players, surgeons who had played video games in the past and were playing video games currently made 37% and 32% less errors (respectively) during examination of their surgical skills. These results join other studies showing individuals with previous regular engagement with video games have better videoendoscopic surgical skills[108,109]. Recent developments in video game technology may strengthen this relationship. For example, skill on a Nintendo Wii, with its motion sensing interface, has been shown to be a good predictor of laporoscopic skill[110]. Such findings are encouraging some scientists to suggest that video game technology may prove a promising method to 'take the brakes off adult plasticity'[111].

Visuomotor skill learning

We know that...

playing action video games can improve some visual processing and motor response skills.

We do not know...

why video games appear so effective in achieving this

all the factors that are likely to mediate these effects, although the content of the game appears critical

the extent to which these enhancements might benefit our everyday lives. For example, in terms of the demands faced by most of us in our daily working life, it is difficult to estimate the benefit of these improvements in terms of our professional performance. However, improvements in some areas of screen-based professional work have been demonstrated.

Learning about affective response

Do violent video games encourage aggressiveness?
Do prosocial games encourage more positive behaviour?

The ability of video games to teach can also result in unwanted outcomes. Self-reported guilt suggests that virtual violence is not a morally insignificant type of act[112]. There have been very many studies investigating a possible link between playing violent video games and the learning of aggressive behaviour, with some suggesting publication bias may have generated unwarranted concern[115]. However, a recent meta-analysis of 136 studies (involving over 130,000 participants) concluded that the scientific literature has effectively and clearly shown video game play is a causal risk factor for aggressive behaviour[118]. Debates amongst researchers continue to linger, including around how to interpret the size of this effect[115,116], but even a small effect (in scientific terms) might translate into high costs for society and the individuals concerned[121].

Evidence for violent video games promoting aggressive behaviour has also arisen from objective measures of event-related brain potential (ERP) in the electrical field generated by brain activity[118]. This study was able to reveal desensitization linked to repeated exposure to violent games. In this study, scenes of real violence elicited reduced signals among those who played violent, as compared to non-violent, video games (see Fig 6). Another study used functional Magnetic Resonance Imaging (fMRI) to generate images of brain activity when carrying out a GO/NO-GO task[119]. This task required participants to press a button in response to a target stimulus and withhold their response to a non-target stimulus. The researchers found participants demonstrated reduced activation in the dorso-lateral prefrontal cortex (DLPFC) in the response inhibition task after 30 minutes of playing a violent video game, compared with playing a non-violent video game. Although no changes in accuracy or timing were observed in this study, the changes in brain activity suggest reduced control over response. In a very simple but convincing experiment, Carnagey and colleagues assigned participants to play either a violent or non-violent video game for 20 minutes and then watch a ten minute videotape containing scenes of real-life violence, while heart rates and galvanic skin responses were monitored. Participants who had previously played a violent video game showed reduced physiological responses while viewing filmed real violence, strongly suggesting a physiological desensitization to violence[120].

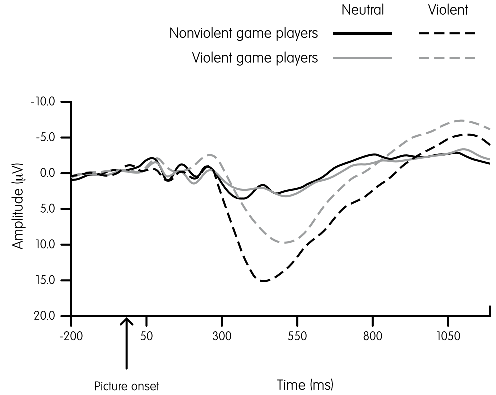

Fig 6
Changes in the electrical field generated by the brain in response to viewing neutral and violent pictures (Bartholew et al.122). This response is shown for young adults who regularly played nonviolent games (nonviolent game players) and for those who regularly played violent games (violent game players). Compared to players of nonviolent games, violent game players showed a reduced response when confronted with scenes of real violence. This effect held even after the researchers controlled for aggressiveness in the personality of the players.

If video games can teach their players to display aggressive affective responses, then it should be possible to observe the reverse effect in response to games that encourage empathy and sensitivity. After playing a prosocial (compared to a neutral) video game for ten minutes, researchers have noted increased empathic concern towards the suffering of others and decreased pleasure at another's misfortune immediately following the game[121]. As with the effects of violent video games, researchers must seek to establish causality through well-designed experimental (testing for a different behaviour after playing one type of game for a short period compared with another), correlational (testing for an association between playing the amount of video games played and the extent of the behaviour), and longitudinal studies (testing whether the amount of video game play between two or more times can be used to predict changes in the behaviour). In studies of Singaporean and Japanese players, researchers have been able to report a link between playing prosocial video games and prosocial behaviour in all three respects[122].

In reality, although perpetrators of well-reported atrocities may have a history of playing violent video games (eg the Columbine massacre[29]), the complexity of human behaviour and the contexts in which real violence occurs make it very difficult to prove or disprove such games are key causal factors. It appears clearly established that the content of a video game can influence subsequent emotional response, but this is not conclusive evidence that a violent video game causes an individual to behave more violently. It is, however, reasonable to hypothesise that regular exposure to violent video games increases the likelihood of such behaviour.

If video games can teach their players to display aggressive affective responses, then it should be possible to observe the reverse effect in response to games that encourage empathy and sensitivity. After playing a prosocial video game for ten minutes, researchers have noted increased empathic concern towards the suffering of others and decreased pleasure at another's misfortune immediately following the game

Learning about affective response

We know that...

the emotional content of video games can influence affective response, that is, playing violent and prosocial video games generally shifts behavioural tendency towards aggressiveness and empathy respectively.

We do not know...

playing a violent video game causes an individual to carry out a violent act.

Attention problems

Does technology cause ADHD? Is there any evidence of digital technology causing problems with attention?

Modern media may be improving children's abilities in a range of tasks involving basic visual attention and motor skills, but what about their attention in class? This can involve a different set of abilities (eg mindfulness and consideration of social boundaries and contexts) and different types of motivation (eg longer-term rewards requiring the deferral of more immediate gratification). It has been suggested that television and computer games may interfere with the development of such attentional capacities, since they displace opportunities to practice paying attention to less exciting tasks that do not involve rapid changes in focus[123,124]. Some commentators have even suggested a link between the rise in diagnosis of Attention-Deficit Hyperactivity Disorder (ADHD) and the boom in computer games[F].

Concerns about digital technologies causing ADHD to some extent mimic the controversies around television and ADHD. Studies of children's television viewing habits have generally suggested an association with subsequent attentional problems across childhood development[124-132]. However, children with attentional problems may be actively encouraged to watch television by parents in need of relief from the higher levels of care required, children with ADHD may watch more TV because it is popular amongst their peers, and hereditary and neurobiological factors may also play a role in mediating the relationship between TV viewing and ADHD. Taking these factors into account, the existing evidence does not justify making the statement that watching television causes ADHD[133] but suggests excessive viewing (seven or more hours per day) can give rise to negative outcomes[134]. Also, as will be emphasised many times in this review, how the technology is being used is usually a strong but under-examined contributor, with some educational television revealing positive effects on preschoolers' readiness[135] while viewing of inappropriate material can be linked preschoolers' hyperactivity[136].

In terms of content, however, it seems the internet leisure activities popular with children (eg games) might not teach the types of attentional capacities required for 'paying attention' in the classroom and other contexts. Given the additional interactivity and the levels of physiological and cognitive engagement they can provide, a case can be made that some internet activities (such as games) might pose a greater threat to some attentional abilities than television. A study looking at the prevalence of attentional

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F
Greenfield, S. in Daily Mail (2009).

problems at a single point in time has found correlations with high levels of video game use[137]. However, the same limitations on interpreting such evidence apply here as they do with television. Also, there are neurological grounds for predicting that children with ADHD would be more vulnerable to becoming 'addicted' to gaming[138] and the impulsivity observed in ADHD has been identified as a risk factor for this addictive behaviour[63]. The most convincing evidence for a cause-effect relationship between gaming and classroom attention arises from research involving a US longtitudinal study of 6-12 year-olds at four time points over a 13-month period, which recorded parent- and child-reported television and game exposure[139]. To measure attentional problems, teachers were asked to report difficulties staying on task, paying attention or whether a child often interrupted other children's work. It should be noted that such reports reflect important issues for academic success but do not imply development of ADHD. This study was able to control for existing attentional problems and gender, and showed that playing games was associated with a greater risk of developing attentional problems, and was a more robust predictor than television viewing. It was noted that those who exceeded the two hour (AAP-recommended) amount of daily screen time (television and computer game play combined) were more likely to be above average in attention problems. Based on the results of this study, it would seem that prolonged playing of computer games can have a detrimental effect on attentiveness in class. As with the reports of positive effects reviewed earlier, the durations of exposure involved suggest computer games are an especially effective environmental influence upon behaviour. The importance of judging the impact of technology by how it is being used may explain a recent report that young children's daily computer use is associated with fewer attentional problems[140].

This study was able to control for existing attentional problems and gender, and showed that playing games was associated with a greater risk of developing attentional problems, and was a more robust predictor than television viewing

As with the reports of positive effects reviewed earlier, the durations of exposure involved suggest computer games are an especially effective environmental influence upon behaviour

Attention problems

We know that...

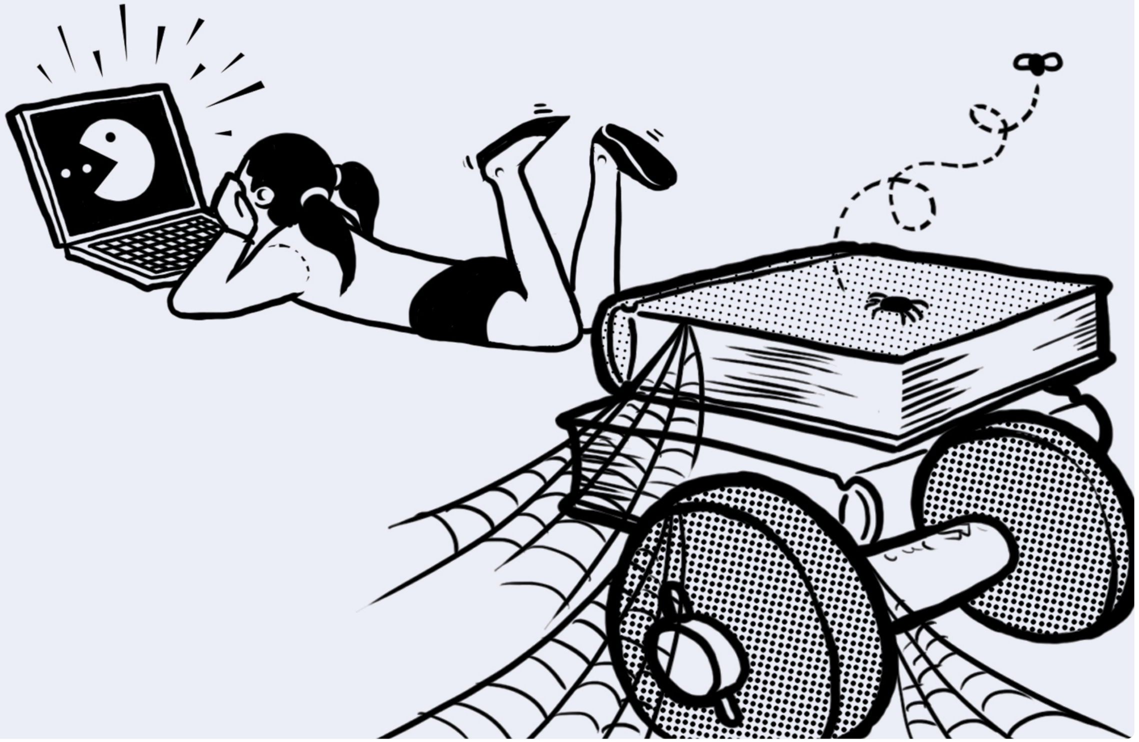
Restricting children's exposure to TV and video games to 2 hours (combined) reduces the likelihood of attentional problems in class (but this conclusion is derived chiefly from only one study, so more research is needed to confirm this).

We do not know...

the use of digital technology by young children is a causal factor in developing ADHD.

Displacement of exercise and homework

Do we know more technology means less exercise?
How can technology disrupt homework?



Apart from their direct effects, the exciting range of online entertainment opportunities may have the potential to displace other, more beneficial, pursuits. Given the concerns around obesity, including amongst children, concerns have been raised about whether the use of computers diminishes activities involving exercise. Evidence in this area, however, is mixed. Researchers have reported negative relationships[141,142], no relationship[143] and even a positive relationship[144] between computer use and exercise amongst children. Another study[145] with young children suggests negative associations with exercise only when the usage becomes excessive[G]. The same study found that computer usage was modestly associated with better academic performance and time spent reading, supporting the notion that home technology can be a useful educational resource. As well as displacing homework, of course, on- and offline computer activity is frequently a part of today's homework, so future research of this type may need to pay closer attention to what the computer is being used for.

Gaming is rarely a part of homework but, contrary to public perceptions, teenagers may not play video games on most days. In the US, Cummings & Vandewater[146] carried out a study of 1,491 children aged 10-19 years-old and asked them to log their gaming habits over a period consisting of one randomly chosen weekday and one weekend day. They found only 36% of their participants played video games during this period, playing from about 60-90 minutes on average. This is about a third of the time that adolescents spend watching TV[147]. Compared with non-gamers, adolescent gamers did not spend less time in social interaction with friends and parents, but spent 30% less time reading and 34% less time doing homework. However, one needs to be cautious in concluding that these individuals would, were it not for video games, be expending more effort on their studies and be achieving higher grades. Although several studies suggest video game play is negatively related to academic achievement at school and college[148-151], one study suggests academic achievement can be positively related to game play[152]. Gamers may, of course, simply be working more efficiently than non-gamers, with some evidence that high achievers spend less time on homework[153]. Also, it may depend on when the games are being played, with the hours spent on playing video games during the week having notably greater association with poorer school performance than time spent gaming at the weekend[154]. Moving beyond time allocation at a single instance in

Compared with non-gamers, adolescent gamers did not spend less time in social interaction with friends and parents, but spent 30% less time reading and 34% less time doing homework

G
In this study, 'excessive' was defined as greater than eight hours per week. Note, when comparing this to AAP guidelines of two hours per day, the latter includes all screen time.

time, Weis and Cerankosky measured changes in the academic performance of non-gamers (boys aged 6-9 years-old) four months after receiving their first video game system. Compared with a control group (who received their video system at the end of the four months), those boys who had possessed a video game for the four months showed less involvement in after-school activities, lower reading and writing scores and greater teacher-reported academic problems[155]. The changes in their academic performance were mediated by the amount of gaming they had been indulging in. Of course, this effect might not be unique to video games but might feasibly be produced by other types of distraction (eg a new bicycle). However, the study does provide clear evidence that playing video games can negatively influence school work and achievement.

Many students also engage in instant messaging during periods set aside for homework. It is not likely that both these activities can be carried out simultaneously, or even that this type of media multitasking develops special skills in switching attention (see multi-tasking above). In a large sample of college students, almost all reported using instant messaging while 'working' and most (57%) considered this practice was detrimental to their studies.

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Displacement of exercise and homework

We know that...

although technology can helpfully support learning, some applications (eg gaming and instant messaging for social purposes) can be a distraction, suggesting parental monitoring of younger students' use of technology may benefit learning outcomes.

We do not know...

use of technology-based activity discourages physical exercise.

Sleep

How can using technology influence sleep?
What effect can this have on learning?

Late night use of electronic media is commonly perceived as a cause of poor sleep[156,157], with the presence of a television or computer in the bedroom linked to later bedtimes[158]. It appears self-evident that internet use and the playing of computer games can interfere with sleep, if these activities displace bed-times and lead to shorter periods in bed. A recent study in the US of teenagers' technology use after 9 pm indicated an average dose of 55 minutes online computer use plus 24 minutes of video games[159].

However, there are reasons to suspect that digital technologies can have a more direct effect on sleep beyond postponing bed-time, since it often involves staring at an artificial source of light. Exposure to relatively low intensity light can affect human circadian rhythms, interfering with the processes by which our bodies 'know' when it's bedtime[141,160]. Higuchi and colleagues have shown that using a bright display terminal can suppress nocturnal melatonin secretion as measured in the saliva, suggesting these displays have the potential to disrupt sleep[161]. Apart from the brightness of the display, however, the task undertaken on the screen may be a stronger factor in determining subsequent sleep quality. In a second study, Higuchi's lab varied both the brightness of the screen and the task that adult participants undertook on the computer late at night, comparing a set of simple tasks with a low mental load with playing a computer game[162]. Objective measures of sleep quality, such as the time taken for participants to get to sleep, showed the computer game had a significantly greater disruptive effect on sleep. The brightness of the display did not appear to influence these measures, but a combination of playing the computer game and a bright screen did reduce self-reported sleep quality.

Good sleep is important for health and development. If computer games contribute to poor sleep, we can also assume that this leads to day-time sleepiness, which is known to influence academic achievement. Sleep also contributes to learning by consolidating the memory of our waking experience. When we sleep, events in the hippocampus help co-ordinate the reactivation of memory traces left over from the day. This helps to reproduce activities in the cortex that characterised these experiences, and brain activity that was observable in our preceding hours of wakefulness is reproduced when we fall asleep[163] (see Fig 7). Although much remains to be understood, these processes appear

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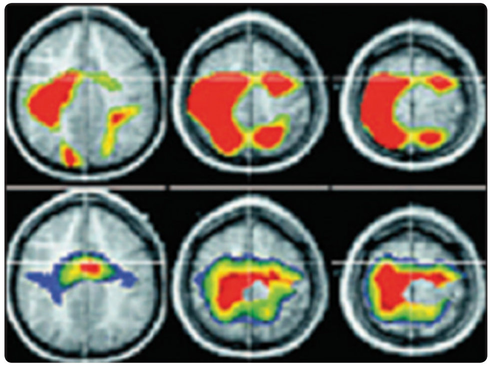

Fig 7
When we sleep, we consolidate the memories of what we have learnt during the day. In these images the sleeping brain (3 bottom images) appears to reproduce the neural activities of those recorded during preceding hours of wakefulness (3 top images, from Maquet et al.[167]).

to consolidate or 'fix' our memories and improve our ability to recall what we have learnt. As well as helping us remember, sleep also prepares us to learn more and to use our knowledge to generate insights[164]. Regular and sufficient sleep is thus essential for the brain to learn efficiently.

In an experimental study by Dworak and colleagues[165], ten school children (average age 13.5 years-old) played a computer game for 60 minutes on one night of the week, watched television for the same time on another evening, and also experience one evening with no technology (as a control). The technology exposure occurred at 6pm, around two to three hours before bedtime, but after a 'homework session'. The memory for information presented in this session was tested immediately at the end of the homework session, and again 24 hours later. This memory testing allowed the researchers to determine how well, after their technology exposure and the night's sleep that followed, they had managed to consolidate their learning in their memory. This study is notable in terms of considering singular exposure to media (which is a modest dose considering that many children might be experiencing accumulative effects over many evenings), in terms of the conservative amounts of gameplay (one hour is close to typical) and the scheduling of the play after homework and well before bedtime (so representing what many parents would consider a well-managed evening). The computer game playing resulted in significantly disrupted sleep patterns (including an approximately 20 minute further delay in sleep onset) and reduced verbal memory performance. Such effects were not seen for television viewing, which may highlight its passive nature. While television viewing expends the same energy as sitting quietly, playing video games results in a higher arousal state of the central nervous system[166]. As suggested by the researchers, since newly acquired knowledge is particularly sensitive to the subsequent consolidation period, the reduction in verbal memory performance observed in this study may be occurring during the video game play and/or as a result of the disturbed sleep, since sleep also helps consolidate memory.

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Although existing studies provide converging evidence that playing video games influences sleep, this is another area where more research is badly needed. For example, consensus has not been reached about how sleep patterns are affected, with disagreement over whether SWS sleep, RME sleep or any particular stage of sleep can be implicated, or whether it is physiological arousal or cognitive arousal that is causal[162,167]. In some cases, methodological differences may explain different findings. For example, one study of children's evening technology use in China found no effect on day-time sleepiness[168], in contrast to other researchers in Belgium[169,170]. However, the use of parent-reporting in the former Chinese study may be less sensitive than the self-reporting used by the Belgian researchers. There may also be factors mediating the effect of technology on sleep, such as age. For example, less sleep impairment was noted in studies with older adolescents and adults after playing computer games[162,167] than in the Dworak[169] study with young adolescents.

In adolescence, the need to maintain peer relationships becomes stronger and this can also lead to other types of technology influencing sleep patterns. In a study of 13-16 year-olds, the Belgian team led by Van den Bulck[171] found that mobile phone use after 'lights out' was very prevalent (most participants using their phones several times a month in this way), and significantly related to increased tiredness both concurrently and a year later. They report that teenagers who used their phone between midnight and 3am were almost four times more likely to be very tired. As pointed out by the authors, since these activities are two-way, it is difficult to suggest this correlation might arise from using phones to occupy sleepless hours. For one party at least, reduced sleep is likely to be the result, rather than just a cause, of using a phone. A large Finnish study of participants aged 12-18 showed clear gender differences in how technology may impact on sleep and health[172]. Digital games and the internet were used more often by boys than girls, and it was these activities that were linked to boys' sleep disruption. Mobile phone usage was more intensive for girls than boys, and female sleep impairment was linked to this activity. In this study, it was demonstrated that poor perceived health was most strongly associated with intensive ICT-usage when it affected sleeping habits. Common sense suggests that how and when a phone is being used will influence whether it affects sleep, and this may explain why evidence exists for[173] and against[174] the notion that regular mobile phone users lack sleep.

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The need to focus on the use of technology, rather than the technology itself, is also suggested by the rare studies of using music technology. Of the two existing studies, one suggests that the general use of music as a sleep aid by school-aged children and adolescents interfered with sleep during weekdays (but not at weekends)[169]. The other study (which restricted the music to a sedative classical variety combined with relaxation training) found an improvement amongst those who slept poorly in a sample of young children[175].

Sleep

We know that...

how and when technology is used is an important factor mediating its effect on sleep

late night technology use is linked to reduction in sleep and sleep quality

computer games may have the potential to disrupt children's sleep and learning even when played earlier in the evening (but this conclusion is derived from only one study, so more research is needed to confirm this).

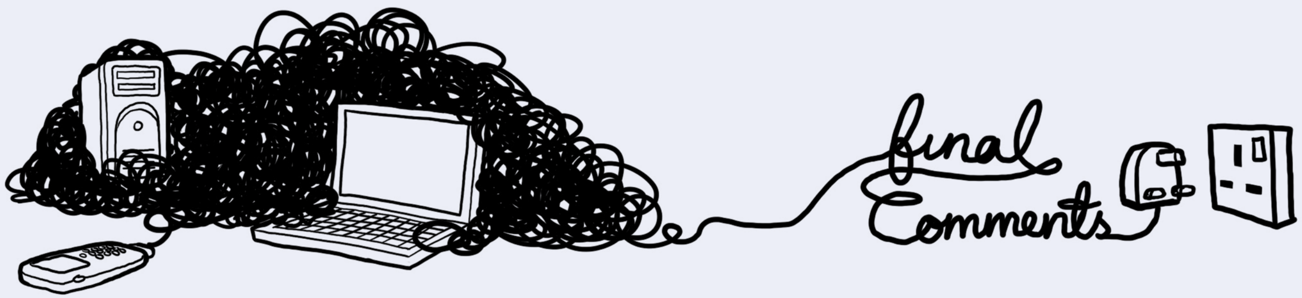
teenagers who use their mobile phones after 'lights out' are considerably more likely to suffer daytime sleepiness.

We do not know...

The extent to which changes in sleep patterns during adolescence should be attributed to changes in circadian rhythms, or to other factors that include the use of technology.

Final comments

What are the most significant risks to well-being from using digital technology? How can these risks be reduced?



As adults, we must make our own decisions about how we choose to use technology, although the research reported here can help inform these decisions. However, the developing brain is more susceptible to environmental influence than an adult's, and children are at the forefront of the technology revolution. This makes it appropriate that the discussion of negative effects of technology should focus on risks to the development of children that can be judged as most significant. This judgement of significance needs to take into account both the likelihood and consequence of the hazard. Based on the literature reviewed, the most significant risks include:

– an increase in aggressive response from playing violent video games

– excessive use of computers/internet access/gaming that interferes with psychosocial wellbeing, attentional and vision problems

– evening use of technology that leads to disrupted sleep (and related consequences).

These risks can be greatly reduced by monitoring the quantity and content of children's use of technologies. Although the guideline provided by the AAP of two hours maximum time for screen-based entertainment (all media, including TV, combined) is a useful rule of thumb, the scheduling of this usage is also an issue. A sensible curfew on technology use is advisable, that takes into account a child's age and the need for a pre-bedtime period free of the more disruptive types of technology such as gaming.

When making decisions about how children are able to access the internet at home (eg whether to allow access from a child's bedroom), parents should be mindful that some monitoring of how the internet is being used can be beneficial for their child. Even when parents have a fair idea of how a child is apportioning their time on the internet and the different activities they are pursuing, there remains the issue of judging whether this is appropriate. This judgement may not have been helped by a media focus on unusual but sensational risks (such as internet-related sexual abuse) rather than the more mundane but prevalent problems such as sleep disruption.

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Since many of today's parents did not grow up in a world that was as technologically rich as their children, they may not feel adequately prepared to provide the guidance that their children need. It may fall to another party such as schools, therefore, to provide the information required for parents and children. Indeed, pupils would benefit from schools delivering skills that support the 'hygienic' use of internet and digital technology (ie use that contributes to wellbeing, healthy development and effective learning).

There is already sufficient research for helpful evidence-based guidance to be developed. However, there is also a range of areas where research has barely begun. We know surprisingly little about how children currently use the internet to support their learning informally in the home environment. For example, how is a child's use of instant messaging while carrying out homework likely to influence the quality of learning? Is this application generally used to gossip or to discuss the homework, and does it help engage children with their homework or distract them from it? This type of information, once available, could help further inform advice provided to schools and students, as well as to parents. Also, many of those findings already in existence deserve further replication and scrutiny, since all research in this area can become quickly outdated as applications rapidly change and develop. (An example of this was reviewed above: over a decade or so, an early negative association between adolescent social connectedness and online communication transformed itself into a positive relationship.)

It is unwise to judge any type of technology as inherently good or bad[176]. Rather, its value depends upon how it is used (by who, when and what for). The internet presents enormous opportunities for positive benefit, through improving our ability to communicate and to access information in many different forms. What is communicated and what information is accessed are not determined by the internet itself but by its users. Discussing the general benefit, or otherwise, of different types of application (social network sites, games, chat rooms etc) can be unhelpful, since it is how these specific applications are created and used that determines their impact on an individual. So we cannot say 'social network sites are good' or 'online games are bad'.

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Gaming, whether on- or offline, perhaps provides the clearest example of the dual nature of technology's power to change us, with the same neural mechanisms implicated in its ability to develop the brain in both constructive and destructive ways. Little wonder then, that authors of popular science have been able to use the same evidence base to reach both positive[177] and negative[178] conclusions about what technology is doing to our brains. The unexpected effects of gaming have only recently come to the attention of neuroscience, and little is yet known about the processes involved. These effects do, however, suggest games are a special case of environmental influence that is potentially more powerful than most other types of daily activity. If the content of the game is inappropriate, or if used to excess, the influence can be negative. On the other hand, scientists are becoming excited by the potential of gaming as a tool for positive influence, with possible applications in education, and for the enhancement and protection of cognitive function. Considerable further research will be required to explore the underlying principles involved, and to develop and properly evaluate such applications.

These effects do, however, suggest games are a special case of environmental influence that is potentially more powerful than most other types of daily activity. If the content of the game is inappropriate, or if used to excess, the influence can be negative. On the other hand, scientists are becoming excited by the potential of gaming as a tool for positive influence, with possible applications in education, and for the enhancement and protection of cognitive function

Recommendations

What needs to happen next? How can we help users, including children and parents, make decisions about technology that support health, learning and development? Where is research most urgently needed?

Parents and their children would benefit from clearer independent information about where a significant body of research indicates the potential risk of a particular type of technology application. In order to allay fears and diminish distraction from the more significant risks, parents would also benefit from knowing where evidence does not exist to support concerns headlined in the popular press.

Academic achievement and student wellbeing would also benefit from schools having access to a brief curriculum and teaching material aimed at delivering skills for the 'hygienic' use of internet and digital technology. These resources would help schools equip their students with the knowledge and understanding required to guide their own use of technology.

The ability to understand risk: that is, an appreciation of the likelihood and consequence of a possible outcome, is also something that requires further consideration. This review highlights levels of risk associated with the use of digital technology that are different to those portrayed in the popular press. Therefore, a further recommendation is to support parents, in particular, in their attempts to assess and act upon such risks. This requires support from the wider research community as well as the development of resources that present current research data in an accessible way.

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In terms of the relationship between digital technology and the brain, more research is needed:

- to further understand how the internet is currently used for informal and formal learning by all age groups, and it how might best be used in the future
- to develop and evaluate approaches to technology-related abuse whose focus extends beyond the technology itself
- to understand more about how using technology can influence sleep
- to determine the longer-term effects of excessive use of computers/internet access/ gaming
- to further develop effective online therapeutic and health applications
- to determine the processes by which gaming influences cognitive function and synaptic plasticity in the brain, and how this knowledge can be applied for educational and health benefits
- to continue to monitor and further evaluate the risks and opportunities for healthy development presented by new technologies and applications as they become available.

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About the brain

Neurons

The adult brain contains about 100 billion brain cells – or **neurons**. Each neuron, such as shown in Figure 1.1, consists of a **cell body**, from which are connected **dendrites** and an **axon**.

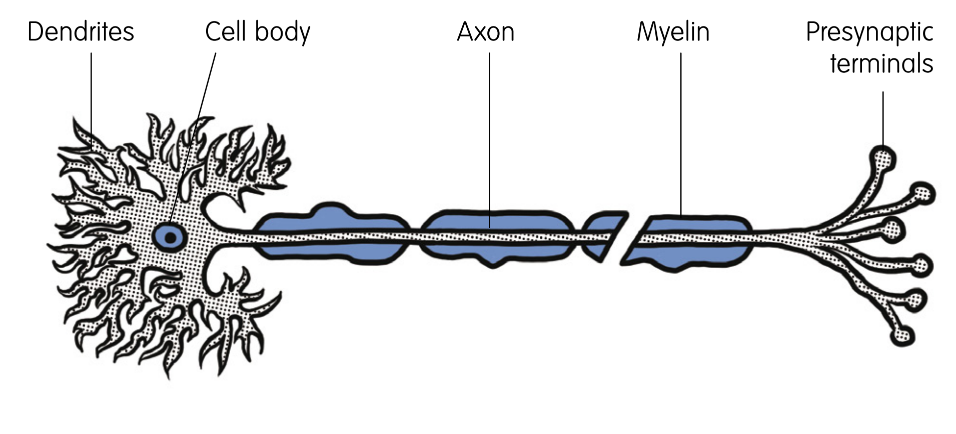

Fig 1.1 Each neuron in the brain consists of cell body, from which are connected dendrites and an axon. The axon ends in presynaptic terminals that form connections (synapses) with the dendrites of other neurons (see Figure 1.2).

The **presynaptic terminals** at the end of the axon make contact with the dendrites of other neurons and allow connections, or **synapses**, to form between neurons. In this way, complex neural networks can be created. A simple network is shown in Figure 1.2.

Neurons

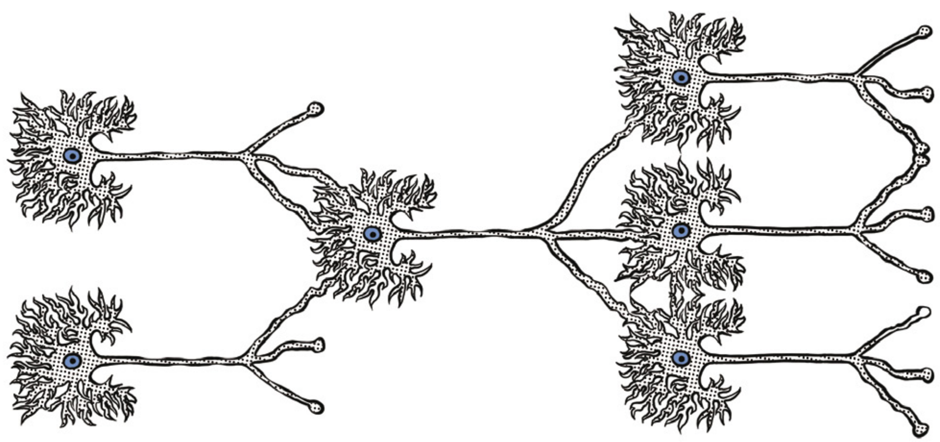

Fig 1.2 Neurons connect together to form networks.

Within such networks, signals can flow down the axons of one neuron and cross the synapse to other neurons, allowing neurons to communicate with each other. The signal passing down the axon is electric, and its progress is hastened by insulation around the axon known as **myelin**. However, the process that allows the signal to pass through from the synaptic terminals to the dendrites of the next neuron is chemical. This process involves transmission across the synaptic gap of special substances known as **neurotransmitters** (eg dopamine).

Forebrain, midbrain and hindbrain

Our brains, like those of other vertebrates, consist of the three main parts (**forebrain**, **midbrain** and **hindbrain**) shown in Figure 1.3. The hindbrain includes structures regulating bodily functions such as sleep and blood flow. It also contains a cauliflower-like structure at the back of the brain called the **cerebellum**, and this is involved in many cognitive processes that require careful timing such as language, music and movement. The midbrain includes structures that relay sensory and movement information. There are also important structures in the midbrain that help us respond to reward. In humans, the forebrain has evolved to be largest part of the human brain and this includes the cortex. The regions most associated with higher-level thought processes exist close to the wrinkly surface of the **cortex**. This part of the brain is often described in terms of two (so-called cortical) hemispheres, left and right, joined together by a mass of fibres known as the **corpus callosum**.

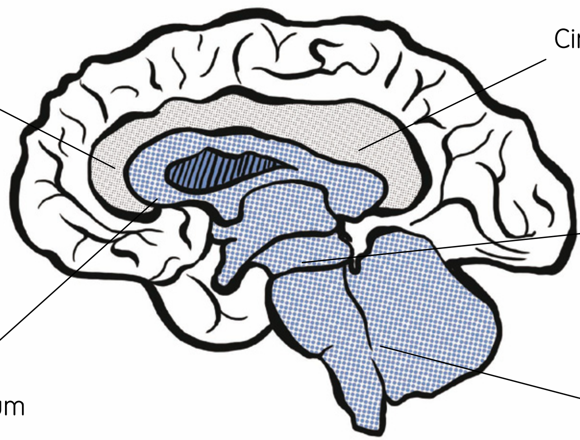

Fig 1.3 Section through the brain showing division into forebrain, midbrain and hindbrain regions. This diagram also shows the position of the corpus callosum which connects hemispheres, and the cingulate cortex.

Our brains, like those of other vertebrates, consist of the three main parts - forebrain, midbrain and hindbrain

The lobes of the brain

The cortex can be further divided into four **lobes**: the **frontal**, **parietal**, **occipital** and **temporal** shown in Figure 1.4. The cortical surface (sometimes referred to as the neocortex) is more wrinkled in humans than any other species, a characteristic thought to reflect our greater reliance upon complex social behaviour. Each type of lobe has been associated with a different set of cognitive functions. The frontal lobes (left and right) may, perhaps, be of particular interest to teachers because, as well as movement, they support many different aspects of reasoning. This is also the home of the dorsolateral prefrontal cortex (DLPFC), which is an important region for working memory – our ability to hold several pieces of information in our attention in the same instant. The temporal lobe has much to do with memory, as well as auditory skills. The parietal lobes are heavily involved in integrating information from different sources, and they include regions linked to some types of mathematical skill. The occipital lobes are critical regions for visual processing. However, no one part of the brain (or hemisphere) is dedicated to, or solely responsible for, any one type of thinking process. The fact that some types of cognitive function, more than others, can be associated with particular regions in the brain is sometimes misinterpreted as implying that the different things we do in a day can be neatly mapped onto different parts of the brain – with a bit for creativity, maths, music etc. Any everyday task recruits a large and broadly distributed set of neural networks that communicate with each other in a complex fashion. So, different brain regions do support different cognitive functions, but 'real world' thinking and actions recruit processes distributed across the brain.

The temporal lobe has much to do with memory, as well as auditory skills

The lobes of the brain

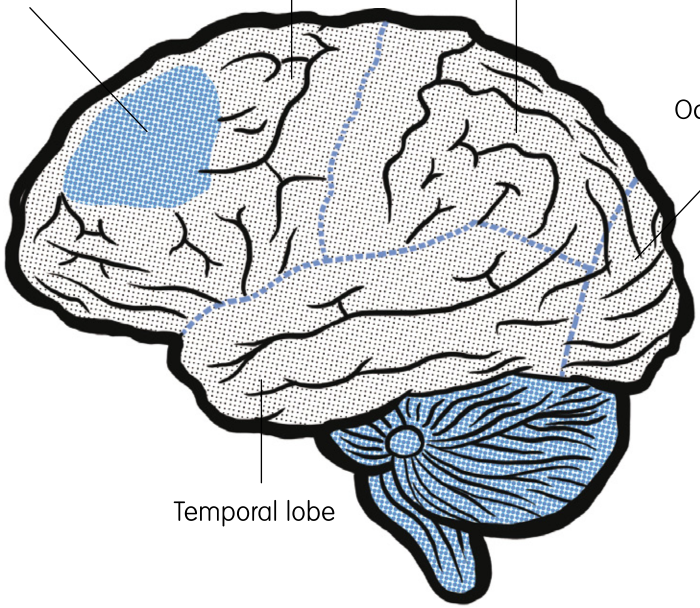

Fig 1.4 Each cortical hemisphere is divided into four lobes. Also indicated is the region referred to as the dorsolateral prefrontal cortex(DLPFC).

The evolutionary pressure to maximise cortical area has resulted in some of our cortex existing well below the outer surface. One notable example of this is the **cingulate cortex** (see Figure 1.3). The **anterior** (or forward) part of the cingulate cortex becomes active when we engage with a wide variety of tasks, and appears to have a significant role in how and where we allocate our attention.

Subcortical structures

Journeying deeper inside each of the temporal lobes, we encounter the **hippocampus** – a part of the brain critical to consolidating new memories, and the **amygdala** which plays an important role in our emotional responses. The closeness of these two structures (each represented twice, ie in both left and right hemispheres) is no coincidence, with the connectivity between them supporting the formation of emotional memories. These also belong to a set of structures collectively called the **mesolimbic** pathway, which is of particular interest in understanding our response to reward, and that can influence our attention and learning. This is one of the dopaminergic pathways in the brain, involving movement of the neurotransmitter dopamine from one region to another. In the mesolimbic system, dopamine flows from the midbrain region to parts of the frontal cortex, the hippocampus, amygdala and also into a region called the **ventral striatum** (ventral meaning lower) to a small pea-sized dense collection of neurons called the **nucleus accumbens** (again, one in the left and one in the right hemisphere). Dopamine activity in the nucleus accumbens appears central to our motivation to approach many different types of reward.

Subcortical structures

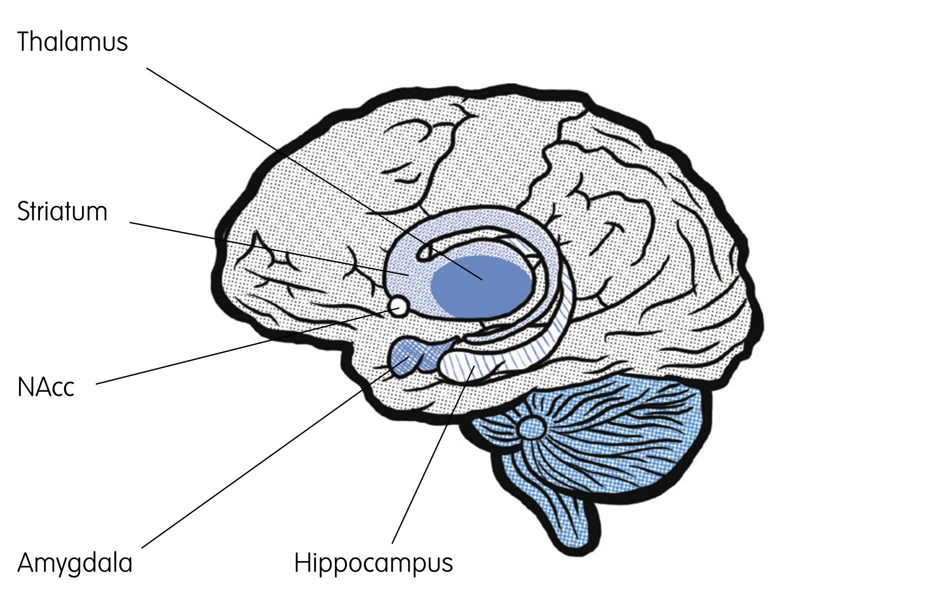

Fig 1.5 Some important sub-cortical (below the cortex) structures include the **thalamus**, and also showing the left hemisphere structures of the hippocampus, amygdala and nucleus accumbens (or NAcc, in the ventral striatum).

A particular memory is distributed throughout the brain and does not reside in any one place

Learning in the brain

Whether we need to learn a simple fact or gain a deep understanding, memory is important for learning. A particular memory is distributed throughout the brain and does not reside in any one place, although there are some regions linked to particular aspects of memory (such as spatial memory, which depends more on the right hemisphere than left hemisphere). But the fact that memory has to be coded in the brain somewhere appears indisputable. So how does the brain change in order to represent a new memory? Neuroscientists generally believe that human learning, as in the formation of memory, occurs by changes in the patterns of connectivity between neurons – or 'synaptic plasticity'.

Glossary

Attention Deficit Hyperactivity Disorder (ADHD) – a developmental disorder involving inappropriate impulsivity, difficulties in maintaining attention, and sometimes hyperactivity.

Cognitive Behavioural Therapy (CBT) – a therapy based on talking with individual sufferers of psychological disorders or in group sessions. It aims to change how the patient thinks ('Cognitive') and what they do ('Behaviour'). Instead of focusing on the causes of your distress or symptoms in the past, it focuses on the 'here and now'.

Declarative memory – our capacity to recall memories that can discussed, including facts from textbooks and episodic memories of what we have experienced. It does not include procedural memories such as how to ride a bicycle.

Dopamine – a neurotransmitter with different functions in different regions of the brain. In the mesolimbic pathway (an important part of the reward system in the brain – see Appendix 1), it is associated with anticipatory desire (or 'wanting').

Electroencephalography (EEG) – a brain-imaging technique that uses a net of electrodes placed on the scalp to measure minute changes in the electrical field due to neural activity.

Event-Related Potential (ERP) – a stereotyped EEG response that is known to occur in relation to a particular type of event.

Functional Magnetic Resonance Imaging (fMRI) – a brain-imaging technique that measures changes in blood oxygen levels in the brain.

GO/NO-GO task – a task requiring participants to press a button in response to a target stimulus and withhold their response to a non-target stimulus.

Neurotransmitter – a chemical that crosses the synapse (connection) between neurons enabling the transfer of information across it.

Plasticity – the brain's ability to continuously change in response to environmental stimulus.

Synaptogenesis – formation of new synapses (or connections) between neurons.

Synaptic plasticity – the ability of synapses to modify the efficiency by which they communicate information.

Synapse – a connection, or specialised junction, between neurons usually consisting of a small gap across which information is passed by chemical processes.

Working memory – the ability to recall and temporarily maintain information in consciousness.

About Nominet Trust

The Internet offers a phenomenal opportunity to stimulate new forms of collaboration, to mobilise new communities of interest, and to unleash the imagination of millions of users in addressing specific local and global challenges.

At Nominet Trust we are committed to making these opportunities a reality - for as many people as possible.

Nominet Trust is a UK-based social investor that supports Internet-based initiatives that contribute to a trusted, accessible Internet used to improve lives and communities.

Through our on-going research programme we identify specific areas of need and channel funding towards initiatives designed to make a significant difference to people's lives.

Founded in 2008, we have already supported hundreds of pioneering initiatives including; the first online clinical research trial, new approaches to intergenerational learning and online peer mentoring to support those experiencing bullying.

To find out more about our work or how you can apply for funding, please visit:

www.nominettrust.org.uk

Visit Nominet Trust's website

About our work

The Nominet Trust is passionate about the power of the internet to improve lives and communities. As such, we support organisations and projects working to:

Increase access to the Internet; providing people with the motivation, skills and tools to get online in a meaningful and sustained way.

Improve online safety; educating people about the potential risks faced from being online and demonstrating how they can avoid coming to any harm.

Use the web for social good; imaginative applications of the Internet to address specific social problems

If you have a compelling idea for a new initiative that contributes to a safe, accessible internet used to improve lives and communities, then we want to hear from you. Equally, if you would like support for an existing Internet project, then please get in touch.

We are particularly interested in initiatives that develop tools or models that can be replicated or scaled-up to benefit others.

To find out more about how you can apply for funding, visit us at:

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