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Effects of Internet use on the adolescent brain: despite popular claims, experimental evidence remains scarce

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Twenty-five years have passed since the invention of the World Wide Web changed society by allowing unfettered access to the Internet. How this technological revolution has affected brain development continues to be an open question. There is particular concern about how Internet use is affecting the brains of adolescents. This Forum article discusses the possible effects of the Internet, as well as the behaviors and capabilities associated with its use, on the adolescent brain.

Introduction

Throughout history, adults have worried about the effects of new tools and technologies on human development. Socrates warned his students of the dangers associated with writing and Plato immortalized his views by writing them down in the dialogue *Phaedrus* (370 BCE) (Box 1).

Today, teachers voice similar concerns about the effects of Internet use on the cognitive abilities of students growing up with access to the World Wide Web [1]. Of the 2462 American middle- and high-school teachers surveyed by the Pew Research Center, 87% felt that widespread Internet use was creating an 'easily distracted generation with short attention spans' and 88% felt that 'today's students have fundamentally different cognitive skills because of the digital technologies they have grown up with'. Although teachers and other adults who spend their time with children and teenagers possess valuable observational knowledge about generational trends, it is unclear whether current scientific evidence supports these claims. The focus of this Forum article is on how Internet use – a complex construct that encompasses multiple activities such as information gathering, entertainment, and communication through the medium of the World Wide Web – as opposed to other media use, might affect the adolescent brain.

The naturally malleable period of adolescence, which is often defined as beginning around puberty and ending when one obtains a relatively stable role in society, makes this a time of particular concern to adults. Agency and many cognitive skills increase during early adolescence, yet some skills (such as navigating the social world) continue to develop throughout the teen years. Likewise, the human brain undergoes profound changes in both its structure and its function during adolescence [2]. Cellular studies of post-mortem brain tissue have shown high levels of dendritic spines in the prefrontal cortex in late childhood/early adolescence, with the number of spines reducing by almost half through the teenage years and into the third decade [3]. Because experience partially determines what connections are kept and strengthened during this period of development, some adults are concerned that Internet use could be 'rewiring' the brains of individuals growing up online.

Brain susceptibility

Just how much can we expect the adolescent brain to be affected by environmental influences like Internet use? Major brain changes, akin to what is suggested by the phrase 'rewiring the brain' are unlikely. Recent longitudinal brain-imaging studies have shown that major changes in brain structure and function might be largely related to genetic and behavioral differences between individuals. Changes in brain structure, as measured by MRI, appear to be under strong genetic control during the transition between late childhood and early adolescence [4]. Changes in the recruitment of the ventral striatum when receiving a reward across adolescence are predominantly related to individual differences in self-reported fun seeking [5]. These studies suggest that environmental influences, like Internet use, would have little effect on neural measures at this level. Well-established sensitive periods for sensory processes and language acquisition end well before adolescence, but adolescence might encompass a sensitive period for sociocultural learning [2]. If so, this would mean that adolescence is a time when we are honing our skills for navigating complex social interactions and that a lack of opportunities to engage in this skill-building behavior could impede development. However, current evidence suggests that typical Internet activities do not impair social development during adolescence.

Internet use and adolescent health

Both adolescents and adults are now using the Internet more than ever. Evidence increasingly suggests that time spent online does not displace time spent doing other activities associated with health and well-being. Indeed, a recent longitudinal study of 14–24-year-olds ($n = 719$) found a positive relationship between moderate Internet use and participation in 'real-world' activities such as sports and clubs [6]. Because the Internet can be used through various media such as mobile phones or computers Internet use sometimes falls under the category of 'screen-based sedentary behavior'. Although it is unclear how time spent specifically using the Internet relates to physical

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Box 1. A quote from Plato's dialogue *Phaedrus*, in which Socrates discusses his concerns about writing.

'For this invention will produce forgetfulness in the minds of those who learn to use it, because they will not practice their memory. Their trust in writing, produced by external characters which are no part of themselves, will discourage the use of their own memory within them.' Socrates

activity, a longitudinal study of 11–13-year-olds (n = 908) suggests that engaging in screen-based sedentary behaviors such as computer use is not associated with less engagement in leisure-time physical activities [7]. Regarding social well-being, a review of the literature in 2009 supported the idea that communicating with friends through the Internet can increase adolescents' social connectedness [8]. These and other studies emphasize the need to distinguish between the effects of different Internet activities (e.g., information gathering, communication) as well as specific aspects of Internet use that may be shared with other forms of media (e.g., screen time).

Internet use and cognition

At this time we cannot be sure whether Internet use is creating a generation with 'fundamentally different cognitive skills', although recent studies have begun to test the potential effects of widespread Internet use on the cognitive abilities of young adults. In 2011, Sparrow and colleagues tested how the expectation of having access to information at a later time affected the memory of undergraduate students [9]. When expected to have future access to information, students were less likely to remember specific information but were more likely to remember where to find the specific information [9]. A recent study tested how being part of highly connected networks (like the Internet) affected the propagation of correct information, as well as the underlying cognitive strategies needed to generate correct information, in a group of university students [10]. The results of the study suggest that being part of highly connected networks can help individuals solve problems by facilitating the propagation of correct information, but that these networks do not propagate the cognitive strategies needed to obtain correct information on one's own [10]. These cleverly designed experiments suggest that the effects of Internet use on cognition are likely nuanced, but could strengthen specific cognitive strategies in young adults.

Internet addiction

Although there are neuroimaging studies that have investigated the effects of Internet use on the adolescent brain, these studies have focused on adolescents classified as excessive Internet users (see [11] for a review). The results of these studies are unlikely to apply to the majority (an estimated 95.6%; see [12]) of adolescents that do not qualify as excessive Internet users. What is not present in the current literature are studies that correlate brain measurements – along with behavior, cognition, and well-being – with engagement in different Internet activities. This might not initially seem like a feasible method of experimentation, given the ever-increasing presence of the Internet in our lives. However, we can begin to address this question by utilizing methods adopted in studies on the effects of other environmental influences (e.g., musical training) and by deconstructing Internet use into measurable components.

Learning from musical-training studies

Like the few studies looking at the effects of Internet use on brain measures during adolescence, some studies of musical training compare the brains of the extreme end of the population (professional musicians) with the brains of nonmusicians. However, some of these studies have adopted methods to measure how musical training in nonprofessionals relates to brain measures, behavior, and cognition in both developing populations and adults [13,14]. These studies have largely adopted such methods to investigate whether there are particular developmental windows when musical training results in greater or fundamentally different effects. By collecting self-reported measures of the age at which participants began their musical training, as well as the duration and intensity of musical training, these studies are able to distinguish between training and maturational effects [13,14]. It might be possible to adopt similar methods in future investigations of Internet use and its subcomponents. This could help clarify if aspects of Internet use during adolescence impact brain measures, behavior, and cognition in a fundamentally different way from Internet use in adulthood.

Concluding remarks

In the 25 years since the World Wide Web was invented, our way of interacting with each other and our collective history has changed. Successfully navigating this new world is likely to require new skills, which will be reflected in our neural architecture on some level. However, there is currently no evidence to suggest that Internet use has or has not had a profound effect on brain development. If we want to know how this highly connected world is impacting our brains, we will need to conduct studies that investigate brain measures and their relationship to behavior, cognition, and well-being in a representative sample of the population. These studies can draw from techniques adopted in studies of other environmental influences, such as musical training, and should differentiate between different Internet activities. Creative experimental designs have begun testing how certain aspects of Internet use can affect cognitive abilities, but many of these studies have been conducted only in adult samples. Finally, even if Internet use is impacting the developing brain during adolescence, we must not forget that the brains of adults remain capable of functional change. Indeed, Internet-based training programs are being developed to capitalize on just that [15].

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The source of consciousness

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Why does a relentless stream of experiences normally fill your mind? No answer is entirely satisfactory. We are not sure how the normal operation of the human brain might exude subjective experiences. Consciousness can thus seem miraculous, and research on consciousness a waste of time and money, ultimately doomed to fail. Yet, there are good reasons for optimism that should be shared with the public to justify research in this area.

Inherently beyond science?

The opinion that conscious experiences lie outside the realm of scientific inquiry regularly appears in the press (e.g., [1]). If the origins of consciousness are supernatural or otherwise beyond human understanding, there is no hope of addressing the question scientifically. Moreover, we are hampered by a lack of objective measures to index consciousness. Yet this is precisely what scientists are now striving to identify using various measures of information exchange in the brain [2,3]. Further research will be needed to validate these new measures, but they potentially represent a step toward testing specific hypotheses about consciousness and thus making it less mysterious.

Importantly, the conviction that consciousness is ineffable may reflect assumptions people commonly make about consciousness based on their own introspections. If these assumptions are incorrect, the reasoning used to take consciousness research off the table may be faulty. Here, we point out some flaws in common intuitions about consciousness. In light of these flaws, we also highlight a broad range of promising directions for research on consciousness and strongly advocate against the position that this fundamental facet of the human mind will forever be beyond human understanding.

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Crucial ingredients for awareness

You may think that if you attentively inspect something you must be aware of it. Not true. A short time experiencing motion-induced blindness is convincing (see Movie S1 in the online version at http://dx.doi.org/10.1016/j.tics.2014.05.012); bright discs completely vanish, even when full attention is allocated to the stimuli.

You may think that sensing, analyzing, and deciding necessitate consciousness. Not necessarily. You can have no awareness of a briefly flashed number but still accurately assess its value, perform a mathematical operation, and produce an appropriate answer [4].

If neither strong sensory stimulation, nor paying attention, nor deeply analyzing guarantees awareness, what is the crucial ingredient? One answer is that awareness depends on a reciprocal exchange of information across multiple areas in the cerebral cortex [5]. Consider how damage to the primary visual cortex usually blocks visual awareness, producing blindness. Yet, a patient might correctly discriminate moving objects and not consciously see them, demonstrating 'blindsight'. In these cases, visual discrimination without awareness presumably reflects restricted cortical processing without the reverberating exchange of information [6]. In a healthy individual, the sensation of movement can be experienced when cortical motion area V5 is artificially activated with a dynamic magnetic field, but not if communication from V5 to primary visual cortex is disrupted [7]. For motion perception, then, and perhaps for other conscious experiences, exchange of information between specific cortical areas seems to be essential.