Transcultural Psychiatry 50(2) 192–215
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DOI: 10.1177/1363461512474623 tps.sagepub.com
SAGE

transcultural psychiatry

Article

Digital media, the developing brain and the interpretive plasticity of neuroplasticity

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Abstract
The use and misuse of digital technologies among adolescents has been the focus of fiery debates among parents, educators, policy-makers and in the media. Recently, these debates have become shaped by emerging data from cognitive neuroscience on the development of the adolescent brain and cognition. "Neuroplasticity" has functioned as a powerful metaphor in arguments both for and against the pervasiveness of digital media cultures that increasingly characterize teenage life. In this paper, we propose that the debates concerning adolescents are the meeting point of two major social anxieties both of which are characterized by the threat of "abnormal" (social) behaviour: existing moral panics about adolescent behaviour in general and the growing alarm about intense, addictive, and widespread media consumption in modern societies. Neuroscience supports these fears but the same kinds of evidence are used to challenge these fears and reframe them in positive terms. Here, we analyze discourses about digital media, the Internet, and the adolescent brain in the scientific and lay literature. We argue that while the evidential basis is thin and ambiguous, it has immense social influence. We conclude by suggesting how we might move beyond the poles of neuro-alarmism and neuro-enthusiasm. By analyzing the neurological adolescent in the digital age as a socially extended mind, firstly, in the sense that adolescent cognition is distributed across the brain, body, and digital media tools and secondly, by viewing adolescent cognition as enabled and transformed by the institution of neuroscience, we aim to displace the normative terms of current debates.

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Keywords
adolescence, brain development, cognitive neuroscience, extended mind, Internet, plasticity

Baroness Susan Greenfield, a prominent UK neuroscientist and public intellectual, recently warned the public against the dangers of Internet and digital technology for children and teenagers, cautioning us about the "unprecedented changes" brought about by young people's interaction with digital technology and urging us to recognize that the issue is "almost as important as climate change" ("Baroness Susan Greenfield," 2010). Major national newspapers reported on Greenfield's "chilling warning" (Derbyshire, 2009) in which she advised that "society should wake up to the harmful effects of the Internet" ("Baroness Susan Greenfield," 2010), as "technologies are infantilising the brain into the state of small children who are attracted by buzzing noises and bright lights, who have a small attention span and who live for the moment" (Derbyshire, 2009).

Her argument, articulated in terms of the developing brain, swept across newspapers, scientific magazines, and blogs, and contributed to a growing debate about the effects of the Internet on the brain. This debate is characterized by questions such as whether we—in digitalized societies—are permanently altering our minds, cultivating certain cognitive capacities at the expense of important others because of our dependence on digital media (Carr, 2010). Underlying this idea is the now popularized "use-it-or-lose-it" phenomenon of neuroplasticity, demonstrated best in neuroimaging studies of taxi drivers, pianists, and jugglers which show that processes of learning and memory can stimulate the growth of new neurons and stabilize synaptic connections in areas of the brain frequently used ("use it") while eliminating connections that are rarely used ("lose it"; Maguire et al., 2000; Pantev et al., 1998; Pascual-Leone et al., 1995).

Of major concern in these debates is whether young people in particular are becoming unempathic, passive, intellectually shallow and uncritical, desensitized, depressed, and attention deficient because of cyber technology (Derbyshire, 2009; Small & Vorgan, 2008). From a historical perspective, anxieties such as these are nothing new, as emergent media technologies have long generated collective fears (Carr, 2010; Kittler, 1999; McLuhan 1962; Pinker, 2010; Shirky, 2010; Starker, 1990). A rich body of work in communication, media, history, and literature studies traces media anxiety as far back as 2,500 years ago when Socrates contested the institutionalization of writing, about which he argued that written "words…can never speak for themselves nor teach the truth adequately to others" (Plato, 2008). The pursuit of wisdom, for Socrates, was not through reading and writing but through real time and space dialogue (Carr, 2010). In the 18th century, the novel was perceived as a cause of female depravity and literacy was considered threatening to women's safety and moral purity, while both women and young people were considered vulnerable to the corrupting influences of the "vivid details and heightened emotional scenes" in realistic novels, and the possibility that "[f]antasy and even madness would replace rationality and conscience" (Starker, 1990, p. 44). Kittler's classic *Gramophone, Film, Typewriter* (1999) identified a radical shift with the invention of those respective technologies in regard to signification, referentiality, and human historical agency. Marshall McLuhan's influential *The Gutenberg Galaxy* (1962) traced the social and cognitive impacts of mass print media. Common to these studies is an underlying concern about how different media technologies remake human consciousness, perception, and cognition—reorganizing sociality, raising questions about what is at stake in our moral worlds, and reframing the ontology of the human. Thus our contemporary fears about digital technologies can be understood as part of a larger historical pattern of technologically related anxiety.

Given the lessons of history, we could at the very least be reassured that our minds have managed to continually adapt to new media technologies and that "civilization" has not crumbled in their wake, or, as some would suggest we could take it a step further and embrace the digital awesomeness that allows us new and unprecedented opportunities for social connection, political mobilization, and the production and dissemination of information (Papathanassopolous, 2011; Shirky, 2010). From this view, digital technologies are enhancing cognitive capacities such as multitasking, enabling us to live successfully in the accelerated space–time compression of our postmodern world. In fact, some have claimed that younger generations growing up with digital technologies are developing the skills to parallel-process and encode information quickly enough to be at a distinct advantage to adapt to the high-tech revolution (Small & Vorgan, 2008). Moreover, they argue that our institutions, particularly educational ones, should articulate themselves with the digital revolution rather than oppose it and undergo significant reforms to meet changing brains and social, political, and economic realities (Davidson, 2011).

Much of the discourse on digital media addresses the potential societal changes wrought by digital technology. The claim that the brain is changing in response to digital media, however, can be understood at many levels. Because of neuroplasticity, we can say that the brain and nervous system are constantly changing in response to environmental stimuli as well as the brain's own activity. Such changes, for example, cellular changes in response to a stimulus or a learning process, are normal functions of a healthy brain. More remarkable are the kinds of changes seen in cortical remapping after intensive training in an activity or after brain injury in some cases, when a region in the brain acquires a new function or specialization. The claim that digital technology is leading to societal transformations through cerebral changes evokes a much deeper collective emotional response, not only because of the association of the biological to the "real" and "indelible." The idea that the use of digital media may be leading to evolutionary adaptations of the human brain more broadly deserves serious debate. However, to date these debates—the fears, enthusiasm, and subsequent recommendations—are shaped by small-scale cognitive neuroscience studies.

In this paper, then, we are less concerned with whether we really are being wired for distraction, superficiality, and unsociability (although certainly some of these fears may indeed be well founded), and more with whether existing neuroscientific evidence derived largely from neuroimaging studies can indeed resolve these questions as the media suggests. We are interested in how brain-based arguments rhetorically function in these debates, particularly when cerebral language and neuro-discourses increasingly assume a privileged explanatory status in explaining and intervening in human behaviour. With anxieties about digital media centering on adolescents, who are the heaviest users and often the first adopters of these media, we hope our analysis will provide needed critical perspective that can clarify, if not shift, the terms of the debate.

We will propose here that the debates concerning adolescents are the meeting point of two major social anxieties, both of which are characterized by the threat of ‘‘abnormal’’ (social) behaviour: existing moral panic about adolescent behaviour in general (Sullivan & Miller, 1999) and growing alarm about intense, addictive, and widespread media consumption in modern societies (Carr, 2010). Neuroscience weighs in and supports these fears but notably, the same kinds of evidence it produces are used to challenge these fears and reframe them in positive terms. In this discussion, we will analyze discourses about digital media, the Internet and the adolescent brain in the scientific and lay literature, and describe the role of neuroscience in paradoxically substantiating and alleviating the anxieties about the shallow, frenzied, distracted, and antisocial futures of compulsive teenage media users. Our aim is not to furnish a comprehensive review of cognitive neuroscience studies in this area, but to identify some of the key claims of cognitive neuroscience and to argue that the evidential basis for these claims is often thin and/or ambiguous. Despite their limitations, these preliminary neuroscientific claims are immensely influential in the popular press and currently underpinning policy-making in the UK and other places. Our task is to consider whether the existing data in neuroscience that we surveyed are robust and nuanced enough at this point to warrant the explanatory authority that media, medicine, and policy makers confer to them. We conclude by suggesting how we might move beyond the poles of neuro-alarmism and neuro-enthusiasm. By analyzing the neurological adolescent in the digital age as a socially extended mind, firstly, in the sense that adolescent cognition is distributed across the brain, body, and digital media tools (Clark & Chalmers, 1998) and secondly, by viewing adolescent cognition as enabled and transformed by the institution of neuroscience (Gallagher & Crisafi, 2009), we aim to reshape the contours of current discussions.

Neurocultures, plasticity, and the cyber-brain

New forms of neuroscientific expertise providing advice on how to conduct one’s life have begun to pervade almost all domains of everyday social life in Europe and North America. Reaching beyond medicine and policy, neuroimaging evidence constitutes the backbone of a new genre of self-help guides, educational technologies, advertising campaigns, and parenting manuals. This growing neurological reflexivity (Rowson, 2010)—that is, the ways in which we are constructing and using information about the activities of the brain to condition and reshape it—hinges on notions of neuroplasticity. Today, policy makers are using neuroscientific knowledge to guide the development of social interventions in the name of public health and enhancement of "mental capital" (Beddington et al., 2008; Fricke & Choudhury, 2011), and neuroscientists, through public engagement activities, are distributing forms of "expertise" through which lay people can develop self-mastery and sort out the good from the bad, the healthy from the unhealthy. On the one hand, neuroplasticity suggests that there is a certain degree of brain malleability and reversibility over the lifespan, which resonates with the optimistic notion that it is never too late to train the mind, whether through meditation, musical practice, psychotherapy, reading, or crossword puzzles. This positive "training the mind" dimension of neuroplasticity more often than not is used to discuss the potentials of adults, not children and teenagers. On the other hand, the clinical and academic literature on neuroplasticity suggests that during certain developmental periods, such as adolescence, the brain is especially susceptible and vulnerable to environmental input and to the formation of irreversible pathways and networks. Importantly, as we will show, this second aspect of neuroplasticity tends to characterize discourses about children and adolescents. Not only does this second dimension of neuroplasticity produce contradictions with the first, but it also foments fears and anxieties that underpin decisions, desires, and interventions.

With statistics indicating that adult Americans spend an average of 33 hours[1] a week surfing the Internet, text messaging, sifting through emails, tweeting and social networking, questions about the way in which mental abilities are shaped through these activities have become a new imperative for neuroscience. Increasingly, neuroscience is called upon to answer questions about how Internet cultures are shaping our minds: How are reading skills, memory, sociality, attention and focus being transformed? Is Google making us stupider? (Carr, 2010). Does the replacement of reading novels with Internet consumption contribute to an increasing lack of empathy in society? (Zaki, 2011). What kinds of minds are being produced by the "cacophony of stimuli" and the demands to shift attention, skim-read, and make decisions at the click of a mouse?

In his book *The Shallows*, Nicholas Carr laments the rise of "pancake people," those who think widely but superficially and skim-read headlines, at the expense of "cathedral-like" people, that is, classics-reading literary types able to think with rigour and depth (Carr, 2010). In asserting that excessive Internet and media immersion is dangerous, Carr explains the risks in terms of adult neuroplasticity, the dynamic state of the brain through which its cellular connections are altered in interaction with environmental stimuli. Carr and others (cf. "Baroness Susan Greenfield," 2010; Small & Vorgan, 2008) have promoted the idea that "the Internet is altering our brains," using neurological phenomena to legitimize health warnings about digital media. These authors allude to studies suggestive of the negative effects of habitual digital technology use on adult brains, including fatigue, impaired learning, and performance. Assertions that media multitasking rewires the brain are built on behavioural studies as well as much widely popularized anecdotal evidence. For example, a study at the University of Michigan found that research subjects learned better after taking a walk in a natural environment rather than after walking in a busy and crowded urban setting (Richtel, 2010). The researchers concluded that this was because the urban context's intense delivery of stimulation fatigued the mind and therefore impaired learning. Researchers have made an analogy between the busy urban environment and the experience of multitasking to suggest that multitasking and the constant bombardment of digital stimuli tires the brain and prevents periods of rest or "downtime" necessary for processing and consolidating long-term memory and learning. Other studies suggest that with rapid multitasking, errors increase across the tasks performed, and that the time it takes to do those tasks increases dramatically (Anderson, 2009).

However, with the exception of some positron emission tomography (PET) experiments (e.g., Meyer et al., 1998) that examine prefrontal cortical activity with task switching, the majority of this research is behavioural, and not brain-based, and involves measuring performance in, for example, math tasks from which researchers extrapolate to comment on multitasking across digital media (American Psychological Association [APA], 2001). Similarly, heavy media multitaskers have been shown to have reduced ability to filter out irrelevant information and to manifest "breadth-biased" rather than selective and focused cognitive control (Ophir, Nassb'l, & Wagner, 2009). Research also points to the neurotransmitter dopamine, frequently associated with reward-driven behaviours, as the culprit in compulsive digital media use. These studies have shown, using PET, that dopamine release correlates with video game play and is abnormally reduced among "computer game addicts" suggesting that they are dependent on the stimuli to elevate their dopamine levels to normal states (Koepp et al., 1998; Weinstein, 2010). The cravings we feel for our digital devices, the pleasure and euphoria we experience and the "withdrawal" we encounter when denied our fix, are attributed to the powerful hook of dopamine (Small & Vorgan, 2008). Digital technology is thought to lend itself to dopamine-seeking behaviours, not unlike drugs, alcohol, gambling, or shopping, and can affect users to the degree that in one experiment, "nonaddicted" volunteers playing alluring videogames became impervious to multiple attempts to distract them. According to Small, the "dopamine system allows them to tolerate noise and discomfort extremely well" (Small & Vorgan, 2008, p. 49). These claims, however, are based on speculations and only a handful of empirical studies which, themselves, draw ambiguous, indirect conclusions, more often than not neglecting to study brain activity, cognitive control, and media use all in the same studies[2] (we return to this below).

While media multitasking is reported to drive "breadth-biased" thinking and the Internet is understood to elicit addictive neurotransmitter responses, considerable emphasis is given to the *benefits* of video games and Internet searching in adulthood as a way to "boost brain power" and drive plasticity. These activities are thought to delay cognitive decline of vision and memory associated with aging by generating new brain cells and reorganizing connections between existing cells (Achtman, Green, & Bavelier, 2008; Mishra, Zinni, Bavelier, & Hillyard, 2011). However, on closer analysis, many of these studies reveal the ambiguities and contradictions in current interpretations of functional neuroplasticity as investigated through neuroimaging techniques. For example, a highly publicized study entitled "Your Brain on Google" compared patterns of cerebral activation during an Internet searching task in a "Net savvy" group and "Net naïve" group, all aged between 55 and 76 years (Small, Moody, Siddarth, & Bookheimer, 2009). The premise of this study is that a relative decrease in intensity or lower extent of activity in a given brain area is indicative of expertise. Given that the savvy group showed increased extent of (rather than the expected decreased) activity, Small and colleagues suggest that Internet searching can alter the brain's responsiveness by engaging certain brain areas to greater degrees. In other words, even experts, the authors claimed, can "rewire their brains," reflected by the increase in spatial extent of brain activity during Internet searching compared with text reading. In this study, increased regional brain activity in the Net savvy group suggested that Internet searching had brought about plastic brain changes, with the increased extent of activity interpreted as "map expansion," that is, the functional enlargement of an area devoted to a particular cognitive operation. Alternatively, however, the changes can be interpreted as the result of task interference and less specialization (Grafman, 2000). In other words, increased spatial activation of brain regions may reflect both increased *or* decreased specialization of a brain region and ability in a skill.

Importantly, this very lack of integrative models in cognitive neuroscience, pertaining to functional neuroplasticity, allows these data to be used to support a wide range of interpretations and ideological biases. This interpretive openness actually increases neuroscientific authority, uses, and applications rather than challenges it (Slaby, Haueis, & Choudhury, 2011).

Growing up digital: The developing brain in Generation M

The debate about the pros and cons of digital technology is intensified in the case of adolescents. Teenagers—referred to variously in the literature as Generation M, Digital Natives, and "screenagers"—constitute the largest proportion of digital media users, interacting with cell phones, Smartphones, laptops, and gaming devices or the Internet often simultaneously. Studies from the Kaiser Foundation show that American youth, between the ages of 8 and 18, spend on average 7 hours and 38 minutes per day on entertainment media (including Youtube, Facebook, and games, but not cell phones and texting; Lewin, 2010). Scientists concerned with teenage digital media usage fear that immersion in these technologies from early childhood has a particularly powerful impact on the brain because of experience-dependent developmental neuroplasticity that peaks around puberty. It has been hypothesized that this structural plasticity corresponds to a "sensitive period" for cognitive development, since postmortem histological studies together with structural MRI studies suggest that adolescence might be a time during which certain stimuli can dramatically alter cortical inputs and responses (Blakemore & Frith, 2005). The analogy often used in the literature to describe the brain during puberty is that of an overgrown garden bush in need of pruning; such a model represents the brain as especially sensitive to environmental stimuli while at the same time pointing to the need for developmental reshaping or "sculpting" by appropriate experiences.

The neuroscience of "young, plastic minds" (Small & Vorgan, 2008) coupled with statistics on the intense media use by youth have provoked fears that the young brain is being "disturbingly reshaped" (Derbyshire, 2009), and research programs have begun to investigate the hypothesis that habits of Internet use among adolescents may lead to increased aggression and decreased empathy. Capturing the central idea in a recent media interview, neuroscientist Professor Susan Greenfield stated that: "if we were to scan the brains of young people who spend a lot of time playing computer games and in chatrooms, we would find that the prefrontal cortex is damaged, underdeveloped or underactive—just as it is in gamblers, schizophrenics or the obese" (Derbyshire, 2009).

Similarly, neuroscientist Gary Small in his book with Gigi Vorgan starts from the premise that "scientists have pinpointed a specific region of the teenage brain that controls the tendency toward selfishness and a lack of empathy" (Small & Vorgan, 2008, p. 31). This premise, which is in fact a distortion of functional neuroimaging research on social cognitive development that they go on to describe (p. 31), leads Small and Vorgan to claim that Internet use exacerbates existing "natural" social cognitive deficits and proneness for instant gratification and risk-orientation in adolescents "impairing social and reasoning abilities" by "stunting development of the prefrontal cortex" (Small & Vorgan, 2008, p. 32). Small goes on to hypothesize that adolescents "could remain locked into a neural circuitry that stays at an immature and self-absorbed emotional level, right through adulthood" (p. 32).

Although suggestions that online gaming, social networking, and online gambling correlate with aggressive behaviours (Ko et al., 2009) remain contested (Ferguson, 2010), links between "Internet addiction" and the onset of aggressive behaviour are increasingly investigated. Teenagers are increasingly referred to as a "multitasking generation," able to manage multiple online tasks simultaneously with apparent ease (Wallis, 2006). However, the costs of developing these "hyperkinetic teenage minds" through chronic use of digital media are a serious concern; some psychologists fear that habitual multitasking can lead to symptoms of attention deficit hyperactivity disorder (ADD; Carroll, 2011).

Debates about the effect of the Internet on the brain are part of a history of hopes and anxieties about external influences on the young, developing brain. Drawing on early experiments with rats, psychologists and neuroscientists have become involved in research on the impact of "enriched environments" on the brain (Greenough, Black, & Wallace, 1987) as well as the effects of emotional and sensory deprivation on educational attainment and cognitive development (O'Connor, Bredenkamp, & Rutter, 1999). Policy makers have looked for evidence from neuroscience to develop guidelines on the importance of play in early childhood education, best practices for teaching languages and mathematics (Beck, 1996), and appropriate levels of exposure to television and other visual media (Courage & Setliff, 2009). This information is passed on to educators and parents, who are seen as architects of the developing brain whose decisions about external stimuli and types of environment influence neurodevelopment during critical periods of child and adolescent development. Since the stakes of scientific evidence in this arena are so high, and the implications far-reaching, close scrutiny of the data and interpretations is crucial. In the past, oversimplification of the concept of critical and sensitive periods has led to misconceptions about cognitive interventions in the first 3 years of life, which, despite scientists' attempts to clarify, have remained entrenched in debates about the role of visual and auditory stimulation in learning during early life. These earlier debates have demonstrated the ways in which "state-of-the-art" scientific evidence, political agendas, and social anxieties can converge to produce brain-based myths that go beyond the data on which they draw (Bruer, 1999).

To our knowledge, most of these studies cited in current debates about the Internet and the brain do not directly investigate relationships between digital media, the developing brain, and cognitive processing. Rather, they examine behavioural data on multitasking during development, and use the construct of the developing adolescent brain rhetorically to lend weight to their speculations. We take a closer look at the experimental studies that do investigate the impact of digital media on the teen brain, and show that their findings leave open the possibility for multiple interpretations. In the next section, we will show that the interpretations are complicated by the fact that the teenage brain is understood to be already in a state of pronounced developmental plasticity. As such, the role of neuroscience in making normative claims about the Internet and teenagers is especially ambivalent: If the Internet is changing the adolescent brain, what is it changing *from* and *to*?

Development of the "teen brain": Vulnerabilities, opportunities and ambiguities

In 2010, the journal *Science* published a compelling and high-profile study in which the authors reported a new "brain age index," calculated using neuroimaging data from a large pool of subjects in the USA, aged between 7 and 30 (Dosenbach et al., 2010). Analogous to a height or weight chart, the authors claim that the brain age curve they constructed from data gained from a 5-minute scan of individuals at rest, holds the clinical potential to differentiate normal from abnormal development. They argue that these brief scans could capture information about the extent of connectivity in neural circuits in the brain, which could be used to determine where a child or adolescent falls on the normal trajectory of brain development and to predict his/her cognitive maturity. Those who fall off the normal curve can be identified as "at risk" (Dosenbach et al., 2010). The brain-age curve is especially powerful in capturing the promise of adolescent brain research, and in conveying the notion of a "normal" neurodevelopmental trajectory. However, data generated from task-based rather than at-rest studies demonstrate considerable heterogeneity in the findings of patterns of brain activity over developmental time.

Certainly, neuroimaging experiments beginning in the 1990s that first showed ongoing brain development beyond childhood have, according to many neuroscientists, revolutionized biological models of child development (Dahl, 2004). That the prefrontal cortex is implicated in the most dramatic change during adolescence is of major significance. The prefrontal cortex is associated with capacities for behavioural control including decision-making, working memory and multi-tasking, and also with social cognitive skills including empathy, perspective-taking, and emotional recognition—the very capacities at stake in the debates about the impact of the Internet on the growing brain. This ongoing developmental period is frequently referred to as a period of "vulnerabilities and opportunities" (Dahl, 2004). Adolescent neuroplasticity is thought to be both a source of risk (for onset of mental illness as well as problem behaviours in the healthy population) and at the same time a resource that can be tapped to harness the brain's potentiality through various behavioural interventions.

In light of the recent expansion of this field and the availability of a large number of datasets, a handful of groups have recently attempted to integrate the data into models of adolescent neurodevelopment (see Burnett, Sebastian, Cohen-Kadosh, & Blakemore, 2011). These characterize adolescent neuroplasticity and its relationship to cognitive development in two ways: (a) the imbalance between the affective/motivational system and the cognitive/regulatory system (Ernst & Fudge, 2009); and (b) the increasing functional specialization of brain areas involved in social cognition, executive function, and emotional processing (Johnson, 2010). The developmental lag between the systems associated with cognitive control and affect are hypothesized by some neuroscientists to dispose teenagers to risky behaviour (Cohen et al., 2010), including "experimentation with novel but risky behaviours such as use of alcohol, tobacco and other drugs" (Romer, Duckworth, Sznitman, & Park, 2010, p. 319), as well as the high incidences of violence, unintended pregnancy, and sexually transmitted diseases (Casey, Getz, & Galvan, 2008). The redistribution of dopaminergic receptors in prefrontal and paralimbic areas accompanying these developmental changes are thought to relate to increased sensation seeking (Ernst & Spear, 2009).

Most other studies investigate maturational changes in mechanisms for cognitive control and social understanding, comparing functional activity and task performance between adolescents and adults. These experiments suggest that the development of social emotional processing (Burnett, Bird, Moll, Frith, & Blakemore, 2008), regulation of emotions (Hare et al., 2008), and the understanding of intentions (Blakemore, den Ouden, Choudhury, & Frith, 2007) all undergo development during adolescence in synchrony with the "remodeling" of the teenage brain. The results show differential neural activation patterns in the brain, with adolescents either activating areas implicated in social cognition to higher degrees than adults or recruiting different subsets of neural regions to adults when performing the same task. The results have been interpreted as reflecting possible changes in ''neural strategies'' with age as well as functional specialization over development. However, the brain activation pattern that correlates with age-related specialization remains unclear.

The term *executive function* is used to describe the capacities that allow us to control and coordinate our thoughts and behaviour (Luria, 1966). Executive functions have a role in cognitive control, for example filtering out unimportant information, holding in mind a plan to carry out in the future, and inhibiting impulses. Difficulties in the interpretation of neuroimaging results are found in studies of executive function. Tasks administered to children, adolescents, and adults in the fMRI scanner have demonstrated age-dependent activation patterns (Casey, Jones, & Hare, 2008; Tamm, Menon, & Reiss, 2002). In some of these studies, adolescents were shown to activate the frontal cortex to a greater degree than adults. One interpretation of the decrease in the extent of activity with age has been that extensive and diffuse activation in the brains of children and adolescence is a compensatory strategy used when the brain is less efficient at integrating executive functions. However, other studies investigating similar executive functions (e.g., Adleman et al., 2002; Kwon, Reiss, & Menon, 2002; Rubia et al., 2001), as well as emotion-processing tasks (Monk et al., 2003) and face recognition (Golarai et al., 2007; Scherf, Behrmann, Humphreys, & Luna, 2007), have demonstrated age-related increases in activity in corresponding prefrontal, limbic, and fusiform regions. Changes in activation patterns (which are taken as a proxy for brain maturation) during periods of development thus need to be interpreted with caution. The inconsistencies in the group comparisons reported in the literature remind us that neuroplasticity renders the brain capable of compensatory strategies depending on an individual's developmental history.

There is a growing body of research that indicates *functional change* with age, reflecting forms of developmental neuroplasticity. However, despite the allure of the brain-age curve, uncertainties remain about how to interpret changes during normal brain development (e.g., is fine-tuning associated with increase or decrease in activity of a brain network with age?) and the microstructural properties underlying such changes (e.g., are functional and structural changes with age attributable to changes in synaptic density, intracortical myelination, or glial cell development?; Burnett et al., 2011).

Given these complexities, making sense of the data from studies of brain activity during Internet use or video gaming becomes all the more open to multiple interpretations. One study frequently cited to support anxieties about teenagers and the Internet used functional MRI to investigate brain activity during violent video game playing in a group of older adolescents (Mathiak & Weber, 2006). The results demonstrated suppressed activation of the amygdala during violent frames compared to nonviolent frames. The authors speculate that the reduced activity of the amygdala may be linked to increased aggression in later life. They suggest that reduction of limbic activation may correlate with avoidance of fear or empathy responses, which would confer greater precision during violent game playing. Training the brain this way over time could lead to the development of aggressive problem-solving scripts. However, this study did not examine any causal or even correlational links to aggressive behaviour.

Another frequently cited study used near infrared spectroscopy to compare changes in cerebral blood flow in children (mean age 8) and adults (mean age 23) while participants played on a Game Boy device (Nagamitsu, Nagano, Yamashita, Takashima, & Matsuishi, 2006). The results showed age-related changes in the utilization of the brain after a short practice period. In children, cerebral blood flow was decreased in the prefrontal cortex during play, while, brain activity in this area was increased in adults. The authors speculate about possible reasons including differences in performance, and levels of interest and attention, that were not controlled for. There were only six subjects in each group (small sample sizes are common in cognitive neuroscience research) and there was considerable interindividual variation.

Given the data on adolescent functional brain development discussed above, interpreting the *meaning* of the decrease in prefrontal cortex (PFC) or amygdala activation is the most notable difficulty in both of these studies of video game use, because there is no baseline against which we can compare this finding. Whether reduced activation indicates diminished abilities due to incomplete pruning and myelination of the neural circuitry, or instead, a cognitive advantage due to efficiency of a restructured and fine-tuned brain structure is still an open question. The effect of video games on the growing brain is therefore difficult to interpret in the absence of a "norm" in current functional neuroimaging studies of cognitive development in adolescence.

While adolescents are reported to be adept at multitasking, the brain is understood to have limits to the "cognitive load" it can handle. The implication is that brain regions cannot process the various tasks to adequate accuracy. Lack of efficiency is reported to be most apparent in young children and adults over 60, as "toggling action" or switching attention across tasks, occurs in an area of the prefrontal cortex, the region of the brain that is considered "one of the last regions to mature and one of the first to decline with aging" (Wallis, 2006, p. 5). However, once again, there is a noticeable discrepancy between the claims in these popular debates and results from empirical research. While studies have shown that young people do multitask more than do older generations (Carrier, Cheever, Rosen, Benitez, & Chang, 2009), we were unable to find data pertaining to the relationship between brain function and media multitasking. The claims made by journalists and scientists rest on the finding that the prefrontal cortex—the brain region associated with multitasking—is the last to develop to maturity during the lifespan. This leaves open the challenge of explaining how adolescents show relatively higher skills in multitasking in spite of the ongoing brain maturation of relevant areas.

Moreover, the alarmist claims made in the media about the effect of the Internet on the developing brain omit existing data on their possible benefits for young people. For example, a training study with young adults demonstrated that 10 days of playing action video games such as Grand Theft Auto, Medal of Honor, or Spider-Man can enhance visual attention and that cognitive and perceptual boosts from gaming can be transferable to other domains (Green & Bavelier, 2003).

How should these findings be incorporated into the existing debate? Bavelier, Green, and Dye (2010) caution scientists and policy makers to differentiate types of technology and note differences in content rather than lumping together "video games" or "the Internet" into one category. In the same way that television viewing can give rise to a range of effects (e.g., viewing of *Sesame Street* by children has shown benefits for language skills while viewing of *Teletubbies* has shown the opposite effect), digital media include a wide variety of content, which will not all have similar effects on cognition (Bavelier et al., 2010). These studies that suggest possible benefits of digital media use are increasingly cited. However, the experimental designs of these studies require careful scrutiny, and it has recently been suggested that the model of the clinical trial would be a more adequate way to test existing claims about the effects of digital media. Most of the studies of Bevalier and colleagues do not take into account differential placebo effects on game skills in training studies (Boot, Blakely, & Simons, 2011; see Costandi, 2011, for a review). Moreover, as Costandi reports, "many studies split their reports of different beneficial outcomes from the same groups of participants over multiple papers, making it unclear how many times the results have been independently replicated" (Design defects section, para. 5). The impact of Bevalier and Green's 2003 study has been impressive—it has been cited more than 650 times (Costandi, 2011) in both media and in academic sources—and while its conclusions may not be wrong, the scientific evidence remains insufficient to support the strong claims made.

Furthermore, it is important to note that existing studies on which media claims draw are based on correlational not causal paradigms. Technology use is also highly correlated with other factors such as household income and parents' education, reminding us that the context of the child cannot easily be disentangled from the effects of digital media per se (Bavelier et al., 2010). Studies are needed that examine how digital technologies affect other activities performed by adolescents. Healy (1999), for example, has examined the detrimental developmental effects when computer use replaces traditional physical playtime, and its impact on creativity. Thus, what is at issue is not necessarily the technology itself but the contexts of its use and the differential impact by age and other variables on users.

Plastic reason: Metamorphosis and mutation

We have tried to show that the polemical debates in the media about digital technologies and the teenage brain operate with a thin set of brain-based evidence and simplified theoretical accounts which fail to differentiate types of plasticity and kinds of media and technology, or to acknowledge alternative interpretations

(Bavelier et al., 2010; Courage & Setliff, 2009). In fact, it is unlikely that further functional neuroimaging experiments on adolescents in cyber environments can resolve the debate or be used as the evidence base for policy guidelines without taking into account behavioural findings. Certainly imaging data can be and should be used as part of triangulated approaches that include psychological and sociological data to make sense of the effects of digital media. However, brain imaging data produced in current studies tell us little about these issues. Nevertheless, this limited brain data is used to support normative claims about adolescents and digital media and, despite the absence of solid evidence, neuroscience occupies a privileged space in the debates. Compared with clinical and anecdotal reports of behaviours associated with heavy Internet and technology use, the notion of *a developing brain with a high degree of malleability* seems to be a powerful argument invoked both by those who critique teenage Internet use and those who encourage it. However, this notion of malleability or plasticity in itself has not clear implications for the impact of Internet use; the science merely suggests that the adolescent brain is particularly *impressionable* in response to environmental influences, whether they are good or bad.

If brain research cannot answer the questions about the value of the Internet for adolescent well-being, how can we explain its appeal? Beyond the privilege we in contemporary Western society grant to the concept that we are our brains—*homo cerebralis sumus* (Hagner, 2000)—there are many reasons that the brain may hold a special status in this particular debate. First, there is a close correspondence between neuroscience and the Internet: the 21st-century model of the brain is no longer analogous to a hierarchical company, but rather to a vast decentralized network organized just like the Internet (Borck, 2011). The Internet has thus come to stand in as a metaphor in contemporary neuroscience for understanding how the brain works. (Interestingly, we might add, the same technologies allowing the screens, computations and images of neuroscience are those of digital media under question.) There is a second resonance between current characterizations of adolescence and the Internet as a medium. As Sherry Turkle (2011) points out, "online life is like an identity workshop". Exploration of identity is also a defining feature of the adolescence. Beyond the fit between neuroscience and the Internet, and the Internet and adolescence, we suggest the notion of adolescents' pronounced neuroplasticity is key to understanding the appeal and the function of the brain in these debates.

In biomedicalized societies, the concept of brain plasticity has generated much excitement giving rise to a new style of thought, connected to a booming industry of brain-based self-improvement or "neuroascesis," particularly since the late 1990s (Doidge, 2007; Ortega, 2011). The idea that the brain has the capacity to modify itself through experience-dependent processes has pushed neuroscience towards a less deterministic and more interactional discourse. Aside from genetic programming, neuroplasticity is after all dependent on environmental inputs, and, as popularized accounts emphasize, the enrichment of a given environment can bring about reorganization and genesis of neurons. In adulthood, plasticity has been celebrated as the means through which recovery can occur after trauma and injury, and the mechanism through which new skills can continue to be learned throughout life (Doidge, 2007). In contrast to the notion of the brain as a fixed organ, which determines certain behaviours or dispositions of a person, the plastic self is alterable, continually evolving and able to steer its own course into an open future by working on its material substrate, the metamorphosing brain. This plastic reason has radically recast visions of the brain giving it a sense of historicity, individuality, and situatedness, and assigning it the ability to respond to psychological experience as well as to generate it (Malabou, 2008; Pitts-Taylor, 2010). In fact, it has become an ethical imperative to deploy one's brain in ways that preserve its openness in order to maintain psychological health (Rees, 2010). In this imperative, adult neuroplasticity articulates with individualizing formations of risk and responsibility. Plasticity in the adult brain is thus seen for the most part as a positive thing—a process that should be harnessed in order to learn, change or recover, and sustained in order to prevent mental illness and the negative effects of ageing.

Plasticity in the case of adolescence is often framed differently—certainly in the debate about the effects of digital media. The adolescent brain, programmed to be in a much more pronounced state of synaptic plasticity compared to the adult brain, is rendered vulnerable and risky by virtue of its plasticity. The unsynchronized maturation of different brain systems, synaptic pruning, axonal myelination, and changes in connectivity and integration, all of which occur in concert with hormonal events, is thought to put the adolescent in a disequilibrated psychological state. This form of plasticity is not understood to be a positive metamorphosis steered by the adolescent, but rather a "work in progress" or a "remodeling stage" happening *to* the adolescent that leaves the brain at risk of being negatively changed by certain environmental influences. Of course, as mentioned earlier, adolescent brain development is not only referred to as a period of vulnerability but also as a period of opportunity. The opportunity refers to the sensitive window for reversibility and optimization through corrective or protective interventions provided by adults (Fricke & Choudhury, 2011). Further, the stakes and consequences of neuroplasticity for adolescents are interpreted differently than for adults, for whom opportunities for neural change entail responsibility and provide hope primarily as individualizing practices. However, while the actual locus of change rests within the brain of the individual adolescent, the risks or consequences of these changes are imagined to occur at a much broader level. The stakes are indeed quite high as changes in individual brains are seen to have the potential to collectively shape the future of society.

Such a rendering of adolescent neuroplasticity seems far removed from the empowering reasoning behind adult neurogenesis. In contrast to the idea that neuroplasticity blurs the distinction of nature and nurture, we propose that it in fact reifies the boundary between "inside" and "outside," defining the adult self *in terms* of this division, and viewing adolescents as incapable of sustaining this division, and thus as having compromised selves. Neuroscientist and historian of science, Laura Otis, has used the "membrane model" to analyze notions of selfhood that stem from germ theory in 19th-century science and literature (Otis, 1999). She shows how, through the mingling of science and politics in imperialistic cultures in this period, cell theory was shaped by anxieties about the control of borders, nationhood, foreign invasion, and corruption. The membrane functions to absorb positive influence and filter out the unwanted, and in the case of selfhood to distinguish the "me" from the "not me." This view has been used to approach the mind by scientists throughout the 19th and 20th centuries, and to distinguish certain categories of people such as children, women, and colonial subjects as those who are unable to protect their mental barriers. Because of this, these categories of persons are imagined as weak-willed, suggestible, and *permeable*. In the discourse of plasticity, adult selfhood appears to rely on a "semipermeable" cortical boundary, or membrane, through which choices to resist or allow environmental stimuli can be articulated. Adolescence on the other hand is defined in terms of a "permeable" cortical boundary, open to environmental infiltration and subsequent neural changes. The teen brain is at risk of being penetrated by outside forces, such as the Internet and digital technology, which may steer the restructuring adolescent brain off track, reinforcing pathways that render the teenager inattentive and unsocial. However, as we have seen, a central question remains for cognitive neuroscience: to understand how development is steered "off track" requires an understanding of normal trajectories of functional brain development, which the field currently lacks.

Conclusion

The social construction of adolescence has been cocreated with moral panics about adolescents. Since the early 1900s with G. Stanley Hall's now legendary description of adolescence (Hall, 1904), Western society has viewed teenagers as both vulnerable and dangerous. New moral panics repeatedly have captured the attention of society, whether the issue be teenage pregnancy, drugs, predatory gangs, or "mean girls." By providing commentary and expertise on the social problem, psychologists, sociologists, educators, and policy makers actually contribute to its construction as a social problem and enable the formation of categories, and of the embodiment of certain kinds of persons, such as the "teenage risk-taker" or the "mean girl." Today, the Western media are filled with items reporting on digital technologies and youth, often with provocative and sensationalized headlines. As we have shown, the anxiety around these technologies engages the notions of neuroplasticity and the teen brain, thereby reproducing the category of adolescence as a distinct and demarcated period in the lifespan (Choudhury, McKinney, & Merten, 2012). In fact the logic of cerebral localization and the idea that the developing brain is made up of networks which are highly plastic are not new, but confirmed with new evidence "due to a cohabitation of new visualization techniques with old psychological parameters" (Hagner & Borck, 2001, p. 508).

In biomedicalized cultures, the "brain" exists as a vital metaphor for what is most true, durable, universal, and uncontestable about who we are (Dumit, 2004;

Hagner, 2000). This compels us to look to the findings of neuroscience as the final authority in revealing the impact of digital technologies, and guiding any necessary moral and ethical action. Neuroscientific discourse is especially compelling as it provides a naturalistic construal of the person in terms of a stable biological substrate on which the influence of the "environment" is overlaid. This biological substrate is amenable to interventions from the educational to the pharmaceutical (Choudhury & Slaby, 2012). Popularized representations of neuroplasticity obscure the complicated conceptual and ontological entanglement between natural, social, and cultural realms and offer simplified and contradictory support to debates about youth and digital media. As much as neuroscience attempts to overcome certain dichotomies such as external and internal through the notion of plasticity, it tends to reproduce these binaries through the ambiguities, interpretive uncertainty, and provisional status of its findings. Furthermore, despite the lack of consensus, scarcity of experimental data and imprecision about types of neuroplasticity, findings are selectively taken up in public debates and develop momentum by virtue of the authority and allure of the *neuro*- (Weisberg et al., 2008). Analysis of the gap between empirical evidence and representation of these studies demonstrates how neuroscientific facts and fears emerge from a process of *bricolage* (Young, 2006). For instance, the discourse on the Internet and the adolescent brain entirely omits a recent functional neuroimaging study pointing to the correlation between increased prefrontal cortex activity over age during adolescence and self-reported ability to resist risky, reward-oriented behaviours (Pfeiffer et al., 2011). How can the model of the "teen brain"—which separates motivational cognition from regulatory cognition—encompass increasing susceptibility at the same time as increasing *resistance to* susceptibilities, and how does this complicate the debates about the effect of the Internet on the growing brain?

The idea of the extended, embedded, and enacted mind can offer a decentering alternative to the current debates. Clark and Chalmers (1998) have proposed that "external" props or devices are in fact extensions of the mind insofar as they extend its functions and activities. The cellphone then is not "other" but exists as an extension of the mind's capacity to store information or to communicate. Through feedback and feedforward loops that move across the boundaries of brain, body, and world, the distinction of brain and environment is collapsed. This view departs from the mentalist legacy of assuming strict dichotomies between mind and body, body and world, and one person's mind and the minds of others (Clark, 1997; Gallagher, 2005; Thompson, 2007). The notion of extended mind stands in sharp contrast to conceptions of "cerebral subjectivity" that combine traditional Cartesian mentalism with the assumption that mental processes can be explained by neuronal processes alone, which culminate in the mainstream neuroscience view that "you are your brain" (Crick, 1994; Metzinger, 2009; Revonsuo, 2005). The extended-mind approach assumes that mental processes are constitutively embodied and environmentally embedded such that they cannot be properly characterized without reference to their bodily dimensions and relations to the physical and social environment. In using technologies like the Internet, Smartphones and so on, the capacities for adolescent thinking are reconfigured. Images of the "cyborg," "cyberpunk," "human-technology symbionts" (Clark, 2011) and the "screenager" (Rushkoff, 1996) displace the inside/outside dichotomy. Taken a step further, the view of the *socially* extended mind (Gallagher, 2011) pushes us to consider how the mind is also constituted in and is distributed across social processes and environments, and would thus include institutions, social structures, and discourses. By thinking with the notion of the socially extended mind, we can go beyond notions of neuro-reflexivity to imagine that the institution of neuroscience, as it shapes discourses about adolescents and their relationships to digital technology, is both constitutive and part of the mind's distribution in contemporary society. Taking a view of neuroscience as an interpretive discipline shot through with cultural metaphors and motifs and of the adolescent mind/brain as socially extended forces us to rethink the popular anxieties about "Generation M" as well as the assumed boundaries between the brain and its environment, and between neuroscience and society.

Funding

The first author is grateful to the Max Planck Society for funding this research.

Notes

1. This statistic was recorded in 2008 by the US analysis group, IDC. The IDC claims that this amounts to almost half of the total time spent each week using all media (70.6 hours), almost twice as much time as spent watching television (16.4 hours), and more than eight times as much time as spent reading newspapers and magazines (3.9 hours).
2. For example, journalist and medical doctor, Ben Goldacre has publicly refuted Professor Greenfield's claims on his Bad Science blog, arguing that they are based on her personal hypotheses and lack peer-reviewed published evidence to substantiate them. He also points out Greenfield's simultaneous endorsement of a computer game called "MindFit" that is designed to enhance cognition. Many of the popular as well as scientific articles about multitasking, media and the brain, while making claims about the brain, draw on behavioural research or multiple existing studies with different methodologies but do not build on studies that directly examine brain, cognition and media correlations (cf. Carrier et al., 2009).

References

Achtman, R. L., Green, C. S., & Bavelier, D. (2008). Video games as a tool to train visual skills. *Restorative Neurology and Neuroscience*, *26*(4), 435–446.

Adleman, N. E., Menon, V., Blasey, C. M., White, C. D., Warsofsky, I. S., Glover, G. H., & Reiss, A. L. (2002). A developmental fMRI study of the Stroop color-word task. *NeuroImage*, *16*(1), 61–75.

American Psychological Association. (2001, August 5). *Is multitasking more efficient? Shifting mental gear costs time, especially when shifting to less familiar tasks* [Press release]. Retrieved from http://www.apa.org/news/press/releases/2001/08/multitasking.aspx

Anderson, S. (2009, May 17). In defense of distraction. *New York Magazine*. Retrieved from http://nymag.com/news/features/56793/

Baroness Susan Greenfield: Society should wake up to harmful effects of internet. (2010, September 15). *The Telegraph*. Retrieved from http://www.telegraph.co.uk/technology/internet/8002921/Baroness-Susan-Greenfield-society-should-wake-up-to-harmful-effects-of-internet.html

Bavelier, D., Green, C. S., & Dye, M. W. G. (2010). Children, wired: For better and for worse. *Neuron*, *67*(5), 692–701.

Beck, J. (1996, October 17). A meeting of minds between neuroscientists and educators is first step in improving America's schools. *Chicago Tribune*. Retrieved from http://articles.chicagotribune.com/1996-10-17/news/9610170145_1_brain-special-education-early-childhood

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., ... Thomas, S. (2008). The mental wealth of nations. *Nature*, *455*(7216), S1057–1060.

Blakemore, S.-J., den Ouden, H., Choudhury, S., & Frith, C. (2007). Adolescent development of the neural circuitry for thinking about intentions. *Social Cognitive and Affective Neuroscience*, *2*(2), 130–139.

Blakemore, S. J., & Frith, U. (2005). *The learning brain: Lessons for education*. Oxford, UK: Blackwell.

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Cognition*. Retrieved from http://www.frontiersin.org/cognition/10.3389/fpsyg.2011.00226/abstract

Borck, C. (2011). Toys are us: Models and metaphors in brain research. In S. Choudhury, & J. Slaby (Eds.) *Critical neuroscience: A handbook for the social and cultural contexts of neuroscience* (pp. 113–134). Oxford, UK: Wiley-Blackwell.

Bruer, J. T. (1999). Education and the brain: A bridge too far. *Educational Researcher*, *26*(8), 4–16.

Burnett, S., Bird, G., Moll, J., Frith, C., & Blakemore, S.-J. (2008). Development during adolescence of the neural processing of social emotion. *Journal of Cognitive Neuroscience*, *21*(9), 1–15.

Burnett, S., Sebastian, C., Cohen-Kadosh, K., & Blakemore, S.-J. (2011). The social brain in adolescence: Evidence from functional magnetic resonance imaging and behavioural studies. *Neuroscience and Biobehavioural Reviews*, *35*, 1654–1664.

Carr, N. (2008, July/August). Is Google making us stupid? *The Atlantic Monthly*. Retrieved from http://www.theatlantic.com/magazine/archive/2008/07/is-google-making-us-stupid/306868/

Carr, N. (2010). *The shallows: What the Internet is doing to our brains*. New York, NY: W.W. Norton.

Carrier, L. M., Cheever, N., Rosen, L., Benitez, S., & Chang, J. (2009). Multitasking across generations: Multitasking choices and difficulty ratings in three generations of Americans. *Computers in Human Behavior*, *25*(20), 483–489.

Carroll, L. (2011, April 12). Will teen multitasking give rise to ADD? *NBCNews.com*. Retrieved from http://www.msnbc.msn.com/id/42557051/ns/nbcnightlynews/t/will-teen-multitasking-give-rise-add-study-may-offer-answer/#.UO1-ehxrocM

Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. *Developmental Review*, *28*(1), 62–77.

Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences*, *1124*, 111–126.

Choudhury, S., McKinney, K. A., & Merten, M. (2012). Rebelling against the brain: Public engagement with the "neurological adolescent". *Social Science and Medicine*, *74*(4), 565–573.

Choudhury, S., & Slaby, J. (Eds.). (2012). *Critical neuroscience: A handbook of the social and cultural contexts of neuroscience*. London, UK: Blackwell.

Clark, A. (1997). *Being there: Putting brain, body and world together again*. Cambridge, MA: MIT Press.

Clark, A. (2011). Précis of *Supersizing the mind: Embodiment, action, and cognitive extension* (Oxford University Press, NY, 2008). *Philosophical Studies*, *152*, 413–416.

Clark, A., & Chalmers, D. J. (1998). The extended mind. *Analysis*, *58*(1), 7–19.

Cohen, J. R., Asarnow, R. F., Sabb, F. W., Bilder, R. M., Bookheimer, S. Y., Knowlton, B. J., & Poldrack, R. A. (2010). A unique adolescent response to reward prediction errors. *Nature Neuroscience*, *13*, 669–671.

Costandi, M. (2011). Video-game studies have serious flaws. *Nature*. Retrieved from http://www.nature.com/news/2011/110916/full/news.2011.543.html

Courage, M. L., & Setliff, A. E. (2009). Debating the impact of television and video material on very young children: Attention, learning, and the developing brain. *Child Development Perspectives*, *3*, 72–78.

Crick, F. (1994). *The astonishing hypothesis: The scientific search for the soul*. New York, NY: Touchstone Press.

Dahl, R. E. (2004). Adolescent brain development: A period of vulnerabilities and opportunities. Keynote address. *Annals of the New York Academy of Sciences*, *1021*, 1–22.

Davidson, C. (2011). *Now you see it: How the brain science of attention will transform the way we live, work, and learn*. New York, NY: Viking.

Derbyshire, D. (2009, February 24). Social websites harm children's brains: Chilling warning to parents from top neuroscientist. *Daily Mail*. Retrieved from http://www.dailymail.co.uk/news/article-1153583/Social-websites-harm-childrens-brains-Chilling-warning-parents-neuroscientist.html

Doidge, N. (2007). *The brain that changes itself: Stories of personal triumph from the frontiers of brain science*. New York, NY: Penguin.

Dosenbach, N. U. F., Nardos, B., Cohen, A. L., Fair, D. A., Power, J. D., Church, J. A., Nelson, S. M., & … Schlaggar, B. L. (2010). Prediction of individual brain maturity using fMRI. *Science*, *329*(5997), 1358–1361.

Dumit, J. (2004). *Picturing personhood: Brain scans and biomedical identity*. Princeton, NJ: Princeton University Press.

Ernst, M., & Fudge, J. L. (2009). A developmental neurobiological model of motivated behavior: Anatomy, connectivity and ontogeny of the triadic nodes. *Neuroscience and Biobehavioral Reviews*, *33*(3), 367–382.

Ernst, M., & Spear, L. P. (2009). Regulatory systems: Motivation and emotion. In M. D. Haan, & M. R. Gunnar (Eds.) *Handbook of developmental social neuroscience* (pp. 342–377). New York, NY: Guilford Press.

Ferguson, C. J. (2010). Blazing angels or resident evil? Can violent video games be a force for good?. *Review of General Psychology*, *14*(2), 68–81.

Fricke, L., & Choudhury, S. (2011). Neuropolitik und Plastische Gehirne. Eine Fallstudie des adoleszenten Gehirns [Mental capital, cortical plasticity and the neurological adolescent]. *Deutsche Zeitschrift für Philosophie*, *59*(3), 391–402.

Gallagher, S. (2005). *How the body shapes the mind*. Oxford, UK: Oxford University Press.

Gallagher, S. (Ed.). (2011). *Oxford handbook of the self*. Oxford, UK: Oxford University Press.

Gallagher, S., & Crisafi, A. (2009). Mental institutions. *Topoi*, *28*(1), 45–51.

Golarai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L., Gabrieli, J. D. E., & Grill-Spector, K. (2007). Differential development of high-level visual cortex correlates with category-specific recognition memory. *Nature Neuroscience*, *10*(4), 512–522.

Grafman, J. (2000). Conceptualizing functional neuroplasticity. *Journal of Communication Disorders*, *33*(4), 345–355.

Green, C. S., & Bavelier, D. (2003). Action video games modify visual selective attention. *Nature*, *423*, 534–537.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development*, *58*, 539–559.

Hagner, M. (2000). *Homo cerebralis. Der Wandel vom Seelenogran zum Gehirn [Homo cerebralis: The transformation of the soul body to the brain]*. Frankfurt, Germany: Insel.

Hagner, M., & Borck, C. (2001). Mindful practices: On the neurosciences in the twentieth century. *Science in Context*, *14*, 507–510.

Hall, G. S. (1904). *Adolescence: Its psychology and its relations to physiology, anthropology, sociology, sex, crime, religion and education*. New York, NY: D. Appleton.

Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry*, *63*(10), 927–934.

Healy, J. (1999). *Failure to connect: How computers affect our children's minds – And what we can do about it*. New York, NY: Simon & Schuster.

Johnson, M. H. (2010). Interactive specialization: A domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience*, *1*(1), 7–21.

Kittler, F. (1999). *Gramophone, film, typewriter*. Stanford, CA: Stanford University Press.

Ko, C., Liu, G., Hsiao, S., Yen, J., Yang, M., Lin, W. C., ... Chen, C. S. (2009). Brain activities associated with gaming urge of online gaming addiction. *Journal of Psychiatric Research*, *43*, 739–747.

Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., Jones, T., ... Grasby, P. M. (1998). Evidence for striatal *dopamine* release during a video game. *Nature*, *393*, 266–268.

Kwon, H., Reiss, A. L., & Menon, V. (2002). Neural basis of protracted developmental changes in visuo-spatial working memory. *Proceedings of the National Academy of Sciences*, *99*(20), 13336–13341.

Lewin, T. (2010, January 20). If your kids are awake, they are probably online. *The New York Times*. Retrieved from http://www.nytimes.com/2010/01/20/education/20wired.html?_r=1&

Luria, A. R. (1966). *Higher cortical functions in man*. Oxford, UK: Basic Books.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Science U.S.*, *97*(8), 4398–4403.

Malabou, C. (2008). *What should we do with our brain?* New York, NY: Fordham University Press.

Mathiak, K., & Weber, R. (2006). Toward brain correlates of natural behavior: fMRI during violent video games. *Human Brain Mapping*, *27*(12), 948–956.

McLuhan, M. (1962). *The Gutenberg galaxy: The making of typographic man*. Toronto, Canada: University of Toronto Press.

Metzinger, T. (2009). *The ego-tunnel: The science of the mind and the myth of the self*. New York, NY: Basic Books.

Meyer, D. E., Evans, J. E., Lauber, E. J., Gmeindl, L., Rubinstein, J., Junck, L., & Koeppe, R. A. (1998). *The role of dorsolateral prefrontal cortex for executive cognitive processes in task switching*. San Francisco, CA: Poster presented at the meeting of the Cognitive Neuroscience SocietyApril.

Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of action videogame players in an attention-demanding task. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *31*(3), 992–998.

Monk, C. S., McClure, E. B., Nelson, E. E., Zarahn, E., Bilder, R. M., Leibenluft, E., … Pine, D. S. (2003). Adolescent immaturity in attention-related brain engagement to emotional facial expressions. *NeuroImage*, *20*(1), 420–428.

Nagamitsu, S., Nagano, M., Yamashita, Y., Takashima, S., & Matsuishi, T. (2006). Prefrontal cerebral blood volume patterns while playing video games – A near-infrared spectroscopy study. *Brain & Development*, *28*(5), 315–321.

O'Connor, T. G., Bredenkamp, D., & Rutter, M. (1999). Attachment disturbances and disorders in children exposed to early severe deprivation. *Infant Mental Health Journal*, *20*(10), 10–29.

Ophir, E., Nassb'l, C., & Wagner, A. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences of the United States of America*. Retrieved from http://www.pnas.org/content/early/2009/08/21/0903620106.abstract

Ortega, F. (2011). Toward a genealogy of neuroascesis. In F. Ortega, & F. Vidal (Eds.) *Neurocultures: Glimpses into an expanding universe*. Frankfurt am Main, Germany: Peter Lang.

Otis, L. (1999). *Membranes: Metaphors of invasion in nineteenth century literature, science, and politics*. Baltimore, MD: Johns Hopkins University Press.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L. E., & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature*, *392*, 811–814.

Papathanassopolous, S. (2011). Introduction: Media perspectives for the 21st century. In S. Papathanassopolous (Ed.) *Media perspectives for the 21st century* (pp. 1–18). New York, NY: Routledge.

Pascual-Leone, A., Nguyet, D., Cohen, L. G., Brasil-Neto, J. P., Cammarota, A., & Hallett, M. (1995). Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills. *Journal of Neurophysiology*, *74*(3), 1037–1045.

Pfeifer, J. H., Masten, C. L., Moore, W. E., Oswald, T. M., Iacoboni, M., Mazziotta, J. C., & Dapretto, M. (2011). Entering adolescence: Resistance to peer influence, risky behavior, and neural changes in emotion reactivity. *Neuron*, *69*(5), 1029–1036.

Pinker, S. (2010, June 10). Mind over mass media. *The New York Times*. Retrieved from http://www.nytimes.com/2010/06/11/opinion/11Pinker.html?_r=0

Pitts-Taylor, V. (2010). The plastic brain: Neoliberalism and the neuronal self. *Health*, *14*(6), 635–652.

Plato. (2008). *Phaedrus* (B. Jowett, Trans.). Retrieved from http://www.academia.edu/610762/Neuropolitik_und_plastische_Gehirne_-_Eine_Fallstudie_des_adoleszenten_Gehirns

Rees, T. (2010). Being neurologically human today: Life and science and adult cerebral plasticity (an ethical analysis). *American Ethnologist*, *37*(1), 150–166.

Revonsuo, A. (2005). *Inner presence: Consciousness as a biological phenomenon*. Cambridge, MA: MIT Press.

Richtel, M. (2010, August 15). Outdoors and out of reach, studying the brain. *The New York Times*. Retrieved from http://www.nytimes.com/2010/08/16/technology/16brain.html?pagewanted=all

Romer, D., Duckworth, A. L., Sznitman, S., & Park, S. (2010). Can adolescents learn self-control? Delay of gratification in the development of control over risk taking. *Prevention Science: The Official Journal of the Society for Prevention Research*, *11*(3), 319–330.

Rowson, J. (2010, December). The social value of neurological reflexivity: Decisions, habits and attention. Paper presented at the Neurosociety conference, University of Oxford.

Rubia, K., Russell, T., Overmeyer, S., Brammer, M. J., Bullmore, E. T., Sharma, T., . . . Taylor, E. (2001). Mapping motor inhibition: Conjunctive brain activations across different versions of go/no-go and stop tasks. *NeuroImage*, *13*(2), 250–261.

Rushkoff, D. (1996). *Playing the future: How kids' culture can teach us to thrive in an age of chaos*. New York, NY: HarperCollins.

Scherf, K. S., Behrmann, M., Humphreys, K., & Luna, B. (2007). Visual category-selectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science*, *10*(4), 15–30.

Shirky, C. (2010). *Cognitive surplus: Creativity and generosity in a connected age*. New York, NY: Penguin.

Slaby, J., Haueis, P., & Choudhury, S. (2011). Neuroscience as applied hermeneutics: Towards a critical neuroscience of political theory. In F. Vander Valk (Ed.) *Essays on neuroscience and political theory* (pp. 503–573). Abingdon, UK: Routledge.

Small, G. W., Moody, T. D., Siddarth, P., & Bookheimer, S. Y. (2009). Your brain on Google: Patterns of cerebral activation during Internet searching. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry*, *17*(2), 116–126.

Small, G., & Vorgan, G. (2008). *iBrain: Surviving the technological alteration of the modern mind*. New York, NY: HarperCollins.

Starker, S. (1990). Fear of fiction: The novel. *Publishing Research Quarterly*, *6*(2), 44–59.

Sullivan, M. L., & Miller, B. (1999). Adolescent violence: State processes,and the local context of moral panic. In J. M. Heyman (Ed.) *States and illegal practices* (pp. 261–284). New York, NY: Berg.

Tamm, L., Menon, V., & Reiss, A. L. (2002). Maturation of brain function associated with response inhibition. *Journal of the American Academy of Child and Adolescent Psychiatry*, *41*(10), 1231–1238.

Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.

Turkle, S. (2011, January 29) Author, author: Sherry Turkle. *The Guardian*. Retrieved from http://www.guardian.co.uk/books/2011/jan/29/author-sherry-turkle-life-screen

Wallis, C. (2006, March 27). genM: The multitasking generation. *Time*. Retrieved from http://www.time.com/time/magazine/article/0,9171,1174696,00.html
Weinstein, A. M. (2010). Computer and video game addiction: A comparison between game users and non-game users. *American Journal of Drug Alcohol Abuse*, *36*, 268–276.
Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience*, *20*, 470–477.
Young, A. (2006). *Pathologies of the social brain*. Unpublished manuscript.
Zaki, J. (2011, January 19). What, me care? Young are less empathetic. *Scientific American Mind*. Retrieved from http://www.scientificamerican.com/article.cfm?id=what-me-care.

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