



## Special Invited Review

## Training the brain: Fact and fad in cognitive and behavioral remediation

Sheida Rabipour<sup>a</sup>, Amir Raz<sup>a,b,\*</sup><sup>a</sup> Department of Neurology & Neurosurgery, McGill University, Canada<sup>b</sup> Departments of Psychiatry & Psychology, McGill University, Canada

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## ABSTRACT

Putatively safe and effective for improving cognitive performance in both health and disease, products purported to train the brain appeal to consumers and healthcare practitioners. In an increasingly health-centered society, these applications constitute a burgeoning commercial market. Sparse evidence coupled with lack of scientific rigor, however, leaves claims concerning the impact and duration of such brain training largely unsubstantiated. On the other hand, at least some scientific findings seem to support the effectiveness and sustainability of training for higher brain functions such as attention and working memory. In the present paper we provide a tectonic integration and synthesis of cognitive training approaches. Specifically, we sketch the relative merits and shortcomings of these programs, which often appeal to parents who must choose between side-effect-laden medication and other less conventional options. Here we examine how neuroplasticity allows the healthy as well the impaired to benefit from cognitive training programs. We evaluate the evidence and consider whether brain training can be a stand-alone treatment or an adjunct to pharmacotherapy, outline promising future prospects, and highlight what training outcomes are plausible in line with available data. Future research would determine whether the field of brain training realizes its potential to revolutionize education and rehabilitation or withers away engulfed in controversy.

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## 1. Introduction

Increasingly ubiquitous, training programs foster the putative promise of enhancing or rehabilitating behavior and brain function. This trend comprises a burgeoning market of products alleged to enhance cognition, emotion, thought and action. Catering to individuals of all ages, but targeting young children and the elderly in particular, such programs claim to benefit healthy populations as well as those diagnosed with specific disorders. Many commercial programs take advantage of computerized training over the Internet, offering the comfort and privacy of home-based brain exercise. Appealing to a wide clientele – from the ambitious and healthy to the desperate and sick – brain training targets parents and professionals looking for an edge in a competitive society, symptom relief, or a potential cure.

Broadly defined, brain training refers to the engagement in a specific program or activity that aims to enhance a cognitive skill

or general cognitive ability as a result of repetition over a circumscribed timeframe. Such training can produce changes measured at the behavioral as well as the neuroanatomical and functional levels. Many forms of brain training appear to improve cognitive function and emotional control, particularly programs that exercise attention (Rueda, Posner, and Rothbart, 2005). By practicing games or tasks that require choosing between two competing responses, the training of attention aims to strengthen the neural networks underlying control processes (Raz & Buhle, 2006). A strong modulator of cognition and affect, attention refers to the selective focus on specific aspects of our environment or to the concentration on specific mental thoughts and operations (Raz & Buhle, 2006). Similar to attention training (AT), many programs target working memory (WM), a system that mediates temporary information storage, modification, and protection from interference (Bledowski, Kaiser, & Rahm, 2010). Apart from attention and WM, studies suggest that practicing sustained attention through meditation (Tang & Posner, 2009), schooling (Diamond, Barnett, Thomas, & Munro, 2007), interaction with nature (Kaplan, 1995a), exercise (Kubesch et al., 2009), and musical training (Kraus & Chandrasekaran, 2010) can also improve cognitive ability and emotional control. The effects of such varied methods on cognitive ability and emotional stability attest to the advantages of specific exercises.

*Abbreviations:* AT, attention training; WM, working memory; FFW-L, Fast ForWord-Language; HRT, habit-reversal training; IBMT, integrative body-mind training; BBC, British Broadcasting Corporation; AKTIVA, Active Cognitive Stimulation-Prevention in the Elderly; TS, Tourette's Syndrome; COI, conflicts of interest.

\* Corresponding author. Address: Institute of Community and Family Psychiatry, 4333 Cote Ste. Catherine, Montreal, QC, H3W 1E4 Canada.

E-mail address: [Amir.Raz@McGill.ca](mailto:Amir.Raz@McGill.ca) (A. Raz).

Brain training is especially relevant for developmental psychopathology. This approach has potential to ameliorate undesired symptoms of disorders such as attention deficit hyperactivity disorder (ADHD), a condition characterized by deficits in behavioral inhibition associated with cognitive processes that mediate goal-directed behaviors (Barkley, 1997). ADHD comprises a useful lens through which researchers examine the effects of training. A spectrum disorder, ADHD contains various degrees of severity that inflict mild to severe impairments, many of which relate to executive attention and may improve as a result of training (Illes & Sahakian, 2011). Currently, primary treatments for developmental psychopathologies such as ADHD often involve psychotropic medications, which sometimes show marginal effects. Even these effects, however, attenuate over time and can generate a number of unwanted side-effects. As a result, parents and clinicians are often reluctant to embrace drug-based therapy despite the scarcity of safe and effective treatment alternatives. Recent allegations add controversy to this dilemma by claiming that certain psychiatrists may have surreptitious ties with drug companies, biasing the research surrounding the production and distribution of medication for youth (“Credibility Crisis in Pediatric Psychiatry,” 2008). In light of such limitations in pharmacological-based remedies, brain training may represent an attractive adjunct to common pharmacological treatment.

The generalizability of brain training represents one of the major claims-to-fame of publicly distributed programs. With scarce data to support advertised claims, however, patrons of brain training often invest considerable resources pursuing programs that promote unsupported, arguably unrealistic, outcomes. While studies of computerized AT and working memory training (WMT) show, perhaps unsurprisingly, that trainees can improve significantly on cognitive skills related to the intervention (Westerberg et al., 2007), at least some findings suggest that training may generalize beyond task-specific skills and apply to untrained overarching abilities (Jaeggi, Buschkuhl, Jonides, & Perrig, 2008; Jaeggi et al., 2010). Reported improvements sometimes extend to increased fluid intelligence, which refers to the ability to solve problems in novel situations (Buschkuhl & Jaeggi, 2010; Mackey, Hill, Stone, & Bunge, 2010). Such transfer effects may result from overlapping neural networks in the prefrontal cortex (PFC), which underlie both WM and fluid intelligence (Gray, Chabris, & Braver, 2003; Klingberg, 2010). Claims regarding the transfer of practiced skills to other untrained cognitive domains are contentious, however, because the appearance of transfer may, in fact, result from training-to-task (Snyder, 2011). Specifically, training programs may obliquely tax the very abilities that researchers subsequently test (Diamond, 2011). In addition, being the wild west of neuropsychology, many studies report experimental results using inadequate controls, if any (Papp, Walsh, & Snyder, 2009). Rather than generalizability, therefore, the improvements observed throughout various programs may arise due to reasons such as training-to-task.

Apparent from adequately controlled studies, brain training is a groundbreaking approach with potential to transform the panorama of non-pharmacological therapy. Despite the mounting prevalence of such products, the immense potential of such interventions for various populations, and the increasing evidence both supporting and disclaiming the effectiveness of training, no other article, to our knowledge, has thoroughly amalgamated the evidence surrounding cognitive programs and the populations that may benefit from training. In the present article, we critically evaluate the validity of claims regarding various brain exercises and cognitive remediation approaches. In an attempt to elucidate the effectiveness of brain training, we examine the impact of these programs in both healthy developing individuals and pathological populations. We further investigate the potential use of such

training as an adjunct – or possible substitute – to current drug-based therapies for children with psychopathologies. We conclude by discussing specific conflicts that may hinder the advancement of research in this field and outline plausible outcomes of brain training with regards to factors that may alleviate or aggravate undesirable childhood behavior.

## 2. Neural and behavioral basis of brain training

Attention plays a central role in social behavior and academic performance. Due to brain plasticity, training can alter the neural correlates of attention and improve attentional control. In this section, we focus on a current, widely recognized model that subdivides attention into three separate systems. We discuss the function of these systems as well as their related neural networks, and delineate how these systems control behavior throughout development. Ultimately, we underline why attention is a suitable faculty to train in both children and adults.

### 2.1. Neuroplasticity and training

Brain training thrives on the lure of neuroplasticity, a change in neural structure and function in response to experience or environmental stimulation (Shaw, Lanius, & Vandendoele, 1994). Research suggests that both genetic and environmental factors impact the development and physical structure of the brain (Lenroot & Giedd, 2008). Investigations of executive attention in children have uncovered notable disparities associated with socio-economic status, even when performance levels are comparable (Hackman & Farah, 2009; Mezzacappa, 2004). Other studies report that severe stress and maltreatment experienced early in life can severely impact neuroanatomy, showing reduced volumes and attenuated development of several neural structures (Teicher et al., 2003). Taken together, these findings indicate that the developing brain is susceptible to change in response to environmental stimuli.

Evidence suggests that neuroplastic processes are present in the adult brain. Repeated practice of skills required for a profession, for example, appears to induce lasting changes within neural structure; London taxi drivers display larger gray matter volumes in neural areas associated with spatial memory (Maguire, Woollett, & Spiers, 2006; Maguire et al., 1998), professional typists undergo greater development of neural regions related to the programming of motor tasks (Cannonieri, Bonilha, Fernandes, Cendes, & Li, 2007), and musicians appear to acquire increased cortical representations of their digits (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995) as well as enlarged motor, auditory, and visual-spatial regions (Gaser & Schlaug, 2003). Even among the elderly, neuroplasticity continues to facilitate changes leading to improvement in cognitive function (Calero & Navarro, 2007). These studies indicate that the greatest changes occur through repeated practice of a skill over an extended period of time, even when learned in adulthood. In addition, extensive training or practicing a specific new skill may modify neural structures and functions over a relatively short period of time; magnetic resonance imaging (MRI) reveals increases in gray matter volumes of regions associated with the processing of complex visual motion in young adults, following 3 months of training on a juggling task (Draganski et al., 2004). Diffusion tensor imaging, furthermore, indicates changes in white matter configuration after just 4 weeks of juggling (Scholz, Klein, Behrens, & Johansen-Berg, 2009). Another study reported changes in the gray matter density of medical students, following 3 months of extensive studying for a medical school exam (Draganski et al., 2006). Recent studies show, moreover, that increases in gray matter volume may occur following as little as 1 week of training in a particular task (Driemeyer, Boyke, Gaser, Büchel, & May, 2008).

Functional and morphological changes in the adult brain may therefore arise as a result of expertise in a field as well as mastering novel skills.

## 2.2. Attention networks

Attention encompasses distinct neural processes that mature independently, at different stages of life. Fundamental to cognitive function, attention begins to develop during childhood (Posner & Rothbart, 2007b) and contributes to self-regulation, the ability to regulate our thoughts and actions (Karoly, 1993; Raz & Buhle, 2006; Rueda, Posner, et al., 2005). William James first proposed that attention may contain multiple “varieties” (James, 1890), deviating from long-held theories of attention as a unitary system. A century later, Michael Posner further elaborated on this idea by putting forth a theory in which attention consists of three highly connected yet independent networks (Posner & Petersen, 1990). This attention trilogy comprises the alerting, orienting, and executive attention systems (Posner & Rothbart, 2007a).

The alerting and orienting networks constitute the more primitive components of attention; the alerting system denotes sustained attention, vigilance, or alertness, and refers to response readiness in preparation for an impending stimulus (Raz & Buhle, 2006). Sometimes considered the foundational form of attention, the alerting system may continue developing well into adulthood (Rueda, Fan, et al., 2004; Rueda, Posner, Rothbart, Davis-Stober, 2004). The orienting network, on the other hand, involves selecting specific information from multiple sensory stimuli (Raz & Buhle, 2006). Believed to develop fully by the age of four, this network mediates shifts of the sensory organs to bring objects of interest into focus (Posner & Rothbart, 2007b).

Of the three attention networks, executive attention is most pertinent to brain training. Also termed supervisory or selective attention, executive attention mediates voluntary control and activates in situations requiring the monitoring and resolution of conflict between computations in separate neural areas (Raz & Buhle, 2006). These conflicts may include planning or decision-making, error detection, execution of new or ill-acquired responses, involvement in stressful conditions, regulation of thoughts and feelings and overcoming of habitual actions. Executive attention involves processes of self-regulation that include effortful control, the ability to suppress a dominant response in favor of a subdominant response (Kochanska, Murray, & Harlan, 2000), as well as inhibitory control, the termination of an ongoing response (Schachar, Tannock, & Logan, 1993). Accordingly, measures of this system often involve conflict-related tasks such as the Stroop task, which requires participants to name the ink color of a color-word by suppressing the tendency to read the word itself (Stroop, 1935). In addition, executive attention plays a role in emotional regulation, the control of emotional responses based on actions of the self or others (Raz & Buhle, 2006). Neural correlates of executive attention lie within the lateral PFC, the ACC, and the basal ganglia, and draw on the dopaminergic system (Posner & Rothbart, 2007b). The ACC itself is believed to have several functionalities. While theories initially implicated the dorsal portion in cognitive conflict and the ventral-rostral portion in emotional conflict (Bush, Luu, & Posner, 2000), recent evidence suggests that the dorsal ACC may integrate negative affect, pain, and cognitive control to facilitate appropriate action based on punishment-related information (Shackman et al., 2011). Furthermore, genes that modulate the dopaminergic system strongly influence executive attention and also appear to associate with impulse-control disorders such as ADHD (Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2002). With rapid development commencing at 4 years of age, the executive attention network may not change significantly after the age of seven (Rueda, Fan, et al., 2004; Rueda, Posner, et al.,

2004). This early development in executive attention appears to have strong potential for environmental modification, including targeted training (Rueda, Rothbart, McCandliss, Saccomanno, Posner, 2005). By developing executive attention, children learn to regulate cognition and behavior, and gradually conform to societal norms.

Executive attention strongly links to WM in situations requiring attentional control and focus. Similar to attention, WM is a modular system and is recruited during processes such as reading and language comprehension, learning, and reasoning (Baddeley, 1992; Daneman & Carpenter, 1980; Tsianos, Germanakos, Lekkas, Mourlas, & Samaras, 2010). Originally hypothesized to mediate executive attention, WM is now believed to draw upon this network in order to maintain and prioritize temporary stores of information (D’Esposito, 2007; Jarrold & Towse, 2006). Neuroimaging studies in humans and nonhuman primates consistently correlate the use of WM with activation patterns involved in executive function, a faculty that encompasses executive attention, including circuits within the lateral PFC (D’Esposito, 2007; Klingberg, 2010). These findings suggest that WM and executive attention rely upon one another’s functionality to control and monitor specific neural processes.

## 2.3. Attention and brain training: transfer of behavioral control

Studies suggest that the attention networks exert differential control over behavior, with specific networks contributing more strongly at certain stages of life (Gupta & Kar, 2009; Rueda, Fan, et al., 2004; Rueda, Posner, et al., 2004). Whereas the executive attention network plays a critical role in many adult pursuits, the orienting network most strongly dictates behavior at earlier developmental periods. In infants as young as 3 months of age, visual and auditory distraction can temporarily dampen distress (Posner, Rothbart, Sheese, & Voelker, 2011). This early reliance on the orienting network may underlie the relative novelty of environmental stimuli for infants and children and often provides refuge for caregivers seeking to soothe a distressed baby by using a distracter. Similar effects have also been reported in adults (Harman, Rothbart, & Posner, 1997). Whereas infants rely most strongly on the orienting network to carry out attentional shifts, adults incorporate the executive attention system in addition to the potent orienting signal (Kanske, Heissler, Schönfelder, Bongers, & Wessa, 2011). Scientists are unsure, however, when the precise shift from orienting to executive control occurs. Studies report the presence of rudimentary forms of control through executive attention in the form of cautious approach to novel stimuli (Sheese, Rothbart, Posner, White, & Fraundorf, 2008) and behavioral inhibition during conflict at 40 months of age (Jones, Rothbart, & Posner, 2003). By three to 4 years of age, children recognize errors and begin to display physical control strategies to inhibit inappropriate responses, although verbal self-regulation of behavior tends to manifest later in life (Jones et al., 2003). The gradual development of executive control in children foreshadows its eventual control over behavior, although the stage for this transfer of control between the orienting and executive attention networks remains elusive.

The overwhelming tendency of infants to attend to novel stimuli in their external environment may serve an evolutionary purpose and simultaneously facilitate the development of executive attention (Posner & Rothbart, 2011). Whereas children – and certainly infants – are not expected to make executive decisions in daily life, adults require a strong command of executive function to thrive in society. Dependence on the rapidly-maturing orienting network during early life allows infants to explore their surroundings and become acquainted with their new environment. Activation of the orienting network may also play a key role in the maturation of the executive network through their complementary

activation in response to presentation of novel stimuli (Posner et al., 2011). In this fashion, caregiver interactions may promote self-regulatory processing through regular activation of the executive network.

The control of emotion and behavior may occur through altered planes of consciousness such as hypnosis. Scientists recognize that children are considerably more hypnotizable than adults (Kohen & Olness, 2011). This observation may arise from a natural tendency to delegate control to the orienting network of attention, where an external source – the child’s caregiver, for example – becomes the source upon which children depend to regulate their behaviors and emotions. Similarly, the hypnotic state promotes an external source of control – this time, by the hypnotist. In such a way, the hypnotic state may promote an increased reliance on the orienting system for behavioral control, rather than the more commonly used executive system (Posner & Rothbart, 2011). In adults, who presumably have fully-developed attention systems, hypnosis affords the opportunity to achieve different states of awareness, to experience emotional realizations, and to perform neural computations that may otherwise have been difficult to achieve. Highly hypnotizable adults, for example, demonstrate elimination of conflict-related interference on the Stroop task after receiving post-hypnotic suggestion (Raz, 2004). Altered mental states may therefore induce differential control over attentional networks and may prove important for modulating behavior and emotion.

### 3. Origins and evolution of brain training

Whereas various cultural practices have influenced states of attention for centuries, the implications of altered mental states on cognitive function were sparsely documented before the late 20th century (Jevning, Wallace, & Beidebach, 1992). Studies in the 1960s and 1970s on relaxation therapy and early forms of AT were among the first research efforts leading to modern behavioral modification paradigms (Douglas, Parry, Marton, & Garson, 1976; Paul, 1969; Pressley, 1979). This era of research witnessed neuropsychological AT, which initially aimed to maximize the functional independence and adjustment of individuals with brain damage (Park & Ingles, 2001). The learning model of recovery (Stuss, Winocur, & Robertson, 1999) triggered theories relating experience, practice, and environment to the restoration of impaired capacities, substantiating the use of AT-like programs for cognitive rehabilitation. Following an early description concerning the therapeutic value of self-monitoring and self-control (Kanfer, 1970), a vast literature has emerged regarding improving self-control in children, a population known to be ill-equipped at maintaining composure in situations that may provoke inappropriate behavior (Pressley, 1979). The potential to improve self-control in children prompted scientists to explore these techniques as non-pharmaceutical treatment alternatives for children with impulse-control impairments. A program aiming to improve inhibitory control in hyperactive children (Douglas et al., 1976) included self-reinforcement strategies as well as verbalization techniques. After teaching children to cope more effectively and independently when faced with cognitive problems in social and academic situations, the program facilitated significant improvements in performance on standardized intelligence tests. Following such reports, scientists began to appreciate the implications of training behavioral control in children.

Research has increasingly focused on training the attention systems as a means of altering behavior. Specific emphasis on AT originated with Attention Process Training, a cognitive rehabilitation method through which scientists trained individuals with neurological impairments to employ specific subtypes of attention (Tamm et al., 2008). In one promising study, individuals suffering

from brain injury showed significant improvements in attentional processing which lasted as long as 8 months following training (Sohlberg & Mateer, 1987). In another study, patients with unilateral neglect verbally regulated the sustained-attention network by engaging in an analogous AT program (Robertson, Tegner, Tham, Lo, & Nimmosmith, 1995) and displayed improvements in untrained tasks of sustained attention and neglect after the 5-h training period. These studies corroborate the use of targeted AT in individuals with specific functional deficits in their attention networks. In the spirit of rehabilitation, Benedict et al. (1994) created a 15-h program to remediate the attentional ability of schizophrenic patients using tasks aimed at increasing information processing capacity. Although the schizophrenic population improved performance on trained tasks, observed enhancements in attention remained below the attentional baseline of controls (Benedict et al., 1994). A later study, however, reported that schizophrenic individuals with comparable baseline measures as controls improved in vigilance, distractibility, and psychiatric status following 18 AT sessions (Medalia, Aluma, Tryon, & Merriam, 1998). Research on AT branched out to target a variety of attention-based disorders. For example, studies in autistic children reported improved attentional capacity that generalized to untrained attention tasks as a result of training on joint-attention tasks (Whalen & Schreibman, 2003). A study examining the 8-h Pay Attention! program (Kerns, Eso, & Thomson, 1999) found improvements in the attentive abilities and academic efficiency of children with ADHD. Research efforts have rapidly expanded the implementation of AT and similar variants to restore specific deficits in executive function and supplement these processes in typically-developing individuals. One innovative attempt modified a program used to train monkeys for space travel and created a promising AT program for children. Following 5 days of training, the study reported significant improvements in performance of both 4- and 6-year-old participants on tests of attention and intelligence (Rueda, Rothbart, et al., 2005). In addition, electrophysiological recordings demonstrated maturation of neural activation patterns associated with the executive attention network to more adult-like signals, including increased amplitude of the electroencephalographic (EEG) N2 component. The study additionally demonstrated an association between stronger effortful control, decreased extraversion, and the long allele of the DAT1 dopamine transporter gene. Thus, training programs that target attention appear to produce measurable structural and functional changes in the brain.

### 4. Culture, lifestyle, and brain training practices

Brain training has significantly impacted mainstream society. From claims of improving the negative symptoms of psychopathologies and neurological impairments to assertions of significantly boosting cognitive skills among the healthy, commercialized software and interactive programs are increasingly capturing the interest of parents, educators, students, and clinicians (see Tables 1 and 2). Tutoring services (e.g., (Kumon North America, 2011; Sylvan Learning, 2011)) entice parents looking to enhance the academic success of their children. While some practices appear to produce measurable improvements in their target population, others lack scientific rigor behind their claims. Here, we discuss the data surrounding select brain training programs and techniques in randomized-controlled studies, unless otherwise indicated.

#### 4.1. Computerized training

Computerized cognitive exercises are among the most popular forms of brain training. In a controlled study assessing the effects

**Table 1**

A list of select commercial software aiming to enhance or rehabilitate specific cognitive skills in health and pathology.

Company (website)	Product name	Product type (as specified on website)	Target population	Scientifically published evaluations
BrainMaster Technologies, Inc. ( <a href="http://www.brainmaster.com/">www.brainmaster.com/</a> )	BrainMaster – Neurofeedback Systems	Neurofeedback training	Individuals of all ages	Martin and Johnson (2006)
Brain Train ( <a href="http://braintrain.com/">braintrain.com/</a> )	Captain's Log, SoundSmart, SmartDriver	Cognitive training	Individuals of all ages with ADHD, head injuries, Learning Disabilities, schizophrenia, and other cognitive impairments	Angelakis, Lubar, Stathopoulou, and Kounios, (2004) See also: <a href="http://www.braintrain.com/main/ivaplus_research_bibliography.htm">www.braintrain.com/main/ivaplus_research_bibliography.htm</a> <a href="http://www.braintrain.com/main/cognitive_training_research.htm">www.braintrain.com/main/cognitive_training_research.htm</a>
Cogmed ( <a href="http://www.cogmed.com">www.cogmed.com</a> )	TNT Reading SmartMind 2 Cogmed JM	WM training for children and adults with attention deficits, learning disorders, brain injury or stroke, and adults experiencing "information overload" or the natural effects of aging	Ages 4–6	See: <a href="http://www.cogmed.com/references">www.cogmed.com/references</a>
Cognifit ( <a href="http://www.cognifit.com">www.cognifit.com</a> )	Cogmed RM Cogmed QM Individualized Training System	Cognitive training	Ages 7 and up Adults Individuals of all ages	See: <a href="http://www.cognifit.com/science/scientific-validation">www.cognifit.com/science/scientific-validation</a>
HAPPYneuron ( <a href="http://www.happy-neuron.com/">www.happy-neuron.com/</a> )	Various games	Exercising memory, attention, language, visual-spatial and executive function skills	Individuals of all ages	Croisile (2006)
Lumosity ( <a href="http://www.lumosity.com/">www.lumosity.com/</a> )	Various games	Exercising memory, attention, processing speed, and problem-solving skills	Individuals of all ages	Kesler, Lacayo, and Jo (2010)
MindHabits, Inc. ( <a href="http://www.mindhabs.com/">www.mindhabs.com/</a> )	MindHabits	Exercises to decrease stress and improve confidence	Individuals of all ages	Dandeneau and Baldwin (2004)
Nintendo ( <a href="http://www.brainage.com">www.brainage.com</a> )	BrainAge	Training with math- and literature-related activities	Individuals of all ages	
Posit Science ( <a href="http://www.positscience.com">www.positscience.com</a> )	Brain Fitness InSight	Auditory training Visual training	Older adults	See: <a href="http://www.positscience.com/science/proven-in-labs">www.positscience.com/science/proven-in-labs</a>
Scientific Learning Corporation ( <a href="http://www.scilearn.com">www.scilearn.com</a> )	Drive Sharp Fast ForWord	Cognitive training for driving skills Language and reading training – adjuncts to classroom material	Kindergarten – grade 12 students	Merzenich et al. (1996) and Fey et al. (2010)
	Reading Assistant		Children and adults wishing to build vocabulary, fluency and comprehension.	
Timocco ( <a href="http://site.timocco.com">site.timocco.com</a> )	Growing with Timocco	Training motor and cognitive skills	Children with cerebral palsy, ADHD, Developmental Coordination Disorder, and Learning Disabilities	
Unique Logic and Technology ( <a href="http://www.playattention.com">www.playattention.com</a> )	Play Attention	Attention training, memory training, cognitive skill training, social skills training, motor skills training, behavior shaping	Children with ADHD	
Your Baby Can, LLC. ( <a href="http://www.yourbabycanread.com">www.yourbabycanread.com</a> )	Your Baby Can Read	Language training	Infants	

**Table 2**  
A list of select programs aiming to enhance specific skills related to academic performance in children.

Program name (website)	Description	Scientifically published evaluations
Arrowsmith School ( <a href="http://www.arrowsmithschool.org">www.arrowsmithschool.org</a> )	Cognitive exercises to improve learning dysfunctions that impact learning and social skills	
Brain Gym International ( <a href="http://www.braingym.org">www.braingym.org</a> )	Specific set of movements aiming to improve concentration and focus, memory, reading, writing, math, test-taking, physical coordination, relationships, self-responsibility, organization skills, attitude	
Center for Applied Special Technology ( <a href="http://www.cast.org">www.cast.org</a> )	Universal Design for Learning program that includes principles for curriculum development to provide equal opportunities to learn for all individuals	See: <a href="http://www.cast.org/research/index.html">http://www.cast.org/research/index.html</a>
Kumon Learning Centers ( <a href="http://www.kumon.com">www.kumon.com</a> )	Math and reading enrichment programs for children	
Strategic Learning Centre ( <a href="http://www.strategiclearning.ca">www.strategiclearning.ca</a> )	One-on-one teaching center to help children with learning disability, ADHD, dyslexia become better and more confident learners	
Sylvan Learning ( <a href="http://tutoring.sylvanlearning.com">tutoring.sylvanlearning.com</a> )	Tutoring in various academic subjects for children	
Tools of the Mind ( <a href="http://www.toolsofthemind.org">www.toolsofthemind.org</a> )	Preschool and kindergarten curricula to improve self-regulation and executive function	See: <a href="http://www.mscedu.edu/extendedcampus/toolsofthemind/about/effectiveness.shtml">http://www.mscedu.edu/extendedcampus/toolsofthemind/about/effectiveness.shtml</a>
University City Children's Center ( <a href="http://uccc.org">uccc.org</a> )	Early care and education system for values & character development, psychodynamic development, early literacy development	

of computerized AT and computer-assisted instruction (Rabiner, Murray, Skinner, & Malone, 2010), children with attentional difficulties improved in measures of attention, with more severe symptoms showing larger improvements. In another study using games that activate all three attention networks, children with ADHD improved in academic skills and decreased ADHD symptomatology, compared to controls (Shalev, Tsai, & Mevorach, 2007).

While the effectiveness of many commercial brain training products is questionable, evidence suggests that some programs facilitate marked improvements in cognitive function. One product repeatedly demonstrated to improve WM capacity in both children and adults is Cogmed, which entails training on WM tasks for 5 days per week over a period of 5–6 weeks. Using this software, children with ADHD as well as healthy adults appear to improve in measures of WM as a result of training (Klingberg, 2007; Klingberg et al., 2005).

Another widely used program is the Fast ForWord-Language (FFW-L) software (Scientific Learning Corporation, 2011), advertised to increase brain fitness, accelerate learning, and improve test scores for children (Semrud-Clikeman & Ellison, 2009). Experiments without a proper control group included tasks of perceptual identification and phonetic element recognition (Merzenich et al., 1996). After training for 19–28 sessions of 20 min over a period of 4 weeks, children with language-based learning impairments significantly improved in auditory perception. Thousands of public school districts in the United States incorporate the FFW-L program into their curricula, and a large number of children across North America use the product for both scholastic and therapeutic purposes (Scientific Learning Corporation, 2011). Reports published outside the peer-review scientific system suggest that this program enables educational benefits following repeated practice (Schultz Center for Teaching, 2009). A recent study, furthermore, demonstrated that children taking part in either the FFW-L program or a narrative-based language intervention improved on time-related effects of narrative measure and non-word repetition (Fey, Finestack, Gajewski, Popescu, & Lewine, 2010). Despite these results, the participants did not display any significant inter-group variability in benefits, suggesting that the FFW-L program scarcely holds superior benefits to conventional language interventions (Fey et al., 2010). Hence, while FFW-L appears to produce training-related gains in temporal processing of information related to language development, the program hardly fosters significant improvements in language and reading ability. Reports show, however, that training with FFW-L alongside a coach increased neural activation in regions associated with selective auditory attention – including the ACC – in children with specific language impairment during language listening tasks, compared to typically developing children who received no training (Stevens, Fanning, Coch, Sanders, & Neville, 2008). These findings also extended to typically developing children, although to a lesser extent. Studies therefore suggest that the FFW-L program improves auditory perception of stimulus tones and may indirectly exercise executive attention.

#### 4.1.1. Neurofeedback training

Neurofeedback, also called EEG biofeedback, represents another computerized technique that appears to hold advantages for specific populations. This method entails training individuals to actively control and change their neural activation patterns by viewing the brainwaves they emit a few milliseconds after they occur (Angelakis et al., 2007; Hammond, 2006). Administered in research and clinical endeavors since the 1960s, neurofeedback converts EEG signals from specific cortical areas to visual or auditory representations that participants receive and subsequently attempt to regulate through training (Congedo, Lubar, & Joffe, 2004).

More recently, neurofeedback systems leverage the increased spatial precision of fMRI technology (deCharms, 2008).

Advertising to improve mental functioning and increase awareness of brain states, neurofeedback companies (e.g., (BrainMaster Technologies, 2009)) offer their products to individuals seeking to sharpen their cognitive skills. Studies suggest that this technique may be beneficial for enhancing cognitive function in elderly populations (Angelakis et al., 2007) and in improving symptoms associated with epilepsy (Kotchoubey et al., 1999; Tan et al., 2009), substance abuse (Sokhadze, Cannon, & Trudeau, 2008), and a number of psychiatric conditions (Heinrich, Gevensleben, & Strehl, 2007). Neurofeedback appears particularly promising for individuals diagnosed with ADHD. After training with this technology, children with ADHD appear to increase scores on tests of intelligence and continuous performance, improve cooperation and school work in the classroom and demonstrate better attentional and behavioral control (Monastra, 2005). Such benefits reportedly endure, in some cases, for several years following the intervention. Similar reviews of randomized controlled trials in children with ADHD (Fox, Tharp, & Fox, 2005; Monastra, 2005) report mixed findings; while some children showed little or no training effects, others demonstrated enhanced intelligence and significant improvements in attention, hyperactivity, and impulsivity. Studies comparing neurofeedback to medication support such training as a serious contender for non-pharmaceutical ADHD treatment. A 12-week, controlled trial comparing neurofeedback with methylphenidate treatment suggested that neurofeedback leads to similar behavioral changes, with decreased parent and teacher reports of ADHD-related symptoms in both groups (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003). Another study found no significant difference in either treatment effects or clinical improvement of individuals with ADHD after 20 sessions of neurofeedback training or use of stimulant medication (Rossiter & LaVaque, 1995). The sustainability of neurofeedback effects, however, remains questionable and may vary on a case-by-case basis. Similar to other forms of computerized training, long-term therapy using neurofeedback technology may prove effective for improving disease-related symptoms of developmental psychopathologies, especially when administered at childhood. Studies therefore provide compelling evidence for the potential of such training as a non-pharmacological treatment alternative for a variety of neurological disorders.

#### 4.2. Applied attention as school-based interventions

Student attentiveness is essential to a positive and productive classroom dynamic and plays a fundamental role in shaping scholastic performance (Duncan et al., 2008). Assessments of learning approaches reveal that child attentiveness is positively associated with academic competence and achievement, as well as relations with both teachers and peers (Li-Grining, Votruba-Drzal, Maldonado-Carreno, & Haas, 2010). Variability in attentiveness may account for differences in child learning speed or the amount of information children can extract from an event (Ruff & Rothbart, 1996). Studies on children with ADHD, moreover, reveal comorbidities between the disorder and a number of learning difficulties, especially pertaining to reading ability (Carlson, Tamm, & Gaub, 1997; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005; Willcutt, Pennington, Olson, & DeFries, 2007). An uncontrolled European study in 3 cohorts of children with ADHD not only supported the association between scholastic impairment and ADHD symptomatology, but reported a 2- to 10-fold increase in impairments of reading, writing, and mathematics in children with symptoms related more strongly to inattention (Rodriguez et al., 2007). Thus, abounding evidence presents attention as an integral component in the academic success of children.

Theories surrounding school readiness stipulate that children must attain social-emotional competencies by practicing effortful control in order to grasp the lessons learned in both social and academic settings (Liew, 2011). With fundamental roles during social interactions, effortful control and emotional regulation draw upon executive function to exert attentional and inhibitory control and help children develop inter-personal relationships (Kochanska et al., 2000; Liew, 2011; Ruff & Rothbart, 1996). At the start of grade school, children exhibiting strong effortful control are more likely to express social competence and have fewer behavior problems, whereas those who struggle to control attention and behavior tend to develop impaired relationships with teachers and peers, and have greater risk of developing academic difficulties (Liew, 2011; McClelland et al., 2007). Studies further show that the manifestation of effortful control and other self-regulatory skills in elementary-age children correlates with higher grades, and may improve early mathematical and literacy prowess (Liew, 2011). Likewise, individuals with attention-related disorders such as ADHD are generally impaired in social, academic, familial, and occupational areas of life (de Boo & Prins, 2007). As a result, school-based programs often involve AT to bolster effortful control and emotional regulation (Kring & Sloan, 2010), critical to success among peers in academic and other environments involving inter-personal relations.

School-based interventions may particularly aid children of lower socio-economic status – a population with marked deficits in control through executive function (Bierman, Nix, Greenberg, Blair, Domitrovich, 2008; Hackman & Farah, 2009; Noble, McCandliss, & Farah, 2007; Stevens, Lauinger, & Neville, 2009). Programs such as “Tools of the Mind” (Barnett et al., 2008; Diamond et al., 2007) and the “Promoting Alternative Thinking Strategies” curriculum, tested in the absence of matched-controls (Kelly, Longbottom, Potts, & Williamson, 2004), for example, appear to decrease behavioral problems and improve emotional understanding, executive function, and academic performance in children with disadvantaged socio-economic backgrounds. Similarly, studies assessing the school-based “Head Start Research-based Developmentally Informed” curriculum (Bierman, Domitrovich, et al., 2008) demonstrate enhanced academic skills as well as improved behavioral and emotional control in children. With increased awareness of the importance of attentional processes in academic and social settings, researchers are beginning to pool more resources into developing effective training programs in schools. Such programs may particularly benefit disadvantaged children and minimize their disparities in cognitive ability.

Acquiring proper social skills during childhood is essential for shaping appropriate behavior and ensuring healthy development (de Boo & Prins, 2007). Training children to exhibit effective social skills appears to improve their social knowledge and assertiveness, and may further generalize to the school setting (McBurnett & Pfiffner, 2008). Social skill training may be particularly relevant for children with impulse-control disorders such as ADHD, who often experience peer rejection and social isolation due to aggressive behavior and lack of inhibitory control (DuPaul, McGoey, Eckert, & VanBrakle, 2001; McBurnett & Pfiffner, 2008). Although individual parameters such as extent of play and teaching strategies remain widely debated in American school districts (Barnett et al., 2008), social skills training appears to promote constructive peer interactions among children.

#### 4.3. Bilingualism

Contrary to the belief that bilingual education hinders cognitive ability and dampens intelligence, proficiency in two languages appears to enhance the development of cognitive control systems relating to attention. Bilinguals develop the capacity to indepen-

dently process two languages, which requires selection of the correct lexical representations of one language while suppressing the representations of the other (Costa, Hernández, & Sebastián-Gallés, 2008). Although scientists scarcely understand the mechanisms underlying this ability, bilingual individuals may employ the executive attention system to suppress an unwanted linguistic response much like inhibition during the Stroop task (Bialystok, 2010; Green, 1998). This process enables control over competing neural networks and communication in the intended language, thereby promote development of the underlying neural systems. Indeed, research reveals that bilingual individuals perform better at non-verbal problem solving tasks requiring inhibition of irrelevant responses and the formation of new conceptual representations compared to monolinguals (Bialystok & Martin, 2004). Bilingual individuals, moreover, display quicker response times in attention-related tasks – including trials involving conflict resolution – as well as more efficient use of their alerting and executive attention networks (Costa et al., 2008). As early as childhood, bilinguals appear to perform better on non-linguistic tasks requiring attentional control (Bialystok & Majumder, 1998) and develop the ability to exert selective attentional control earlier than monolinguals (Bialystok, 1999). Such advantages of bilingualism grow increasingly powerful at old age, with research indicating that elderly bilinguals have significantly greater inhibitory control compared to monolinguals of the same age group (Bialystok, Craik, & Ryan, 2006). Continuously switching between two languages may further promote the capacity to maintain two sets of instructions in mind and select the correct response in a particular situation – another ability that is stronger in elderly bilingual populations (Bialystok et al., 2006). Thus, having command of more than one language appears to enhance executive function similarly to participation in training programs. Bilingual education may therefore represent a favorable tool for the development of executive control in children and the further strengthening of this system throughout adulthood.

#### 4.4. Music training

Stemming in part from the widespread “Mozart effect” myth (Steele, Bass, & Crook, 1999) – which suggests that spatiotemporal abilities increase after listening to music composed by Mozart – musical training increasingly captivates the public. Despite the fallacy of the Mozart effect, evidence suggests that musical training does produce significant improvements in faculties such as verbal memory (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003) and general intelligence, as demonstrated in children randomly assigned to either music training, drama, or no-training controls (Schellenberg, 2004). Requiring a high degree of repetition, concentration, and devotion over many years of continuous practice, this form of training shares many of the qualities possessed by more structured cognitive training programs. Furthermore, music training generates positive emotions, which have been linked with improved plasticity (Altenmüller, 2009). Following 6 months of piano keyboard training, children have demonstrated enhanced spatiotemporal reasoning compared to children receiving private computer lessons or no training (Rauscher et al., 1997). Studies also show enhanced development of visuospatial WM ability and non-verbal reasoning, in addition to increases in child IQ scores as a result of musical training (Bergman Nutley, 2011). Musicians have also displayed superior control in certain auditory tasks compared to non-musicians (Bialystok & DePape, 2009). Recent research further links musical proficiency to enhanced executive control during conflict-related tasks unrelated to music (Bialystok & DePape, 2009). Considering the attentional and WM load as well as the knowledge of specific acoustic and syntactic rules that music requires (Kraus & Chandrasekaran, 2010), this association is not

surprising. The widespread interest in musical training as a tool for general cognitive enhancement therefore appears to have scientific merit.

Due to the cognitive demands of musical practice, music training may facilitate changes that enhance the functionality of regions related to auditory perception as well as executive attention. The behavioral benefits of music training are accompanied by structural modifications within specific brain regions, as well as changes in gray matter volume (Gaser & Schlaug, 2003; Munte, Altenmüller, & Jancke, 2002). In addition to the structural changes, music practice appears to alter neural activation patterns that underlie auditory discrimination and executive attention. Musicians show more pronounced neural signals in response to irrelevant sound signals and can better detect meaningful information such as speech amid a noisy background (Kraus & Chandrasekaran, 2010). Neuroimaging studies further reveal an association between neural areas related to WM function and parietal brain regions during sight reading of musical notes (Bergman Nutley, 2011). Hence, the complex process of learning to play a musical instrument has influences on neural function and anatomy that cannot be attributed to pre-existing qualities, and may constitute another promising form of brain training.

#### 4.5. Physical exercise

Aside from advantages to physical health, exercise appears to have a beneficial impact on cognitive function, particularly in children (Hillman, Erickson, & Kramer, 2008) and elderly individuals (Colcombe & Kramer, 2003). The relatively recent infatuation with sedentary lifestyle seen in developed countries creates the precedent of minimal physical activity throughout a typical school or work day. With childhood obesity on the rise and an increasing prevalence of weight-related health conditions such as diabetes, educational and public health campaigns attempt to heighten public awareness about the importance of exercise to physical health. Studies report that as little as 30 min of aerobic exercise per day significantly enhance children’s capacity for creativity and the capacity to deduce several correct answers in response to a given question (Tuckman & Hinkle, 1986) – a measure of cognitive flexibility (Diamond & Lee, 2011). Studies further indicate that aerobic exercise may significantly enhance executive function, improve performance in mathematics, and increase activity in the PFC (Davis et al., 2011). In addition, a meta-analysis of fitness training programs revealed that fitness programs encompassing aerobic exercise may enhance executive control and visuospatial ability in healthy but sedentary elderly adults (Colcombe & Kramer, 2003). The evaluated studies further reported improvements in all of types of cognitive tasks and following all methods of training, with combinations of strength and aerobic training producing greater benefits than aerobic exercise alone. Critics have nonetheless pointed out that many fitness training studies do not adequately control for experimenter involvement and, in some cases, lack control groups altogether (Green & Bavelier, 2008). Therefore, while aerobic exercise may promote the development of various cognitive abilities in children and the elderly, proper controls are necessary to discern the scientific validity of such claims.

#### 4.6. Interaction with nature

Perhaps surprisingly to fervent believers in circumscribed training programs, regular interaction with nature appears to facilitate improvements in cognitive function and behavioral control. Proponents of the beneficial effects of nature strive to increase outdoor exposure lost to the industrial ideals of modern society, offering nature retreats, environmental awareness workshops (Charles, Louv, Bodner, Guns, & Stahl, 2009; Civic Results, 2008), and even



university courses that teach students to harness nature as a context for therapeutic interventions (Naropa University, 2011). Some academic programs, moreover, educate children outdoors rather than in traditional classrooms (Denison Pequotsteptos Nature Center, 2009; Forestry Commission Scotland, 2009) and, according to teacher reports, appear to improve interpersonal work habits, classroom behaviors, and engagement with the learning process. Many of these programs stem from the attention restoration theory, which posits that nature has the capacity to relieve the attention system of its functional load in order to restore effectiveness in cognition (Kaplan, 1995b). According to this theory, nature provides a medium that requires less inhibition of competing stimuli, giving executive function a chance to rest. Controlled and uncontrolled studies suggest, for example, that leisurely outdoor activity may relieve ADHD symptomatology in children (Taylor & Kuo, 2009; Taylor, Kuo, & Sullivan, 2001). In addition, children who have greater exposure to nature from their home environments appear to attain superior attentional control (Wells, 2000) and to react better in response to stressful life events, experiencing lower psychological distress and higher perceptions of self-worth (Wells & Evans, 2003). Studies suggest that walking in natural environments as opposed to urban areas or viewing pictures of nature may improve executive attention (Berman, Jonides, & Kaplan, 2008), and that having near-home views of nature may improve concentration, inhibition, and self-discipline (Taylor, Kuo, & Sullivan, 2002). Interacting with natural environments may therefore enable more efficient executive function and benefit attention as well as self-control.

#### 4.7. Meditation training

Often regarded as methods of relaxation and mental clarity alone, meditative practices aim to train attention and awareness as a means of increasing control over mental processes (Walsh & Shapiro, 2006). Meditation training programs often include one or a combination of focused attention and open monitoring, two common Buddhist techniques that target specific cognitive processes (Slagter, Davidson, & Lutz, 2011). Focused attention meditation involves voluntarily sustaining focus on a given object, whereas open monitoring consists of non-reactively monitoring the content of an ongoing experience, to become aware of the nature of associated cognitive or emotional patterns (Lutz, Slagter, Dunne, & Davidson, 2008; Raffone & Srinivasan, 2010; Slagter et al., 2011). Mindfulness is another common contemplative technique related to open monitoring (Raffone & Srinivasan, 2010) and constitutes one of the most widely studied meditative practices (Walsh & Shapiro, 2006). One definition describes mindfulness as the practice of purposefully and objectively attending to thoughts, emotions, and daily actions (Allen, Blashki, Gullone, & Melbourne-Acad-Mindfulness-Interes, 2006; Tang & Posner, 2009). Meditation therefore represents another technique that fosters the development of cognitive and attentional capacity.

Studies have shown that training with open monitoring or focused attention can trigger neural processes underlying the executive attention system. Reports of activity in the ACC and in both the medial and lateral areas of the PFC (Lutz et al., 2008; Raffone & Srinivasan, 2010) suggest that meditation training (e.g., practicing focused attention) improves conflict processing as well as emotional- and self-regulation, with experienced meditators showing increased activation in these areas compared to non-meditators (Hölzel et al., 2007). In addition, focused attention and open monitoring both associate with neural adaptations such as increased regional blood flow and glucose metabolism in the PFC and ACC (Baijal & Gupta, 2008). Accordingly, studies show that meditators who practice methods of either focused attention or mindfulness can better sustain their attention (Valentine & Sweet, 1999) and

demonstrate improved performance on a number of conflict-related tasks. These include superior perception during binocular rivalry tasks (Lutz et al., 2008), reduced semantic processing required for lexical decision tasks (Pagnoni, Cekic, & Guo, 2008), decreased response variability for dichotic listening tasks (Lutz et al., 2009), and increased mismatch negativity for auditory tones (Raffone & Srinivasan, 2010). Neuroimaging studies additionally reveal that regular meditators who practice open monitoring or focused attention may activate attention-related neural regions more efficiently in response to conflict (Kozasa et al., *in press*). The beneficial effects of these meditative practices may be sustained throughout aging; experienced meditators show fewer age-related declines in gray matter volume of certain neural regions and display higher volumes of several brain regions, including the PFC (Ott, Hölzel, & Vaitl, 2011). Thus, specific forms of meditation can invoke activation of the executive attention system and may thereby improve its functionality over time.

Recent evidence suggests that mindfulness meditation may enhance the neural processes underlying attention and WM. In light of such findings, scientists are now considering the clinical implications of meditation training, particularly for conditions that involve broad aspects of psychological well-being (Chiesa, Calati, & Serretti, *in press*). Studies indicate that mindfulness training may improve cognitive functioning and reduce stress, anxiety, negative affect, and the symptoms associated with various diseases (Chiesa et al., *in press*; Creswell, Way, Eisenberger, & Lieberman, 2007). Adults and adolescents with ADHD, furthermore, have demonstrated improvements of behavioral and neurocognitive impairments following a mindfulness group-training program (Zylowska et al., 2008). This program may have an additional favorable impact on the development of inhibitory control and self-regulation. While experience may increase the benefits of meditation, short-term training also appears to promote observable effects. A school-based mindfulness program in elementary-aged children, for example, demonstrated improvements in behavioral regulation and executive function after a mere 8 h of training, administered over a period of 8 weeks (Flook et al., 2010). By promoting a heightened state of concentration that triggers activity of the attentional networks, meditative practices such as mindfulness training may improve behavior (Jha, Krompinger, & Baime, 2007) and prove useful – at least as ancillary treatment – for individuals with attention-specific deficits.

Despite the promise of meditative practices in improving cognitive function, research surrounding this form of training has yet to unearth optimal protocols and administration strategies that are most beneficial in various populations (Burke, 2010). A number of factors contribute to this ambiguity, such as the use of different scales to measure experimental findings and the scarce inclusion of active control groups in studies (Davidson, 2010). An interesting study addressing this latter issue incorporated sham meditation as part of the experimental design and reported improvements in psychological variables such as mood, depression ratings, and fatigue, following 3 days of mindfulness training (Zeidan, Johnson, Gordon, & Goolkasian, 2010). Observed improvements in behavior, however, may arise as a result of diverse meditative techniques. As a result, in addition to incorporating active controls, studies examine combinations of potentially beneficial training techniques with hopes of creating variants that would induce maximal benefits on attention. One such variant, a Chinese technique known as integrative body-mind training (IBMT), integrates aspects of several meditative practices (Tang & Posner, 2009). In one study, individuals randomly assigned to practice IBMT for 5 days demonstrated significantly better attentional capacity and control over stress compared to individuals who practiced other meditative techniques during the same period of time (Tang et al., 2007). Furthermore, a mere 3 h of this training program was enough to induce an

increase in activation of the ACC and improve the self-regulation of adult participants (Tang et al., 2010). Recently, Tang et al. (2010) also showed that adults who trained in IBMT for 11 h had a higher density of cortical white matter, including a region known to connect the ACC with functionally important neural areas. Further research is nonetheless required to properly attribute the different components of meditative practices to the observed effects on cognitive ability. Future studies may glean more precise information by adequately controlling for all variables involved in specific programs to better parse the training components that promote such positive outcomes.

#### 4.8. Parenting

One of the strongest influences on childhood behavior is the family setting, largely a function of parent or caregiver interactions with a child. Animal studies attest to the importance of parenting, with early monkey studies (Harlow & Mears, 1979) identifying the primary purpose of nursing as a way to ensure intimate body contact between mother and infant – essential for establishing sensory stimulation that facilitates neural development (Illes & Sahakian, 2011). Rodent studies further show that maternal behaviors can reduce neuroendocrine response to stress (Liu et al., 1997) and even alter the genetic expression underlying neuroendocrine and behavioral stress responses (Weaver et al., 2004). Maternal behavior also appears to promote synaptic development in the hippocampus, a structure associated with memory, and may enhance spatial learning and memory in rats (Liu, Diorio, Day, Francis, & Meaney, 2000). Such studies attest to the importance of parenting for the proper development of cognitive ability and emotional stability.

The challenges of caring for children in a typical working-class family increase for parents who have little support or assistance. Studies suggest that disturbed family environments may contribute to the development of childhood psychopathologies. A review of ADHD neurobiology, for example, identified six family-related factors that significantly correlated with the development of childhood mental disturbances, including severe marital discord, low social class, large family size, paternal criminality, maternal mental disorder, and foster placement (Faraone & Biederman, 1998). In light of such reports, a number of therapeutic programs target parents and families as a whole, and sometimes include supplemental interventions for the children. One such program, the Community Parent Education method, implements a 10-week parent education program with concurrent social skill building for children and has gathered evidence showing improved parenting skills and fewer child behavior problems (Tamm et al., 2008). Parent training also appears to improve inattention, over-activity, conduct problems, compliance, and aggression in children (Wells, 2008). Following a 12-session mindfulness training program for mothers with no focus on behavior management, mother–child interactions improved and child compliance increased (Singh et al., 2010). Other studies suggest, moreover, that developing effortful control in children may offset the effects of negative or neglectful parenting (Liew, 2011). These findings highlight the importance of parent–child relationships and of using proper parenting methods to guide behavioral development in children.

The added difficulty of raising children with developmental psychopathologies often leads parents to resort to unjust or ineffective punitive measures. For this reason, a central feature of several parent training approaches includes proper allocation of attention and appropriate management of disorderly behavior. One study of a program for ADHD-related behavior management (Barkley, 1998) revealed that positive attention may in itself induce greater compliance in younger children and further illustrated the importance of attending to child behavior in the school setting in addition to other public environments. Expan-

sions to this program show benefits of parent relaxation training as well as stress-management (Wells, 2008). More recent parent training paradigms have tested the effects of incorporating modern technology or interactive components into the standard program. Adding a sport or recreational component to a father-training program, for example, may enhance the typical benefits of these programs by not only improving behavior-related symptomatology and peer-interactions, but by further increasing attendance and satisfaction with the program, as well as homework compliance (Fabiano et al., 2009). Similarly, an evaluation of a program implementing internet-based training for mothers with infants at risk for poor social–emotional development found increases in mother–child interactions in addition to marginal improvements in impairments associated with interactive behavior and depressive symptomatology (Baggett et al., 2010). These studies indicate that, through training, parents can learn to interact positively with their children, thereby improving parent–child relationships and helping parents teach children proper standards of behavior.

### 5. The effectiveness of training practices: examining the evidence

In this section, we provide a critical examination of the impact of cognitive training in both healthy and pathological individuals. We investigate the generalizability of training and whether specific exercise can transfer to other domains of cognitive function.

#### 5.1. Generalizability and transferability: improving overall function or just specific skills?

As brain training rises in popularity, mounting skepticism challenges the effectiveness of such programs on cognitive ability. While brain training programs may improve performance on a specific subset of skills or tasks, the benefits may not generalize to other domains. One such example is the Bates Method, a behavioral approach to improving visual acuity by altering attentional states through practices such as hypnotherapy (Marg, 1952; Raz, Marinoff, Zephrani, Schweizer, & Posner, 2004). Once considered a groundbreaking technique for visual correction, the Bates Method was disproved by studies suggesting that attention can only influence the priority or processing preference of the fovea, which can impact parameters such as visual detection or reaction time without improving visual acuity *per se* (Raz et al., 2004). Similarly, a number of reviews have evaluated the quality and robustness of training effects in an effort to determine the transferability of different brain training methods to other cognitive or behavioral functions. Recent evidence has led many to believe that perhaps they should not expect much from these methods. A group of British scientists, in collaboration with the British Broadcasting Corporation (BBC) television program “Bang Goes the Theory”, stunned participants and viewers of the program with the allegation that computerized brain training does not benefit general cognitive ability (Owen et al., 2010). Employing the largest sample size ever used in cognitive-training research, the study reported no significant increase in general cognitive performance following 6-weeks of online training in WM tasks, apart from improvement in the practiced tasks. In response to this negative outcome, countless media articles suggested that brain training likely represents wasted effort. Notwithstanding this gross generalization, largely circulated by public media reports, a close examination of the parameters used in the study reveals several limitations. Weak environmental controls, insufficient training duration, and a questionable study population limit possible conclusions. Furthermore, the study involved a sample of healthy individuals, although research suggests that individuals with lower baseline scores may

benefit more from such training. This study nonetheless accentuates the need for more properly controlled studies, thorough analysis of the available data, and careful interpretation of results, to determine the capacity for transfer of computerized brain training programs.

The question of transferability is perhaps most relevant for commercial products. The Cogmed program – advertised as effective in both healthy and pathological populations, both young and old – is among the most thoroughly studied of these products. In an inaugural study, children with ADHD and healthy adults who trained with components of the Cogmed program showed generalized improvements in cognitive control and general fluid intelligence, with additional reduction in symptoms related to ADHD in the pathological population (Klingberg, Forssberg, & Westerberg, 2002). The findings were later replicated in healthy adults (Olesen, Westerberg, & Klingberg, 2004; Westerberg & Klingberg, 2007), although both studies were unclear about the possibility of improvements due to test–retest effects (Shipstead, Redick, & Engle, 2010). A subsequent study in children with ADHD demonstrated significant improvements on measures of attention and intelligence compared to controls, which persisted 3 months after completing 25 sessions of visuo-spatial, backward-digit, and letter-span tasks from the Cogmed program (Klingberg et al., 2005). Notably, however, children randomly assigned to the control group displayed increased scores at the 3-month evaluation period, which may indicate insufficient level of difficulty in the testing measures used (Shipstead et al., 2010). Furthermore, parent – but not teacher – reports indicated reductions in ADHD symptoms (Klingberg et al., 2005). Following 20 sessions of training with Cogmed, children with low WM capacity showed enhanced WM performance that persisted for 6 months, relative to controls (Holmes, Gathercole, & Dunning, 2009). Although this study appeared to demonstrate generalizability to cognitive domains unrelated to the training, the participants did not improve on measures of intelligence, reading, or mathematical reasoning, and follow-up measures did not include comparisons to the control group (Shipstead et al., 2010). A replication of Klingberg et al. (2005) showed that, compared to no-treatment controls, adolescents with ADHD displayed improvements in inattentiveness and executive function, as well as symptoms related to the disorder, as indexed by parent reports (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010). These effects persisted at the 4-month follow-up assessment, and were mirrored by near-significant findings based on teacher reports. Studies therefore suggest that certain commercial brain training products may improve specific skills, although evidence remains scarce regarding the transferability of training to unrelated domains of cognitive function.

While computerized programs show promise along the short term, studies often carry a number of caveats that restrict possible interpretations of the experimental findings, and scarcely demonstrate sustainability of more than several months. In children with ADHD, for example, a program exercising verbal and visuo-spatial short-term memory in addition to WM facilitated improvements on measures of the trained abilities that lasted 6 months (Holmes et al., 2010). Limitations of this study, however, include a lack of control groups, direct ADHD measures, and transfer to IQ scores (Shipstead et al., 2010). The transfer effects of brain training are also inconsistent in healthy populations. In one study, participants significantly improved performance on the Stroop task in addition to reading comprehension as a result of a 4-week WM training program, but did not display increases in general fluid intelligence or in spatial reasoning (Chein & Morrison, 2010b). A different study reported that, after participating in a WM-training program, preschool children exhibited better performance on attentional tasks requiring monitoring, but did not show any improvements on Stroop-like, inhibitory, or problem-solving tasks (Thorell, Lindqv-

ist, Bergman Nutley, Bohlin, & Klingberg, 2009). After participating in 20 sessions of an adapted complex WM span task over 4-weeks, healthy individuals improved on measures of temporary memory and verbal reasoning and further increased their cognitive control, as indexed by their performance on the Stroop task (Chein & Morrison, 2010a). The participants also improved their reading comprehension, which correlated with increases in spatial WM. These findings suggest that this novel training paradigm may improve certain aspects of general attentional mechanisms, such as the management of information maintenance in concordance with other neural processes (Chein & Morrison, 2010a). Such transfer of WM training to untrained attention and memory tasks also appears in older adults (Berry et al., 2010). Although studies often report promising findings, researchers have yet to reach a consensus regarding suitable control groups, accurate measures of parameters such as sustainability, and outcomes that simply result from participation in a training program. As a result of such discrepancies in experimental parameters and measurement tools, comparisons between studies that reportedly measure the same cognitive or behavioral construct are difficult to establish.

## 5.2. Effectiveness without efficacy: ulterior benefits of brain training

The advantages of brain training may reside in the nuances of effectiveness rather than efficacy. In clinical terms, efficacy refers to the ability of a substance, usually a pharmaceutical agent, to produce a desired effect through a particular mechanism of action. Effectiveness, on the other hand, refers to the practical use of a substance. Research has often revealed cases of efficacy without effectiveness (Glasgow, Lichtenstein, & Marcus, 2003); pharmaceutical agents, for example, sometimes produce side-effects that are more noxious than the condition they are meant to treat, thereby rendering them ineffective. In contrast, evidence also suggests that, in some cases, a substance may prove effective without being efficacious. Such phenomena may occur via the placebo effect, or positive effects associated with sham or irrelevant treatment (Benedetti, Mayberg, Wager, Stohler, & Zubieta, 2005). Similarly, although the improvements observed as a result of brain training may be induced due to reasons other than the training itself, such interventions may still be effective through an analogous placebo-like effect. The variety of programs that improve cognition and behavior, coupled with reports of little transferability of brain training, leads to speculation that brain training may not contain a specific mechanism of action. The act of providing treatment for a particular condition, however, may in itself decrease the associated symptoms (Kermen, Hickner, Brody, & Hasham, 2010; Tilburt, Emanuel, Kaptchuk, Curlin, & Miller, 2008). Improvements in cognitive performance may also occur as a result of motivational factors, including active interest in individual performance (Green & Bavelier, 2008). Brain training may therefore represent an effective intervention or potential treatment for clinical populations even if research deems the specific mechanism tenuous.

## 6. Who can benefit from brain training?

Brain training programs may impact an assortment of neurological states. From the healthy to the neurologically impaired, programs aim to enhance or rehabilitate cognitive function in both young and old. In this section, we examine evidence for the benefits of brain training programs in various populations.

### 6.1. Brain training in typical development

Evidence indicates that brain training can enhance healthy neural development. Unlike pathological populations, typically

developing children and adults train the brain to fortify skills already acquired in an effort to distinguish their abilities among peers and thrive in an increasingly competitive society. While the effects are often subtle, such training may sometimes yield dramatic results. One particularly effective technique comprises strategy training, which involves learning effective approaches to encode, maintain, and retrieve information from WM (Chein & Morrison, 2010a). One study reported the memorization of 80 digits after learning the strategy of grouping numbers into running times (Ericsson & Chase, 1982). A more recent example of strategy training is the story of Joshua Foer, the 2006 USA Memory Champion (Foer, 2011). A freelance journalist with no previous experience in competitive memorizing, Foer not only defeated his competitors – experienced mnemonists – in the championship, but also broke the world record in the speed card category. His trick consisted of an age-old memorization technique by which he trained himself to associate tedious facts, difficult for the human brain to remember, with eccentric images that an individual is unlikely to forget. Neuroimaging studies suggest that competitive mnemonists and high-rankers of World Memory Championships use similar stratagems during performance of WM and long-term verbal memory tasks (Maguire, Valentine, Wilding, & Kapur, 2003). Despite having typical brain morphology compared to controls, this population displays increased regional activation of areas associated with spatial memory and navigation, which may underlie the learning of route strategies to recall long lists of items (Maguire et al., 2003). Therefore, typically developing individuals may also display enormous improvements in performance following specific types of training.

## 6.2. Training the aging brain

With mounting evidence for cognitive decline in the elderly, brain training programs for geriatric populations seem increasingly relevant and enticing. In 2005, a global prevalence study estimated that 24 million individuals were living with dementia, of whom 3–4 million were residing in North America, and that this number would double every 20 years (Ferri et al., 2005). While the leading cause of age-related dementia is Alzheimer's disease (Ferri et al., 2005), studies have identified a number of risk factors associated with impaired cognitive ability including decreased physical activity (Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001; Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001), lack of education (Callahan et al., 1996), health conditions such as diabetes and hypertension (Kuo et al., 2005), and the presence of certain pathological (McKeith et al., 1996) and genetic traits (Duff et al., 1996). Reports of delayed cognitive decline as a result of brain training have propelled a market of products aimed at preventing or even reversing the effects of age on cognition. These programs, often administered through computerized media or video game consoles, carry varying degrees of scientific validity. The popular BrainAge program (Nintendo, 2007) is one prominent example among the myriad of commercialized products that holds little scientific evidence of efficacy. A recent study using this game console, moreover, suggests that elderly individuals work more efficiently using a paper-and-pencil interface, although decreased technological sophistication appears to evoke lower levels of arousal (Nacke, Nacke, & Lindley, 2009). On the other hand, certain training techniques have shown promise for the delay or prevention of neurodegenerative diseases. Animal studies indicate that enriched environments may increase cognitive function (Arendash et al., 2004) and reduce pathological traits for Alzheimer's, including neural deposition of amyloid protein (Lazarov et al., 2005). In humans, training appears to improve memory in individuals with mild cognitive impairment (Belleville et al., 2011) or mild-to-moderate Alzheimer's (Zanetti et al., 1997). A recent evaluation by the

National Institutes of Health found little evidence for pharmaceutical or dietary preventative measures for cognitive decline (Davignus et al., 2010), underlining the importance of increasing research pertaining to cognitive training in such populations. With positive preliminary findings in elderly individuals with cognitive impairments, this type of training may constitute a crucial source of remediation for cognitive decline.

Training need not be circumscribed or even deviate from typical daily activities. An interesting take on cognitive training in elderly populations, the Active Cognitive Stimulation-Prevention in the Elderly (AKTIVA) program entails engagement in leisurely activities that nonetheless provide some form of cognitive stimulation (Tesky, Thiel, Banzer, & Pantel, 2011). By combining cognitively demanding activities previously shown to help prevent or delay onset of dementia, AKTIVA offered a potentially fun and engaging way to promote sustainability of cognitive function throughout old age. A randomized controlled study assessing the effectiveness of this program reported significant improvements in speed of processing in participants over 75 years of age, as well as subjective ratings of age-related memory declines in participants younger than 75 years of age. Overall, however, this study revealed no significant benefits of the AKTIVA program compared to controls (Tesky et al., 2011). While such paradigms may offer an enjoyable and convenient method for training, these findings highlight the importance of discerning what components underlie the success of effective programs.

In healthy elderly populations, brain training appears to delay the natural progression of cognitive decline by enhancing learning capacity and specific forms of memory (Buiza et al., 2009; Park, Kwon, Seo, Lim, & Song, 2009). The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study (Jobe et al., 2001) – the largest randomized controlled trial to date studying cognitive decline in healthy elderly individuals – provides evidence for the effectiveness of 10 1-h sessions of reasoning training, memory training, and speed of process training in improving performance on the specific abilities trained (Ball et al., 2002). Participants who received four additional reasoning and speed training sessions at 11-months following program completion, moreover, appeared to experience these benefits to a significantly greater extent; these booster effects were not observed for the memory training group. These effects were sustainable throughout the 24-month follow-up (Ball et al., 2002), with later studies further reporting delays in the decline of health-related quality of life for speed-trained participants (Wolinsky et al., 2006) during the same period of time. Nonetheless, effect sizes for these benefits were small and decreased over time. Furthermore, while reasoning and speed training benefited a relatively large percentage of participants on the corresponding cognitive abilities tested, few participants improved on the memory-related cognitive abilities trained. These improvements also generalized to cognitively demanding daily abilities such as everyday processing speed and driving habits, although only for the speed training group. Despite these findings, all participants remained functionally independent throughout the course of the observation period (Ball et al., 2002). A review of studies on cognitive training in healthy elderly individuals nevertheless concluded that while such training may effectively improve performance on tasks related to the training, little evidence demonstrates generalizability to general cognitive domains (Papp et al., 2009). Thus, although brain training may improve specific cognitive abilities in the healthy elderly, this type of intervention does not appear to improve overall cognitive function.

## 6.3. Training for recovery after stroke

Cognitive training also appears to benefit the process of rehabilitation following stroke. Neuroimaging studies reveal that, once

stroke recovery occurs, patients undergo structural changes within the brain that enable functional compensation for damaged neural areas (Stuss et al., 1999). While the most common impairments experienced after stroke involve motor-related disabilities, cognitive deficits also manifest in a large percentage of patients and may persist for years following the event (Langhorne, Bernhardt, & Kwakkel, 2011; Skidmore et al., 2011). Evidence surrounding the effectiveness of such interventions for stroke rehabilitation, however, remains conflicting. On one hand, certain studies report post-training improvements in functions such as alertness and sustained attention (Lincoln, Majid, & Weyman, 2000), WM (Westerberg et al., 2007), as well as perception and spatial neglect (Langhorne et al., 2011). One study revealed enhanced skill-acquisition in stroke patients who participated in a meta-cognitive program aimed at increasing their sense of autonomy (McEwen, Polatajko, Davis, Huijbregts, & Ryan, 2010). Despite these encouraging results, the extent to which such training improves cognitive function and whether it benefits quality of life for patients is unclear. Furthermore, other cognitive functions often damaged by stroke, such as linguistic ability, do not appear to improve significantly as a result of the cognitive training techniques used (De Jong-Hagelstein et al., 2011). Cognitive remediation techniques may therefore assist the natural recovery pattern in patients following stroke, although further study remains to elucidate the most effective methods as well as the extent to which such training measurably improves daily life.

#### 6.4. *The potential of brain training for psychopathology*

With the dramatic surge in attention-related disorders, parents and professionals are growing increasingly eager to optimize the system of attention both in school and at work. One example is ADHD, a disorder laced with symptoms relating to inattention, hyperactivity-impulsivity, or a combination of the two (Barkley, 1997; Steinhausen, 2009; Wells, 2008). With an approximate prevalence of 5.3% worldwide, in boys more than in girls, ADHD is the most common childhood-onset psychopathology and persists into adulthood in 30–50% of clinically-diagnosed cases (Barkley, 1997; Wallis, Russell, & Muenke, 2008). Another example is Tourette's Syndrome (TS), a neurodevelopmental impulse-control disorder (Robertson, 2003). With a brief review of some complexities surrounding the etiology and treatment of these disorders, we discuss the potential of specific forms of brain training as alternatives to medication.

##### 6.4.1. *The appeal of brain training to ADHD*

ADHD affects neural structures associated with attentional processes. Neuroimaging studies indicate that children with ADHD have smaller global brain volumes compared to typically developing children, in addition to localized decreases in PFC, caudate, cerebellum, and corpus callosum size (Kieling, Goncalves, Tannock, & Castellanos, 2008; Steinhausen, 2009). Studies also report diminished activity in the circuits underlying executive attention, including regions of the PFC and ACC (Spencer, Biederman, Wilens, & Faraone, 2002), which may bring about the observed differences in cognitive control. Developmental manifestations of ADHD can be extremely pronounced and involve WM, speech internalization, modulation of goal-directed behaviors, as well as self-regulation of drive and affect (Faraone & Biederman, 1998). While these deficits may be more prominent in children, studies report analogous impairments of attention, self-control, and time estimation in adolescents with ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001).

ADHD is perhaps best recognized through the marked difficulties that children exhibit with interpersonal relationships. A study in the United States found that, among a population of children

diagnosed with ADHD, over one third of parents reported significant emotional and behavioral difficulties in their children, with nearly 40% reporting deficits in aspects of daily living (Strine et al., 2006). These difficulties may arise, in part, as a result of an inferior capability to distinguish emotionally-charged facial expressions (Pelc, Kornreich, Foisy, & Dan, 2006). In addition, studies show peer-rejection rates of children with ADHD span 52–82%, which may be due to increased aggression, poorer social skills, and inflated self-perception (Murray-Close et al., 2010). Such reports indicate that children with ADHD stand to benefit from programs that may teach them to control their emotions and behavior.

Treatment options for ADHD are sparse and most commonly comprise psychostimulant medication, which shows marginal effectiveness. Improvements in the conduct and academic performance of medicated children (Elia, Ambrosini, & Rapoport, 1999) confirm the short term efficacy of psychostimulants, of which methylphenidate and amphetamine are most commonly prescribed. This type of medication appears to reduce characteristic behaviors associated with ADHD, including inattentiveness, hyperactivity, and impulsivity (The MTA Cooperative Group, 1999), with additional improvements in compliance, aggression, and academic achievement (Halperin & Healey, 2011). Reports further indicate varying levels of improvement in performance and reaction time on various WM and executive function tasks in individuals with ADHD taking stimulant medication (Barnett et al., 2001; Swanson, Baler, & Volkow, 2011). These studies suggest that psychostimulant medication effectively decreases ADHD symptoms.

Current ADHD medication, however, has several limitations that incite parents and professionals to demand superior treatment options. First, while short term effects of these drugs are well documented, there is ongoing debate regarding the effects of long-term psychostimulant consumption. While some studies report continued stimulant efficacy for a number of years following initial treatment in children and adults (Bejerot, Ryden, & Arlinde, 2010; The MTA Cooperative Group, 1999), high drop-out rates and findings of a drop-off in effect after a few years render the collective evidence inconclusive at best (Swanson et al., 2011). Even the positive short-term benefits of psychostimulant drugs come at the price of unwanted side-effects and potential long-term risks. Both methylphenidate and amphetamine trigger similar, dose-dependent, adverse effects, of which insomnia and diminished appetite – seen in approximately 80% of children with ADHD – are the most common (Elia et al., 1999). Reports also identify cardiovascular problems such as elevated resting heart-rate and blood pressure, in addition to stunted growth and the development of tics (Bejerot et al., 2010; Daughton, Liu, West, Swanson, & Kratochvil, 2010; Elia et al., 1999). Another concern pertains to substance abuse, highly comorbid with ADHD and sometimes triggered by continued stimulant-use (Daughton et al., 2010; Szobot et al., 2011). Finally, not all individuals respond to psychostimulants. Reports indicate that 70% of ADHD patients respond to the first stimulant drug administered, and an additional 10–20% respond if a second class of stimulant is tried in succession (Daughton et al., 2010). These response rates, however, do not appear to vary with ADHD subtype (Solanto et al., 2009). These findings clearly warrant demand for safer and more effective treatment options.

Scientists have attempted treating ADHD with alternate types of medication, including non-stimulant drugs, antidepressants, antipsychotic medication, and alpha-adrenergic agonists. While non-stimulant medications have reportedly fewer side-effects and long-term risks, their impact on ADHD symptoms is not as strong as psychostimulants (Daughton et al., 2010). Likewise, antidepressant, antipsychotic, and alpha-agonist medications show only mild efficacy, although the findings come from small populations and include reports of adverse side-effects (Daughton et al., 2010; Elia et al., 1999; Ipser & Stein, 2007). Reports of death in

children taking a combinations of psychostimulants and alpha-agonists, moreover, represent a clear illustration of the need to determine the ramifications of taking several classes of drugs simultaneously (Elia et al., 1999). Such reports suggest that these types of drugs may not constitute viable alternatives to psychostimulant treatment in ADHD.

Given the potentially noxious effects of psychostimulant medication and the relative ineffectiveness of other drug types, widespread efforts aim to develop non-pharmacological therapies that would regulate unwanted ADHD symptomatology without the threat of long-term adverse effects. Currently, many studies indicate that children with ADHD strongly benefit from family therapy – with particular emphasis on parent training – as well as social skill training (Elia et al., 1999; McBurnett & Pfiffner, 2008; Wells, 2008). Certainly, providing a more structured and supportive environment may offset conditions that play a role in triggering the onset of ADHD symptoms in children, and has potential to markedly improve the pathophysiological course of the disorder.

Cognitive treatments for ADHD entail brain training programs and show promising effects in both children and adults (Galbiati et al., 2009). Studies of programs such as Cogmed (Klingberg, 2008; Olesen et al., 2004), report improvements in both cognitive ability and behavioral symptoms of ADHD (Halperin & Healey, 2011). Other programs appear to facilitate increased cognitive performance and attentional ability in children, although these benefits do not always extend to improvements in behavior (Kerns et al., 1999). The effects of certain forms of training, furthermore, are comparable with the effects of medication (Klingberg et al., 2005). Similar to pharmacotherapy, however, many of these training programs do not afford children the opportunity to develop their own self-control (Singh et al., 2010). Cognitive training programs supplemented by interpersonal interactions may therefore allow children to receive behavioral monitoring and continual feedback, thereby teaching them to monitor their actions and respond in a situation-appropriate manner. Programs for children combining medication with cognitive training, including specific forms of meditation, reveal significant improvements in symptoms related to inattention, impulsivity, and hyperactivity, as well as enhanced self-esteem and child-parent relationships (Rubia, 2009). The reported improvements in cognitive performance and ADHD symptomatology as a result of cognitive training attest to the promise of such interventions as a component of ADHD treatment.

#### 6.4.2. Brain training in Tourette's Syndrome

While pharmacological options exist for the treatment of TS (e.g., haloperidol, pimozide, or clonidine), general consensus posits that such therapies are suboptimal, and prominent researchers have recently lamented that medication therapies for TS are woefully inadequate (Singer & Walkup, 1991). Drug efficacy for TS is inconsistent and unpredictable, and at best, offers only symptomatic relief (Peterson & Cohen, 1998). Benefits often come at the expense of intolerable side-effects, including sedation, parkinsonism, tardive dyskinesia, cognitive dulling, dry mouth, fatigue, dizziness, weight gain, and metabolic problems (Swain, Scahill, Lombroso, King, & Leckman, 2007). Most current treatments for TS are potentially toxic to the central nervous system. Moreover, those treatments tend to be terribly ineffective for many individuals and at best provide a modest reduction of the symptomatology (Phelps, 2008). Specialists hence recognize the need for alternatives and therapeutic adjuncts.

Behavioral interventions such as habit-reversal training (HRT) have been shown to be effective in ameliorating the symptoms of TS (Feldman, Storch, & Murphy, 2011; Himle, Woods, Piacentini, & Walkup, 2006; Piacentini et al., 2010; Woods et al., 2011). We have outlined how attentional interventions, including AT, can aid in overcoming the debilitating symptoms of impulse control

disorders via improvements to this network, with a special focus on TS (Raz, Keller, Norman, & Senechal, 2007). Similar to HRT, AT reduced the symptoms of TS in a pilot study involving 12 experimental and 12 control participants. Our preliminary findings suggest that, compared to a control condition – watching popular children's videos, relaxing, and playing general video games with intermittent dialogue pauses matching for child–adult interactions – AT decreased visible tics and impulsivity in young individuals with TS and increased their ability to regulate emotions and persist with goals in the face of distractions. Findings from our pilot data further purpose that these changes translate into an increase in the quality of life (Raz, *in press*). Thus, tic-awareness programs, recognizing internal urges, switching to voluntary behaviors that are physically incompatible with the tic, relaxation guidance, and learning to identify antecedents of the tics, appear to be a promising behavioral approach for people with TS.

## 7. The business of brain training and conflicts of interest

Brain training constitutes a lucrative market. Widespread concern regarding cognitive decline in the aging population and obsession with maximizing efficiency in school and at work have created a society of brain trainers that spare little expense on cognitive fitness. With individual programs costing hundreds to thousands of dollars, this industry feeds on growing consumer interest to yield enormous profit. In 2010, the Scientific Learning Corporation – developer of programs such as FFW – generated revenues over \$43 million (Ernst, 2010). In the US alone, revenues of brain fitness software attained \$265 million in 2008, increased from \$100 million in 2005 (Martin, 2009), and may accumulate revenues in the billions by 2015. While healthcare systems have contributed a large portion of this figure, individual consumers are playing an increasingly prominent role, as are educational systems, athletic organizations, and the US military (Fernandez, 2008). In addition, programs targeting age-related cognitive decline represent a particularly profitable market, with hundreds of retirement homes now offering brain fitness products to tenants. Hence, brain training is nothing short of big business.

The brain training industry sometimes engenders conflicts of interest (COI) that could bias the scientific integrity of published work. Similarly to pharmaceutical and medical device companies (Brennan et al., 2006), distributors of cognitive exercise programs often fund studies evaluating their product or assign product testing to academic shareholders (Corporation, 2010; Pearson, 2011; Scientific Learning Corporation, 2011). Such COI may impede the objectivity of studies by provoking the omission of results unfavorable to the desired outcome or the reporting of findings that are favorable to the funding companies (Easterbrook, Gopalan, Berlin, & Matthews, 1991; Lexchin, Bero, Djulbegovic, & Clark, 2003; Turner, Matthews, Linardatos, Tell, & Rosenthal, 2008). Alternately, authors with ties to industry (Smith et al., 2009) may overextend the interpretations of their results by emphasizing statistical significance while ignoring relatively small effect sizes that would indicate little or no clinical significance. Thus, COI potentially compromise the integrity of research.

COI are especially troubling in clinical contexts (e.g., psychotherapy, neurofeedback), where target populations may ultimately rely on biased research and thereby overlook a more appropriate remedy when searching for a treatment. Defenders of COI speculate that scientists may not obtain the funds necessary to conduct research on potentially groundbreaking treatments or programs without the benefit of commercial support (Stossel, 2007, 2008). In a similar vein, some brain training investigators working with industry claim that separation of research and business is impractical because product distribution is less efficient outside of

commerce (Merzenich, 2011); however, little, if any, evidence supports this claim. The history of clinical research, furthermore, attests to the dangers of distributing substances in need of more rigorous testing before becoming publicly available (Brody, 2008). Proponents of COI also assert that segregation between clinical goals and promotional motivation is impossible; even researchers strive to put their work in a positive light and professionals of the medical field advertise in order to attract clientele (Stossel, 2007). However, unlike such conflicts, which are inherent to human ambition, commercial COI result from voluntary choice and are therefore avoidable (Kassirer, 2009b). Furthermore, although researchers often claim that no incentive could compromise their impartiality, evidence suggests that self-serving biases occur subtly and unintentionally (Kassirer, 2009b). COI may therefore tarnish experimental findings and bias clinical practice.

The scientific community often considers disclosure to absolve the existence of COI in research. Researchers who shelter themselves behind the veil of disclosure, however, merely attest to the existence of a COI, but neither confirm nor deny the existence of partiality in their work (Kassirer, 2009a). The onus of identifying bias therefore passes to individuals who have no objective measure of the partiality of a study. In addition, disclosure may hinder the objectivity of studies by allowing scientists to retain their favorable ties with corporations so long as they make their potential partiality known to the public. Instead of merely disclosing COI in research and brushing the issue aside, a more effective stratagem may include the elimination of potentially questionable relations, the validation of scientific rigor within study design, and the independent replication of all influential findings.

## 8. Conclusion

Brain training draws on both evidence and hype. Examination of the findings reveals that consumers – largely oversold on individualized modules and programs (e.g., for ADHD) – often rely on claims that are scientifically unsubstantiated. For these programs to be clinically useful, they will have to accomplish what few interventions, if any, have achieved: generalize circumscribed laboratory and computer skills to tangible gains in the classroom, during play, and in other ecological settings. This lofty goal, however, has hardly been achieved.

Few scholars have distinguished their research efforts by providing scientific evidence to support the impact of their computerized training in both children and adults. Specific researchers have demonstrated sustainable behavioral improvements using independent programs. Following brief interventions, children have demonstrated improvements in measures of non-verbal intelligence, language development, and control over affect and executive function. In addition, electrophysiological and neuroimaging studies report a shift of signature brainwaves toward more adult-like patterns and maturation of neural modules implicated in attention, respectively. Some of these benefits further extend to both healthy and pathological adults. These programs, however, have rarely made a trailblazing breakthrough in improving symptoms and resolving impairments. In this regard, such approaches to cognitive remediation show promise, but hardly represent stand-alone treatments.

While computerized programs constitute the most accessible form of brain training, researchers have shown benefits from specific contemplative techniques and lifestyle-related practices. Programs encompassing mind–body meditative techniques in healthy adults, for example, demonstrate training-related alterations of white matter connectivity in neural areas associated with the executive attention system, and appear to alleviate feelings of stress and pain. Meditation training has also proven beneficial in adults

with ADHD, enhancing their performance on conflict and inhibition tasks, and decreasing their reported symptoms related to the disorder. Other methods of training show similar benefits for improving cognitive function and behavioral control through executive attention. These include bilingualism, musical training, physical exercise, regular interaction with nature, and proper parenting. Such findings support practice in alternate forms of training that need not involve circumscribed programs.

Cognitive training in psychopathology may represent an adjunct, if not a possible alternative, to some pharmacological treatment options. Psychiatric treatment of developmental psychopathologies largely relies on drug interventions. Pharmacological approaches may engender undesirable side effects and sometimes carry only marginal benefits, especially over time. With the current credibility crisis surrounding pediatric psychiatry and pharmacotherapeutics, crafting effective drug-free treatment alternatives seems highly relevant. Current findings, although preliminary, suggest that training options are safe, fun, and provide larger gains for children who suffer from greater cognitive deficits. Combining training with medication, furthermore, appears to produce maximal benefits that exceed behavioral or pharmacological treatments alone. Thus, given extant knowledge about available treatment options, brain training paradigms may be worthy of consideration, especially for populations with specific developmental deficiencies.

Despite promising findings in both healthy and cognitively-impaired individuals, studies often contain a number of caveats that weaken the interpretations drawn from experimental results. Such limitations relate to inadequate controls and measures of cognitive function, behavior, and training sustainability. The context of brain training research, furthermore, sometimes contains COI that prompt overly ambitious conclusions. Notably, studies indicate that such training does not constitute a “quick fix” for a lifetime of impairments. Rather, long-term exposure and application of the training is likely to create lasting results. These caveats highlight the importance of skepticism concerning experimental findings as well as the possible necessity to re-evaluate current research standards in this field.

Incorporating brain training into school curricula – alongside mainstream courses such as history, language, physical education, and math – may provide the long-term exposure needed to reap the benefits. By mimicking Eastern traditions that integrate contemplative practices into daily routine, cognitive training may have some tangible benefits to offer. In this regard, brain training likely impacts parameters related to improved quality of life, including self-esteem, depression, anxiety, and stress. While further research will have to determine the forms of training that would most benefit specific populations, the effectiveness and sustainability of such programs will likely depend on training frequency and method of delivery.

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