Published in final edited form as:
Prev Sci. 2013 June ; 14(3): 218–228. doi:10.1007/s11121-012-0345-7.

Adolescent Neurocognitive Development, Self-Regulation, and School-Based Drug Use Prevention

Pallav Pokhrel,
Cancer Prevention and Control Program, University of Hawaii Cancer Center, 677 Ala Moana Blvd., Suite 200, Honolulu, HI 96813, USA

Thaddeus A. Herzog,
Cancer Prevention and Control Program, University of Hawaii Cancer Center, 677 Ala Moana Blvd., Suite 200, Honolulu, HI 96813, USA

David S. Black,
Semel Institute for Neuroscience and Human Behavior, University of California Los Angeles, Los Angeles, CA 90095, USA

Adnin Zaman,
Keck School of Medicine, University of Southern California, Los Angeles, CA 90089, USA

Nathaniel R. Riggs, and
Colorado State University, Fort Collins, Colorado, CO 80523-1570, USA

Steve Sussman
Keck School of Medicine, University of Southern California, Los Angeles, CA 90089, USA

Pallav Pokhrel: ppokhrel@cc.hawaii.edu

Abstract

Adolescence is marked by several key development-related changes, including neurocognitive changes. Cognitive abilities associated with self-regulation are not fully developed until late adolescence or early adulthood whereas tendencies to take risks and seek thrilling and novel experience seem to increase significantly throughout this phase, resulting in a discrepancy between increased susceptibility to poor regulation and lower ability to exercise self-control. Increased vulnerability to drug use initiation, maintenance, and dependence during adolescence may be explained based on this imbalance in the self-regulation system. In this paper, we highlight the relevance of schools as a setting for delivering adolescent drug use prevention programs that are based on recent findings from neuroscience concerning adolescent brain development. We discuss evidence from school-based as well as laboratory research that suggests that suitable training may improve adolescents' executive brain functions that underlie self-regulation abilities and, as a result, help prevent drug use and abuse. We note that considerable further research is needed in order (1) to determine that self-regulation training has effects at the neurocognitive level and (2) to effectively incorporate self-regulation training based on neuropsychological models into school-based programming.

Correspondence to: Pallav Pokhrel, ppokhrel@cc.hawaii.edu.

Keywords

Neurocognition; School based; Adolescents; Prevention

Introduction

Recently, several dual process models of self-regulation have been posited based on social cognition (e.g., Gerrard et al. 2008; Hofmann et al. 2009) or neurocognitive research (e.g., Bickel et al. 2007; Bechara 2005) that have implications for adolescent drug use etiology and prevention (Gerrard et al. 2008). In general, these models are in agreement concerning the two modes of self-regulation as represented by reasoned and reactive processes that have been alternatively referred to as “reflective” and “impulsive” systems (Hofmann et al. 2009), or “impulsive” and “executive” systems (Bickel et al. 2007). Higher risk-taking tendencies during adolescence have been explained in terms of greater imbalance between the two neurobiological systems at this developmental stage (Steinberg 2005, 2010; Casey et al. 2008). In this paper, we argue that school-based prevention programming may benefit from utilizing recent developments in neuroscience to address adolescents’ neurocognitive risk for drug use and abuse. The following sections provide a brief overview on the application of neuroscience to adolescent development, indicate current school-based prevention strategies that may positively impact adolescent brain development, and suggest new directions for the development and implementation of drug use prevention programs.

Neuroscience, Self-regulation, and Adolescent Drug Use

Broadly defined, self-regulation refers to regulation of thoughts, emotions, and behavior in order to achieve a goal or maintain a personal standard (Baumeister and Vohs 2004). Poor self-regulation consistently has been associated with health risk behaviors, including drug use (e.g., cigarette use, alcohol abuse, illicit drug use), as individuals are thought to engage in risky behaviors because of their inability to self-regulate properly (de Ridder and de Wit 2006). Recent neuroscience research suggests that adolescents in particular are at higher risk for drug use and abuse because of their brain-related developmental vulnerability to poor regulation (Steinberg 2010; Spear 2010). The neural networks in the brain responsible for self-regulation show suboptimal development during adolescence compared to adulthood (Chambers et al. 2003; Spear 2010). Due to the still maturing neurocircuitry, especially the networks involving prefrontal cortical regions, adolescents tend to show poorer inhibitory control (i.e., ability to control a prepotent response) and higher impulsivity and risky decision-making tendencies. Further, developmental changes in certain brain regions (e.g., nucleus accumbens) related to reward motivation are likely to place adolescents at increased risk for using drugs. This is because the changes in the motivational regions of the brain are likely to result in increased sensitivity to the rewarding effects of drugs and decreased sensitivity to drugs’ aversive effects (Spear 2010). Thus, risk-taking tendencies during adolescence tend to outweigh self-control abilities, which are undergoing development owing to the strengthening and refinement taking place in the brain networks responsible for executive control functions.

Adolescent Brain Development and Executive Functions

The executive function system represents a higher-order control system that regulates lower-order brain functions (e.g., sensory perceptions, short-term memory, language and motor skills) and manages goal-directed, future-oriented behaviors (Spear 2010). According to Fuster (2008), executive functions (EFs) represent "the ability to organize a sequence of actions toward a goal" (pp.178). Thus, EFs form the neurocognitive basis of self-regulation (Fuster 2008). Most neural substrates underlying EFs are considered to be located in the prefrontal cortex of the brain. Currently, there seems to be relatively little understanding regarding all the various neural substrates involved in the different EF processes. Further, there seems to be no straightforward consensus regarding the distinct processes constituting the EF system (Spear 2010). However, research shows that deficiencies in EFs are related to abnormalities in attention, working memory, long-term memory retrieval, planning, temporal integration of memory and goal, decision making, monitoring, and inhibitory control (Fuster 2008). Thus, EFs may be divided into four types: attention, working memory, inhibitory control, and goal-directed regulation (e.g., goal setting/planning, self-monitoring, and decision making/problem solving). These processes are interrelated, and some or all of these processes act synergistically to maintain and conclude a goal-directed behavior (Fuster 2008).

Successful execution of actions toward short-term goals requires attention control, working memory, and inhibitory control that are functional. Attention control is one of the basic EFs and represents the ability to focus on the processing of a specific information, excluding all others (Fuster 2008). Some aspects of attention control include alertness, set shifting (i.e., shifting attention according to the action being enacted), and interference control (i.e., ability to resist inference against ongoing attentional focus). Inhibitory control represents the ability to suppress any internal or external influence that may interfere with the currently ongoing sequence of actions, and working memory represents the ability to retain information pertinent to a task in short-term memory and use that information to perform that task.

Execution of actions toward long-term goals requires related but more complex cognitive functions such as goal setting/planning, self-monitoring, problem solving/decision making. Planning represents the ability to utilize information obtained from selective retrieval of long-term memory, such as memory of past actions, for the anticipation of future events. Planning provides a conceptual scheme for the execution of a goal-directed behavior and, based on the anticipation of consequences, lays out the order of prospective actions. Reasoned decision making involves choosing an action after rationally evaluating the potential risks and rewards associated with its outcomes (Gerrard et al. 2008). Successful execution of goal-directed behaviors also depends largely on the ability to self-monitor. Monitoring enables one to assess the discrepancies between one's actions and one's goals, thus creating feedback which allows one to correct subsequent actions (Carver and Scheier 1981).

Research shows that the development of EFs parallels the structural maturation of the prefrontal cortex (e.g., Anderson et al. 2002). The prefrontal cortex is one of the last cortical structures of the brain to reach full ontogenetic development and may not achieve complete maturation until the later parts of young adulthood (Fuster 2008). For example, improvements in planning and decision making during adolescence, compared to childhood, may be linked with structural developments in the dorsolateral and ventromedial prefrontal cortex, respectively (Yurgelun-Todd 2007). Most notable of these developmental changes occur in the form of changes in gray and white matter volumes. Recent neuroimaging studies suggest that a continuous increase in the brain white matter volume occurs during adolescence (Paus 2005). For example, a significant growth is noticed in the posterior corpus callosum, the collection of over 200 million nerve fibers that allow communication between the right and left hemispheres of the brain (Paus 2005). In addition, the gray matter volume, which increases substantially in early childhood, appears to decrease during adolescence in certain cortical structures, including the prefrontal cortex (Giedd 2004).

Reduction in cortical gray matter volume and increase in white matter volume may occur due to increased myelination and/or due to increased synaptic pruning (Paus 2005). Myelination refers to the process of covering an axon (i.e., the projection of a neuron that conducts electrical impulses away from the neuron's cell body) with a fatty substance called myelin. Increased myelination results in a more efficient propagation of electrical impulses (action potentials) along an axon. Synaptic pruning appears to serve a number of functions that facilitate the development of EFs. Synaptic pruning involves selective removal of "inefficient" synapses (Chambers et al. 2003). For example, the process appears to stabilize the firing patterns of cortical neurons, which in turn is thought to enhance working memory capacity. Thus, both myelination and synaptic pruning likely enhance the efficiency of cortical information processing as well as the connectivity between cortical and subcortical regions and may significantly influence EF development (Steinberg 2005; Paus 2005; Chambers et al. 2003; Spear 2000). Thus, the brain development during adolescence is driven by myelination and synaptic pruning to a large part and involves organization and reorganization of neural networks that form the substrates for EFs.

Adolescent Brain Development and Risk Taking

Several studies suggest that risk-taking tendencies increase during adolescence (Boyer 2006; Leather 2009). Spear (2010) has outlined three main ways in which elevated risk taking is related to the developing adolescent brain. First, decision-making skills are not fully developed in adolescence. For example, adolescents may not be able to make quick risk-averse decisions based on limited information. In addition, adolescent decision making is more vulnerable to the influence of momentary emotions or social context (e.g., peers), as a result of which adolescents are more prone to discounting the negative consequences of a risky behavior. Recent findings based on the Iowa Gambling Task (IGT; Bechara et al. 1994), which measures affective decision making (i.e., decision making under the influence of emotions), show that adolescents, compared to adults, are less likely to avoid a risky choice based on an aversive feedback that signals a probable negative consequence (Cauffman et al. 2010). Performance on the IGT has been linked with the ventromedial prefrontal cortex (Bechara 2005).

Second, novelty/sensation-seeking tendency increases during adolescence (Arnett 1992; Sargent et al. 2010), which is related to adolescents' tendency to engage in risky behavior in order to experience novelty, excitement, and other sensations of intense positive arousal (Zuckerman 1992). Research shows that increase in reward sensitivity during adolescence corresponds to the simultaneous changes occurring in reward-related neurocircuitry in the brain, especially the dopamine system (Casey et al. 2008; Chambers et al. 2003; Spear 2000). Dopamine is a neurotransmitter in the brain, and the input of dopamine into the nucleus accumbens, in response to reward stimuli, is crucial in attributing a motivational value to the reward stimuli and, subsequently, influencing behaviors related to those rewards (Spear 2010). The dopamine projections from the ventral tegmental area into the nucleus accumbens form an important part of the mesocorticolimbic dopamine system, which is central to the brain reward system which also involves parts of the prefrontal cortex (Spear 2000). Several motivational stimuli have been associated with dopamine stimulation in the nucleus accumbens, including the drugs of misuse, agents of natural reward (e.g., food, sex), and novelty-seeking behavior (Bardo et al. 1996). Research shows that the level of dopamine turnover in the nucleus accumbens (i.e., the rate at which dopamine is made and used) among adolescents is higher than among children and adults (Spear 2000; Chambers et al. 2003) and that this dopaminergic hyperactivity might be associated with greater reward-related incentive salience or greater sensitivity to the hedonic effects of reward agents, including drugs (Volkow et al. 2007; Berridge 2007; Spear 2010).

Third, adolescents are more prone to taking risks because they are subject to greater impulsivity and poorer inhibitory control, owing mostly to the relative immaturity of the neurocircuitry in the ventral regions of the prefrontal cortex (Spear 2010). Adolescents in general show greater impulsivity and poorer inhibitory control compared to adults (Spear 2000; Steinberg 2010). Further, research shows that adolescents show less clearly defined (i.e., diffused) activation of neurocircuits while trying to inhibit responses in laboratory tasks, as opposed to adults who show more clearly defined or focused activation, suggesting that these networks are less than optimally developed among adolescents (Luna et al. 2010). In general, it appears that mature, adult neurocircuitry shows better-defined interconnections among different cortical and subcortical regions of the brain involved in various executive control processes and motivational regulation, such that diverse brain regions are recruited more efficiently among adults while enacting response inhibition (Luna et al. 2010).

EFs and Adolescent Drug Use

Thus, the relatively under-developed EF system and elevated tendencies to take risks place adolescents in general at greater vulnerability for risky behavior. Further, research suggests that individual differences in EFs among adolescents are related to drug use behavior (e.g., Tarter et al. 2003; Xiao et al. 2008). In longitudinal samples, early adolescent deficiencies in EFs have been found to predict later drug use disorders (Habeych et al. 2005; Tarter et al. 2011). In addition, adolescents showing life-course persistent antisocial behavior tend to show poorer EFs compared to adolescents not showing antisocial behavior or adolescents showing adolescence-limited antisocial behavior, based on behavioral measures of attention and inhibitory control (Raine et al. 2005). In fact, temperamental characteristics suggesting poor self-control at the age of 3 have been found to predict problem behavior in adolescence (Caspi et al. 1995).

Thus, it appears that EF characteristics in childhood or young adolescence set the stage for the development of later deviant behavior, including drug use. EF characteristics are likely to predict more proximal predictors of drug use such as peer affiliation and academic competence (Tarter et al. 2011). Tarter et al. (2011) found that adolescents who showed poorer EF skills (e.g., affect, behavior, and attention control) at age 10–12 were more likely to associate with deviant peers at age 16, and the deviant peer affiliation at 16 was likely to mediate the effects of poor childhood EF skills on cannabis use disorder at age 22. They also found a direct effect of EF skills at age 10–12 on the development of cannabis use disorder at age 22. Taken together, these findings suggest that individual differences in EFs in childhood or adolescence are strongly predictive of individuals' likelihood of developing drug use and dependence later in adolescence or adulthood. Thus, there seems to be a strong link between healthy EF development and prosocial youth behavior. Moreover, interventions designed to improve adolescents' EF abilities may prevent adolescent drug use and abuse. The structural changes occurring in the adolescent brain suggests that the adolescent brain is malleable and that enhancing the positive brain development may result in improved EFs.

Can Interventions Help Improve EFs?

The fact that certain brain regions do not reach full maturity until young adulthood suggests that those brain regions retain meaningful neuroplasticity during adolescence. Neuroplasticity refers to the ability of the neurons and neural networks to organize and reorganize their connections in response to programmed development, new experience, or damage. For development in certain brain regions, especially the prefrontal cortex, adolescence represents a “critical period.” In the context of brain functional development, critical period refers to a developmental window during which genetic and environmental processes interact to establish functional characteristics (Crews et al. 2007). Thus, by extension, adolescence represents a critical period for EF development.

Mainly three processes seem crucial in making EF development amenable to the influence of environmental experiences: neurogenesis, synaptic pruning, and myelination (Spear 2010). The rate of neurogenesis or formation of new neurons is four to five times higher among adolescents than among adults, which suggests that the adolescent brain has greater resources to make neuroplastic adaptations in response to environmental experiences (Crews et al. 2007; He and Crews 2007; Spear 2010). In addition, synaptic pruning seems to depend on experience such that some synapse elimination processes may occur in response to environmental stimuli (Spear 2010). Further, research shows that the rate of myelination of axons is directly related to the level of activation (e.g., impulse flow) they experience (Stevens et al. 2002). Thus, myelination is activity driven, which suggests that the rate of myelination in the developing adolescent brain may be enhanced through persistent practice of suitable tasks that increase axonal activity (Spear 2010). Indeed, the development of neural pathways linking frontal brain regions to other brain regions appears to be more sensitive to practice in childhood and adolescence than adulthood (Bengtsson et al. 2005; Spear 2010).

Various recent studies have reviewed the current state of research on training-induced enhancement in EFs (Diamond and Lee 2011; Bryck and Fisher 2012; Shipstead et al. 2012). Reviewing the findings of intervention studies designed to enhance EF development in children 4–12 years old, Diamond and Lee (2011) concluded that repeated practice of tasks that require the use of EFs may enhance EF abilities in children, especially those children that show poorer EFs at baseline. Diamond and Lee (2011) outlined five types of programs that have been found to be effective in improving EFs among children: computerized training, combination of computer and noncomputer games, aerobic exercise, martial arts and mindfulness practices, classroom curricula.

Bryck and Fisher (2012) classified existing EF training methods into two broad categories: laboratory-based training and neurobiologically informed ecological interventions. In line with the findings of Diamond and Lee (2011), their review indicated that studies based on both methods are generally effective, not only in improving EF abilities but also in positively impacting behavioral, psychosocial, or physiological outcomes. Laboratory training studies usually target a specific EF process (e.g., working memory) and include computerized training. For example, Klingberg et al. (2005) tested a computerized working memory training intervention among children with attention deficit hyperactivity disorder (ADHD). The intervention required participants to repeatedly practice (i.e., 5 days per week for 5 weeks, 30–40 min per day) visuospatial working memory tasks, which included tasks such as remembering positions of objects in a 4×4 grid and remembering letters or digits. Each training session consisted of 90 working memory games. Klingberg et al. (2005) found that when compared with the control group, children who received the intervention showed significant improvement in working memory based on tasks that were not part of the intervention, both during the immediate posttest and at follow-up 3 months later.

Neurobiologically informed ecological interventions are defined as traditional, school, or family-centered interventions that utilize brain training and subsequent improvements in EFs with the purpose of bringing changes in behavior or socio-emotional adjustment (Bryck and Fisher 2012). In the current paper, our focus is on one type of ecological method, namely school-based interventions. In the following sections, we discuss current practice related to application of brain training strategies to school-based intervention. In addition, we discuss possible future directions for research attempting to apply knowledge gained from neuroscience research, including brain training, into school-based drug use prevention programming.

Adolescent Neurocognitive Development and School-Based Prevention

Schools may provide an effective setting to implement the neuropsychologically based drug use prevention program to a relatively large number of adolescents in the form of classroom curricula. Currently, there are very few school-based prevention programs that are based on neuropsychological models and assess changes in EFs as mediators of program effects. However, there have been a number of programs that have targeted children’s EF-related social–emotional competence. Riggs et al. (2011) classify such programs into three categories: (1) programs that promote cognitive and/or social–emotional skills, usually with the aim of inducing social adjustment, but do not assess EFs and are not overtly based on

NIH-PA Author Manuscript

NIH-PA Author Manuscript

neuropsychological models, (2) programs that aim to improve EFs but do not assess behavioral outcomes, and (3) programs that are based on neuropsychological models and assess EFs as possible mediators of the intervention effect on targeted behavior.

Programs Promoting EF-Related Social–Emotional Skills

Relatively few school-based interventions have targeted EFs directly. However, there have been a number of prevention programs that have aimed at improving adolescents' or children's self-regulation skills related to social–emotional competence. Below, we discuss four school-based interventions that exemplify programs which, even though they do not target (or measure) EFs directly, promote self-regulation skills that are dependent on EFs.

I Can Problem Solve (ICPS; Shure 2001, 1992) is a universal program (i.e., program targeting all population groups) designed to prevent or reduce internalizing and externalizing symptoms, enhance resilience, and promote well-being among children through improvements in interpersonal cognitive problem-solving skills. Theoretically, ICPS is based on the proposition that better interpersonal problem-solving skills result in proper social adaptation among children, which in turn protect them from internalizing and externalizing symptoms and later problem behaviors such as substance use.

The ICPS program is designed for children ages 4–12 (i.e., preschoolers–sixth graders). The program is delivered by teachers in the form of 20-min classroom sessions, three to five times a week, over the course of the academic year. As part of the program, children are taught the skills to link actions with their consequences, especially in the interpersonal domain, and to find alternative solutions to interpersonal problems. Instruction occurs through games and group discussions that involve use of words, pictures, puppets, and role playing. Additionally, teacher-initiated dialog is used to solve actual interpersonal problems among children. For example, children are taught to identify words that are precursors to understanding consequences of various actions. The program has been successful in improving impulse control (Shure 2001).

Second Step (Frey et al. 2000) is another universal classroom-based program that is designed to enhance children's school readiness and social adaptation by improving social–emotional competence. The age group addressed by the program ranges from preschoolers up to ninth graders. The program includes four components, delivered over 28 weeks: “skills for learning” component (e.g., listening, focusing attention, assertiveness), empathy component, emotion management component, and interpersonal problem-solving component. Thus, self-regulation training is the focus of the program throughout the curriculum. Trained teachers deliver two lessons every week. The programs for preschool and elementary school children primarily use the aid of visual media (e.g., posters, videos, poster, puppet shows) in imparting the lessons. The program for middle school/junior high students includes uses of visual media as well as classroom activities (e.g., role play) and group discussions. The Second Step program has been empirically evaluated and has been found to improve social emotional competence and to significantly reduce aggressive behaviors among children.

Al's Pals: Kids Making Healthy Choices (Al's Pal; Geller 1999) is a universal, classroom-based curriculum designed for young children (3- to 8-year olds). The curriculum is designed to train children on skills related to self-control, emotional regulation, empathy, interpersonal problem solving, and pro-health decision making. The goal of the program is to improve social–emotional competence, communication, impulse control, and problem-solving skills. In order to promote healthy decision making, children are trained to avoid unsafe behaviors such as substance use. The program curriculum consists of 46 lessons and is delivered by trained teachers via 10–15-min lessons, twice a week, over a period of 23 weeks. The lessons are centered on a hand puppet named Al, who represents a positive role model. Using interactive teaching tools such as scripted puppet-led discussions, plays, songs, posters, and books, children are helped to learn and practice self-regulation skills. Lessons are based on real-life childhood experiences. In addition, teachers delivering the program are required to practice and model the main concepts of a lesson throughout the lesson day. The program has been found to show significant reduction in negative attitudes/ behaviors (e.g., aggression) and improvements in positive attitudes/behaviors (e.g., adaptive coping).

Montessori (1964) curriculum is based on the Montessorian theory of "normalization," which refers to the acquisition of learning and social–emotional skills that are conducive to normal, prosocial development. The Montessori programs facilitate children's normalization process by training them to find joy in work and be self-disciplined. The programs help students develop attention control skills and skills necessary to exercise self-control in interpersonal interactions. These programs are available for 0–18-year olds, but the most commonly implemented levels of Montessori education are primary (3–6-year olds) and elementary (6–12-year olds). The primary and elementary programs are delivered in multi-age groups where child-to-child interactions are promoted; each child is challenged according to his ability, and children are not tested or graded. The primary program consists of "practical life activities" (i.e., activities designed to enhance control, movement, concentration, etc.), "sensorial materials" (e.g., materials designed to improve sense experiences such as sight, sound, and texture), and activities related to language, mathematics, music, and art. The program is designed such as to encourage children to learn from experience. The focus of the elementary program is to train the children on how to think and develop skills to learn complex tasks and lessons. The elementary curriculum integrates mathematics, grammar, literature, history, geography, natural sciences, art, and physical education, among other disciplines. Although improving EFs is not a stated aim of the Montessori program, research suggests that 5-year-old Montessori students are likely to perform better on EF tasks compared to the control group (Lillard and Else-Quest 2006).

Programs Promoting EFs as Main Outcome

The following two school-based interventions exemplify programs that explicitly target EFs in children and have assessed executive functions as primary outcome. *Tools of the Mind* (Bodrova and Leong 2007) is a program for young children (3–6-year olds) delivered in the classroom setting by trained regular teachers. Based on Vygotsky's (1978) theory of the development of mental functions, which stresses the importance played by children's plays or make-believe games in their mental development (e.g., ability to form internal representations of the outside world), the program is considered to address three EFs: working memory, set shifting, and inhibitory control (Diamond et al. 2007). Thus, the program primarily uses plays to enhance the development of early childhood working memory, inhibitory control, and attention control. The core of the program consists of 40 teacher-run activities which include dramatic plays and visual aids that help students use memory and focus attention more effectively. Compared to standard curricula, the program has been shown to significantly improve children's EFs as measured by task measures such as the Dots and Flanker tasks (Diamond et al. 2007).

Chicago School Readiness Project (CSRP; Raver et al. 2008; Ravier et al. 2011) is designed to improve EFs among low-SES, preschool-aged children with the purpose of improving their social and emotional adjustment. This program is unique in that it provides training to teachers (i.e., Head Start teachers) rather than students. The program attempts to improve children's EFs by helping teachers create a well-regulated learning and emotional environment in the classroom. Teachers' lack of training in managing classroom behaviors may not only cause continued disruptive behavior among students but also burn out the teachers themselves because of the constant need to engage with disruptive students. Thus, CSRP trains teachers on strategies to manage children's classroom behaviors, to set rules and routines, and to appropriately use reinforcement and feedback to encourage prosocial and discourage deviant behavior. Teachers are provided the support of mental health consultants throughout the school year. The mental health consultants help teachers implement the strategies they have learned during training in the classroom. In addition, the mental health consultants run several stress reduction workshops to help teachers manage their stress. A recent randomized efficacy trial involving 35 Head Start classrooms showed that CSRP is likely to significantly improve children's EFs (Raver et al. 2011).

Program Promoting EFs as Mediators of Prevention

To our knowledge, only one school-based prevention program has assessed EFs as a mediator program effect on problem behavior: *Promoting Alternative Thinking Strategies* (PATHS). PATHS is a universal school-based prevention program with a focus on assisting young children (pre-schoolers to sixth graders) with social and emotional learning by helping them improve EF skills (Greenberg et al. 2004). The PATHS program is based on a model of development called affective–behavioral–cognitive–dynamic model, which is essentially a neurocognitive model that emphasizes the importance of EF development in emotional and behavioral regulation (Greenberg et al. 2004). For example, the PATHS curriculum is designed to facilitate children's neurocognitive development by training them on tasks and skills that would facilitate the control of higher-order cognitive processes over risk-taking tendencies associated with reward-related limbic regions (referred to as "vertical control"). In addition, the program is designed to improve communication between the two brain hemispheres, which is integral to the internal verbalization of affect (referred to as "horizontal communication"; Greenberg 2006; Riggs et al. 2006). Thus, PATHS is based on the findings from neuroscience that suggest that the development of neurocircuitry linking cortical regions with other brain regions can be enhanced through training and practice.

In PATHS, vertical control is addressed through training adolescents on strategies for self-control (e.g., "self-talk") that facilitates inhibitory control and planning (Greenberg 2006). For example, the PATHS curriculum uses a "Control Signals" poster as a tool to self-regulation strategies. The Control Signals poster uses a traffic signal to guide goal-directed behaviors (e.g., red light signaling to stop and calm down, yellow light to slow down and think, and green light to try out the plan; Riggs et al. 2006). Horizontal communication is addressed by teaching students to identify and label emotions using, for example, “Feeling Face” cards, which include color-coded facial images of affective states (Riggs et al. 2006). A PATHS trial involving 7- to 9-year olds found that the curriculum was effective in reducing externalizing and internalizing behaviors at 1-year follow-up and that inhibitory control and verbal fluency partially mediated the program effects (Riggs et al. 2006).

Discussion

Recent research in developmental neuroscience has greatly improved the understanding of adolescent risk-taking behaviors, including drug use. Suboptimal maturation of neural circuits associated with EFs during adolescence places adolescents at greater risk for drug use. In addition, studies consistently show that individual differences in EFs as a child or adolescent is related to concurrent and future drug use such that adolescents who show poorer EFs are at greater risk. Findings further suggest that neuroplasticity during childhood and adolescence is highly sensitive to environmental stimuli, suggesting that appropriate training and practice may result in enhanced self-regulation abilities among youth through structural and functional changes in the brain. Together, these findings suggest that training youth on EF-related skills may protect them from drug use and abuse. In this paper, we argue that school as a setting could be effectively used to implement drug use prevention programs that are based on neuropsychological models.

Among current school-based drug use prevention programs, only few are directly or indirectly based on neuropsychological models. Most such existing programs have focused on promoting social–emotional competence or school readiness among young children (e.g., preschoolers to 12-year olds) through development of skills related to emotional regulation, interpersonal problem solving, academic learning, or through EF development. Primarily, these programs have used curricular lessons led by trained teachers or health educators to train children on emotional and/or cognitive regulation skills using a variety of interactive and instructional techniques such as plays, puppet shows, posters, and experiential learning. The majority of programs involving self-regulation skills training do not seem to assess improvement in EF as program outcome. However, there are programs that, even though they do not claim to target EF (e.g., Montessori), have been found to improve children’s EFs (Lillard and Else-Quest 2006).

Currently, extremely few programs seem to have tested the effects of improvement in EFs on youth problem behavior, including drug use behavior. The only school-based program that is based on a clearly defined developmental neurocognitve model (PATHS; Greenberg 2006) has been designed for children (preschoolers to 12-year olds) and has not yet been tested in relation to drug abuse prevention among adolescents. However, it should be noted that prevention programs for adolescents have commonly included, to varying extents, self-regulation skills training as an intervention component, mostly in the form of cognitive–behavioral skills training [e.g., “Life Skills Training”] (Botvin et al. 1990, 1994). Such strategies have mostly attempted to train youths on coping and anxiety management and effective communication and assertiveness (Rones and Hoagwood 2000). In essence, arguably, such studies may enhance the rate and quality of age-related brain development. However, influencing potential neurocognitive mediators of prevention has not been among the objectives of these programs, and as a result, their possible effects on such mediators have not been widely tested.

Thus, currently, there is a lack of school-based drug use prevention programs that are based on neuropsychological models, especially those that target adolescents 13 or older in age. There are clearly many advantages to promoting EFs or EF-related skills among young children, including potentially long-term protection against problem behaviors (Tarter et al. 2011). However, promoting self-regulation skills among adolescents via neurocognitive development is of special importance in the context of drug use prevention because childhood gains in self-regulation may not adequately protect against reward-related developmental changes that place individuals at increased risk for drug use and abuse as adolescents (Dishion et al. 2011). Thus, it is important to develop and test neurobiologically based prevention programs for different age groups of adolescents. Developing such programs would necessitate conducting more high-quality basic neuropsychological research across adolescent age groups. The strategies that are currently in use to improve EFs among young children (e.g., plays, puppet shows) may not be appropriate for adolescents, particularly for older adolescents.

Future Directions

Considerable future research is needed to develop and test effective neurobiologically based prevention strategies and incorporate them into adolescent school-based drug use prevention programs. An important initial step would be to test existing school-based prevention programs that include self-regulation components for their possible effects on EF development. Such programs may be expanded or refined by incorporating novel strategies that have been proven to be effective in laboratory settings. In addition, techniques that have been successfully tested in laboratory or laboratory-like settings with small number of youths could be adapted into curricula and tested in school settings for effectiveness in drug use prevention. Several strategies that have been found to aid EF development among children (e.g., 4–12-year olds; Diamond and Lee 2011) may be effective for adolescents as well. Two such strategies that thus far have been mostly tested preliminarily seem especially promising in terms of their applicability to school-based drug abuse prevention programming: computerized training and mindfulness meditation.

Computerized Training—Over the past decade or so, numerous studies have tested the effects of computerized working memory training programs on improving EFs using samples of children, adolescents, and adults from various populations (see Klingberg 2010; Diamond and Lee 2011; Shipstead et al. 2012). In general, findings from these studies suggest that training individuals on working memory tasks through repeated practice is likely to improve their EFs, notably working memory capacity and attention and set-shifting abilities (Klingberg 2010). Although several limitations regarding these findings have been discussed (Shipstead et al. 2012), which need to be addressed by future research (e.g., how far does the training effect transfer into other behaviors?), the implications this line of basic research has for school-based programs are significant. The majority of the extant studies on computerized working memory training have used Cogmed Working Memory Training (2006) software (Shipstead et al. 2012). The Cogmed training utilizes adaptive videogames involving verbal and visuospatial tasks through which participants practice working-memory-related exercises (e.g., forward/backward recall) over about 20 sessions, each lasting 30–60 min. Cogmed has mostly been tested on young children, with or without ADHD (Diamond and Lee 2011; Shipstead et al. 2012).

Currently, it is not clear whether computerized working memory training is likely to have meaningful preventive effect on adolescent drug use. Few recent studies with adult drug abusers suggest that working memory training may help reduce the level of drug abuse at the immediate posttest (Bickel et al. 2011; Houben et al. 2011). Clearly, more research is needed to determine whether working memory training is likely to prevent drug use initiation or escalation among adolescents. Further, such research needs to be conducted using a relatively large number of adolescents so that the research has viable implications for the translation of findings into school-based prevention programs. Incorporating computerized training into school-based prevention may pose various challenges to implementation feasibility (e.g., availability of time during school hours to implement the program; delivering computerized training to large groups of students). Thus, rigorous program development work is needed to overcome such challenges (Sussman 2001).

Mindfulness—Mindfulness refers to attaining a mental state in which attention is sustainably focused on the nonjudgmental awareness of thoughts and sensations at a given moment (Kabat-Zinn 1994). Mindfulness meditation practices are increasingly being discussed as a useful means of improving EFs among adolescents (e.g., Dishion et al. 2011; Riggs et al. 2011; Diamond and Lee 2011). Mindfulness involves focusing attention on the present moment and diligent monitoring of external and internal stimuli being experienced in the present. Findings from controlled trials, based primarily on adult samples, suggest that mindfulness meditation practices may result in significant improvements in attention regulation and self-monitoring and may also help enhance working memory capacity (for review, see Chiesa et al. 2011). However, the number of such trials [e.g., of the 23 studies reviewed by Chiesa et al. (2011), six were randomized controlled trials] are relatively small, and they are mostly based on small, nonrepresentative samples. Hence, although promising, current findings relating mindfulness meditation practices to improvements in EFs may need to be considered preliminary.

Further, studies that have researched health or behavioral outcomes of mindfulness meditation practices among children and adolescents have been relatively scarce. Based on a recent review of intervention studies in the area (i.e., Burke 2010), the studies that have examined attention control or other aspects of EFs as outcome have generally found significant positive effects (e.g., Napoli et al. 2005; Zylowska et al. 2007). In addition, a number of studies found mindfulness meditation to have helped reduce externalizing and internalizing symptoms (Semple et al. 2005; Lee et al. 2008). However, only 4 of the 15 studies reviewed were controlled trials, and only four were school-based samples. The studies were mostly feasibility-type studies involving small samples. Clearly, much further research is needed to ascertain the protective effects of mindfulness on adolescent drug use and to determine if such effects are mediated through improvements in EFs. Existing studies suggest that mindfulness interventions for adolescents and children, including school-based ones, are feasible to implement. Mendelson et al. (2010) conducted a pilot school-based mindfulness trial among 97 fourth and fifth graders in which 51 students received the intervention and 46 waitlisted students functioned as the control group. The intervention included guided mindfulness practices and was delivered by two trained instructors. Each intervention class consisted of 25 students, and the sessions, each 45 min long, were delivered four times a week for 12 weeks. The intervention was implemented within school hours, during a nonacademic period. Results showed that implementing the intervention was feasible and also indicated that the intervention had significant effects on stress reduction and emotional adjustment. Thus, large-scale randomized trials are now needed to advance the research on the application of mindfulness research to the development of adolescent drug use prevention programs.

Conclusion

Clearly, much more research is needed in order to substantiate and improve the application of neuropsychological models to school-based drug abuse prevention and research. However, based on current findings in neuroscience and prevention science, future research in the area is likely to yield promising results. Thus far, most school-based interventions that directly or indirectly address neurocognitive development have been studied among young children. Similar studies need to be conducted among adolescents, especially in the context of drug use behavior, noting that some intervention strategies that help EF development in children may not be effective for adolescents. Thus, novel strategies that are suitable for adolescents need to be tested for effectiveness and feasibility of school-based implementation. Preliminary findings suggest that computerized training and mindfulness meditation practices could be effectively integrated into school-based prevention programming. However, well-designed, large-scale trials are needed to better estimate the usefulness of these strategies in helping adolescent neurocognitive development and drug use prevention through school-based programs.

Acknowledgments

This paper was supported by grants from the National Institute on Drug Abuse (#sDA13814, DA016090, DA020138, and P50 DA16094).

References

Arnett J. Reckless behavior in adolescence: A developmental perspective. Developmental perspective Developmental review. 1992; 12:339–373.

Anderson, V.; Jacobs, R.; Harvey, AA. Executive functions after frontal lobe injury: A developmental perspective. In: Stuss, DT.; Knight, RT., editors. Principles of frontal lobe functions. New York: Oxford University Press; 2002. p. 504-527.

Bardo MT, Donohew RL, Harrington NG. Psychobiology of novelty seeking and drug seeking behavior. Behavioural Brain Research. 1996; 77:23–43. [PubMed: 8762157]

Baumeister, R.; Vohs, K. Handbook of self-regulation. New York: Guilford; 2004.

Bechara A. Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. Nature Neuroscience. 2005; 8:1458–1463.

Bechara A, Damásio AR, Damásio H, Anderson SW. Insensitivity to future consequences following damage to human prefrontal cortex. Cognition. 1994; 50:7–15. [PubMed: 8039375]

Bengtsson S, Nagy Z, Skare S, Forsman L, Frossberg H, Ullen F. Extensive piano practicing has regionally specific effects on white matter development. Nature Neuroscience. 2005; 8:1148–1150.

Berridge KC. The debate over dopamine's role in reward: The case for incentive salience. Psychopharmacology. 2007; 191:391–431. [PubMed: 17072591]

Bickel WK, Miller ML, Yi R, Kowal BP, Lindquist DM, Pitcock JA. Behavioral and neuroeconomics of drug addiction: Competing neural systems and temporal discounting processes. Drug and Alcohol Dependence. 2007; 90S:S85–S91. [PubMed: 17101239]

Bickel WK, Yi R, Landes RD, Hill PF, Baxter C. Remember the future: Working memory training decreases delay discounting among stimulant addicts. Biological Psychiatry. 2011; 69:260–265. [PubMed: 20965498]

Bodrova, E.; Leong, D. Play and early literacy: AVygotskian approach. In: Roskos, KA.; Christie, JF., editors. Play and literacy in early childhood. Mahwah: Lawrence Erlbaum Associates; 2007. p. 185-200.

Botvin G, Baker E, Dusenbury L, Tortu S, Botvin E. Preventing adolescent drug abuse through a multimodal cognitive-behavioral approach: Results of three studies. Journal of Consulting and Clinical Psychology. 1990; 58:437–446. [PubMed: 2212181]

Botvin G, Schinke S, Epstein J, Diaz T. Effectiveness of culturally focused and generic skills training approaches to alcohol and drug abuse prevention among minority youths. Psychology of Addictive Behaviors. 1994; 8:116–127.

Boyer TW. The development of risk-taking: A multi-perspective review. Developmental Review. 2006; 26:291–345.

Bryck RL, Fisher PA. Training the brain: Practical applications of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science. American Psychologist. 2012; 67:87–100. [PubMed: 21787037]

Burke CA. Mindfulness-based approaches with children and adolescents: A preliminary review of current research in an emergent field. Journal of Child and Family Studies. 2010; 19:133–144.

Carver, CS.; Scheier, MF. Attention and self-regulation: A control theory approach to human behavior. New York: Springer; 1981.

Casey B, Getz S, Galvan A. The adolescent brain. Developmental Review. 2008; 28:62–77. [PubMed: 18688292]

Caspi A, Henry B, McGee RO, Moffitt TE, Silva PA. Adolescent behavior problems: From age three to age fifteen. Child Development. 1995; 66:55–68. [PubMed: 7497829]

Cauffman E, Shulman EP, Steinberg L, et al. Age differences in affective decision making as indexed by performance on the Iowa Gambling Task. Developmental Psychology. 2010; 46:193–207. [PubMed: 20053017]

Chambers RA, Taylor JR, Ponteza MN. Developmental neurocircuitry of motivation in adolescence: A critical period of addiction vulnerability. The American Journal of Psychiatry. 2003; 160:1041–1052. [PubMed: 12777258]

Chiesa A, Raffaella C, Serretti A. Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings. Clinical Psychology Review. 2011; 31:449–464. [PubMed: 21183265]

Crews F, He J, Hodge C. Adolescent cortical development: A critical period of vulnerability for addiction. Pharmacology Biochemistry and Behavior. 2007; 86:189–199.

de Ridder, D.; de Wit, J. Self-regulation in health behavior. West Sussex: John Wiley & Sons Ltd; 2006.

Diamond A, Barnett WS, Thomas J, Munro S. Preschool program improves cognitive control. Science. 2007; 318:1387–1388. [PubMed: 18048670]

Diamond A, Lee K. Interventions shown to aid executive function development in children 4 to 12 years olds. Science. 2011; 333:959–964. [PubMed: 21852486]

Dishion, TJ.; Felver-Grant, JC.; Abdullaev, Y.; Posner, MJ. Self-regulation and adolescent drug use: Translating developmental science and neuroscience into prevention practice. In: Bardo, MT.;

Fishbein, DH.; Milich, R., editors. Inhibitory control and drug abuse prevention. New York: Springer; 2011. p. 281-201.

Frey KS, Hirschtein MK, Guzzo BA. Second step: Preventing aggression by promoting social competence. Journal of Emotional and Behavioral Disorders. 2000; 8:102–113.

Fuster, JM. The prefrontal cortex. London: Elsevier; 2008.

Giedd JN. Structural magnetic resonance imaging of the adolescent brain. Annals of the New York Academy of Sciences. 2004; 1021:77–85. [PubMed: 15251877]

Geller, S. Al's Pals: Kids making healthy choices. Richmond: Wingspan, LLC; 1999.

Gerrard M, Gibbons FX, Houlihan AE, Stock ML, Pomery EA. A dual process approach to health risk decision making: The prototype willingness model. Developmental Review. 2008; 28:29–61.

Greenberg MT. Promoting resilience in children and youth: Preventive interventions and their interface with neuroscience. Annals of the New York Academy of Sciences. 2006; 1094:139–150. [PubMed: 17347347]

Greenberg, MT.; Kusché, CA.; Riggs, N. The PATHS Curriculum: Theory and research on neurocognitive development and school success. In: Zins, J.; Weissberg, R.; Walber, H., editors. Building school success on social and emotional learning. New York: Teachers College Press; 2004.

Habeych ME, Sclabassi RJ, Charles PJ, Kirisci L, Tarter RE. Association among parental substance use disorder, p300 amplitude, and neurobehavioral disinhibition in preteen boys at high risk for substance use disorder. Psychology of Addictive Behaviors. 2005; 19:123–130. [PubMed: 16011382]

He J, Crews FT. Neurogenesis decreases during brain maturation from adolescence to adulthood. Pharmacology Biochemistry and Behavior. 2007; 86:327–333.

Hofmann W, Friese M, Strack F. Impulse and self-control from a dual systems perspective. Perspectives on Psychological Science. 2009; 4:162–176.

Houben K, Wiers RW, Jansen A. Getting a grip on drinking behavior: Training working memory to reduce alcohol abuse. Psychological Science. 2011; 22:968–975. [PubMed: 21685380]

Kabat-Zinn, J. Wherever You Go There You Are: Mindfulness Meditation in Everyday Life. New York, NY: Hyperion; 1994.

Klingberg T, Fernell E, Olesen PJ, et al. Computerized training of working memory in children with ADHD—a randomized, controlled trial. Journal of the American Academy of Child and Adolescent Psychiatry. 2005; 44:177–186. [PubMed: 15689731]

Klingberg T. Training and plasticity of working memory. Trends in Cognitive Sciences. 2010; 14:317–324. [PubMed: 20630350]

Leather NC. Risk-taking behaviour in adolescence: A literature review. Journal of Child Health Care. 2009; 13:295–304. [PubMed: 19713410]

Lee L, Semple RJ, Rosa D, Miller L. Mindfulness-based cognitive therapy for children: Results of a pilot study. Journal of Cognitive Psychotherapy. 2008; 22:15–28.

Lillard A, Else-Quest N. Evaluating Montessori education. Science. 2006; 313:1893–1894. [PubMed: 17008512]

Luna B, Padmanabhan A, O'Hearn K. What has fMRI told us about the development of cognitive control through adolescence. Brain and Cognition. 2010; 72:101–113. [PubMed: 19765880]

Mendelson T, Greenberg MT, Dariotis JK, Gould LF, Rhoades BL, Leaf PJ. Feasibility and preliminary outcomes of school-based mindfulness intervention for urban youth. Journal of Abnormal Child Psychology. 2010; 38:985–994. [PubMed: 20440550]

Montessori, M. The Montessori method. New York: Schocken; 1964.

Napoli M, Krech P, Holley L. Mindfulness practice training for elementary school students. Journal of Applied School Psychology. 2005; 21:99–125.

Paus T. Mapping brain maturation and cognitive development during adolescence. Trends in Cognitive Sciences. 2005; 9:60–68. [PubMed: 15668098]

Raver CC, Jones SM, Li-Grining C, Metzer M, Champion KM, Sardin L. Improving preschool classroom processes: Preliminary findings from a randomized trial implemented in Head Start settings. Early Childhood Research Quarterly. 2008; 23:10–26.

Raver CC, Jones SM, Li-Grining C, Zhai F, Bub K, Pressler E. CSRP's impact on low-income preschoolers' skills: self-regulation as a mediating mechanism. Child Development. 2011; 82:362–378. [PubMed: 21291447]

Raine A, Moffitt TE, Caspi A, Loeber R, Stouthamer-Loeber M, Lynam D. Neurocognitive impairments in boys on the life-course persistent antisocial path. Journal of Abnormal Psychology. 2005; 114:38–49. [PubMed: 15709810]

Rones M, Hoagwood K. School-based mental health services: A research review. Clinical Child and Family Psychology Review. 2000; 3:223–241. [PubMed: 11225738]

Riggs, NR.; Greenberg, MT.; Rhoades, B. Early risk for problem behavior and substance use: Targeted interventions for the promotions of inhibitory control. In: Bardo, MT.; Fishbein, DH.; Milich, R., editors. Inhibitory control and drug abuse prevention. New York: Springer; 2011. p. 249-262.

Riggs NR, Jahromi LB, Razza RP, Dilworth JE, Mueller U. Executive function and the promotion of social–emotional competence. Journal of Applied Developmental Psychology. 2006; 27:300–309.

Sargent JD, Tanski S, Stoolmiller M, Hanewinkel R. Using sensation seeking to target adolescents for substance use interventions. Addiction. 2010; 105:506–514. [PubMed: 20402995]

Shipstead Z, Redick TS, Engle RW. Is working memory training effective. Psychological Bulletin. 201210.1037/a0027473

Semple R, Reid E, Miller L. Treating anxiety with mindfulness: An open trial of mindfulness training for anxious children. Journal of Cognitive Psychotherapy. 2005; 19:379–392.

Shure, MB. I can problem solve: An interpersonal cognitive problem-solving program: Intermediate elementary grades. Champaign: Research Press; 1992.

Shure, MB. Raising a thinking preteen: The "I Can Problem Solve" program for eight to-twelve-year-olds. New York: Owl/Holt; 2001.

Spear, LP. The behavioral neuroscience of adolescence. New York: W.W. Norton; 2010.

Spear L. The adolescent brain and age-related behavioral manifestations. Neuroscience and Biobehavioral Reveiws. 2000; 24:417–446.

Steinberg L. Cognitive and affective development in adolescence. Trends in Cognitive Sciences. 2005; 9:69–74. [PubMed: 15668099]

Steinberg L. A dual systems model of adolescent risk-taking. Developmental Psychobiology. 2010; 52:216–224. [PubMed: 20213754]

Stevens B, Porta S, Haak LL, Gallo V, Fields RD. Adenosine: A neuron-glial transmitter promoting myelination in the CNS in response to action potentials. Neuron. 2002; 36:855–868. [PubMed: 12467589]

Sussman, S. Handbook of program development for health behavior research & practice. Thousand Oaks: Sage; 2001.

Tarter RE, Kirisci L, Mezzich A, Cornelius JR, Pajer K, Vanyukov M, et al. Neurobehavioral disinhibition in childhood predicts early age at onset of substance use disorder. The American Journal of Psychiatry. 2003; 160:1078–1085. [PubMed: 12777265]

Tarter RE, Fishbein D, Kirisci L, Mezzich A, Ridenour T, Vannyukov M. Deviant socialization mediates transmissible and contextual risk on cannabis use disorder development: A prospective study. Addiction. 2011; 106:1301–1308. [PubMed: 21320228]

Volkow ND, Wang GJ, Tlang F, et al. Profound decreases in dopamine release in striatum in detoxified alcoholics: Possible orbitofrontal involvement. Journal of Neuroscience. 2007; 27:12700–12706. [PubMed: 18003850]

Vygotsky, LS. Mind in society: The development of higher psychological processes. Cambridge: Harvard University Press; 1978.

Xiao L, Bechara A, Cen S, et al. Affectve decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in 10th-grade Chinese adolescent smokers. Nicotine & Tobacco Research. 2008; 10:1085–1097. [PubMed: 18584472]

Yurgelun-Todd D. Emotional and cognitive changes during adolescence. Current Opinion in Neurobiology. 2007; 17:251–257. [PubMed: 17383865]

Zuckerman, M. Sensation seeking: The balance between risk and reward. In: Lipsitt, LP.; Mitnick, LL., editors. Self-regulatory behavior and risk taking. Norwood: Ablex; 1992. p. 143-152.

Zylowska L, Ackerman DL, Yang M, et al. Mindfulness meditation training with adults and adolescents with ADHD. Journal of Attention Disorders. 2007; 11:737–746. [PubMed: 18025249]

NIH-PA Author Manuscript
NIH-PA Author Manuscript