Published in final edited form as:

Pediatr Clin North Am. 2016 June; 63(3): 447–457. doi:10.1016/j.pcl.2016.02.006.

Neurocognitive Processes and Pediatric Obesity Interventions: Review of Current Literature and Suggested Future Directions

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Summary

Childhood obesity is a significant problem in the United States, yet current childhood obesity prevention programming approaches have limited efficacy. Self-regulation is a set of processes (e.g., cognitive control, emotion coping) that organize behavior in order to achieve a goal. As such, self-regulation may shape health behaviors and over time, long-term health outcomes. Obesity-prevention approaches that incorporate a focus on the cognitive and behavioral mechanisms that underlie self-regulation early in the lifespan may therefore lead to better outcomes. Executive functioning (EF) is a central aspect of self-regulation; skills include attention, working memory, and inhibitory control. Deficits in these areas are associated with higher weight status in children. The current paper reviews the development of EF from childhood to adolescence, identifies social-contextual influences on EF development, presents how different aspects of EF relate to behaviors known to be associated with increased risk for childhood obesity, and considers how EF-weight associations may change across development. Implications for intervention, including the need to consider the direction of association and possibility of bidirectional associations, the multiple potential pathways between EF and weight status, and a brief review of EF-enhancement intervention approaches are discussed.

Keywords

Pediatric obesity; executive functioning; behavior change; intervention	

Introduction

Childhood obesity is a critical and ongoing public health problem, with almost 25% of children overweight by age 4 years and 35% by adolescence. Once established, childhood

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Funding

I have no commercial or financial conflicts of interest.

Funding source: NIH Science of Behavior Change Common Fund Program, award UH2HD087979 to A. L. Miller administered by NICHD

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obesity is difficult to treat and tracks into adulthood. There is thus an urgent need to prevent and treat childhood obesity, but current prevention and treatment approaches focused on improving diet and physical activity patterns have had limited efficacy. One reason for this may be a lack of focus on the basic mechanisms of behavior change, specifically self-regulation processes that may shape whether recommended health behaviors are adopted. If enhancing self-regulation in childhood could improve health behaviors relevant for obesity prevention, this may lead to new intervention targets and in turn, better long-term health outcomes.

Self-regulation occurs at many levels (cognitive, emotional, psychological, biological, behavioral) and concerns the ability to control thoughts, emotions, and actions to achieve a desired outcome or goal. ^{5_7} Self-regulation can shape health behaviors through multiple pathways. For example, the ability to delay an immediate desired behavioral reward (e.g., eating a cookie) in favor of achieving a longer-term goal (e.g., weight loss) is a central focus of most weight management approaches. Furthermore, having the cognitive capacity to plan ahead and the mental flexibility that makes it possible to juggle priorities effectively are both likely important in maintaining an exercise routine. Individuals who are cognitively strained, or "depleted", may have difficulty engaging in healthy behaviors. ⁸

Self-regulation develops during childhood and can set the stage for adult self-regulation capacity. ^{9,10} In adults, self-regulation deficits are linked to poor chronic health conditions, including obesity, which often require long-term behavior and lifestyle changes in order to manage. ¹¹ Identifying how self-regulation processes that emerge early in life relate to health behaviors is therefore a critical first step toward interventions that address mechanisms of behavior change. Furthermore, improving self-regulation processes early in the lifespan may provide a novel, prevention-oriented approach to health promotion.

Executive Functioning in Children

Executive functioning (EF) is a central aspect of self-regulation. EF refers to a set of interrelated neurocognitive functions that concern attentional, mental flexibility, and self-control capacities. Such skills emerge rapidly during the early childhood years and continue to develop throughout later childhood and into adolescence. ¹² EF skills generally include attention shifting, working memory, and inhibition of prepotent responses, or inhibitory control (Figure 1). ¹³ These skills function to direct and control cognitive and to some extent, behavioral, processes to focus on a task at hand as well as to plan for the future.

EF has both "cool" and "hot" components that are activated under conditions that vary in motivational salience. ¹⁴ That is, cool features of EF reflect the child's capacity to control attention and make choices in a situation that does not involve emotional challenge or high-stakes decisionmaking, whereas hot EF skills are important when the child needs to make decisions that are motivationally salient. Cool components of EF thus include working memory and attentional capacity whereas inhibitory control is considered a "hotter" EF skill. Cooler EF skills have been associated with the lateral prefrontal cortex, which shapes complex cognitive skills such as planning and attentional flexibility, ¹⁵ whereas hotter EF skills have been associated with the orbitofrontal cortex, which is hypothesized to be

involved in more affectively-salient decisionmaking. ^{16,17} Yet, the mapping of EF skills to specific brain structures is still emerging, and the developmental trajectories of cool and hot EF skills are still not fully understood. ^{18,19}

EF skills have been found to underlie functioning in many domains including academic achievement (particularly cool EF; ²⁰) and emotion regulation (particularly hot EF²¹) as of early childhood. Both cool and hot components of EF may also have implications for health behaviors, yet EF skills have rarely been examined with regard to health-related behaviors in children.

Determinants of EF in Children

Understanding the determinants of EF is important in order to identify opportunities for intervention to enhance EF. The preschool to early school years are a critical period for the development of EF. Deficits in EF may arise as a result of toxic stress exposure during early life, which can occur in the context of poverty and is known to have long lasting effects on brain development and organization. Research has identified both genetic factors and early behavioral precursors of EF, including infant and toddler attention skills, emotional reactivity, and sleep. Social-contextual features have been consistently associated with EF capacities, and the importance of parenting has recently been highlighted. Children who are born into poverty, experience intrusive parenting, or have parents with low EF themselves display reduced EF skills even as early as the preschool years. On the other hand, positive caregiving and secure attachment are associated with better early EF skills signal and preschool curricula that provide highly scaffolded, playbased and predictable social environments can have beneficial effects on EF. As with other developmental phenomena, EF skills are most likely a result of the interplay between genetic and other biological factors and the child's caregiving environment.

Development of EF

Taking a developmental perspective is essential in order to understand how EF could shape health behavior. Early childhood is a period of rapid brain growth with constant remodeling of neural architecture and synaptic pruning; ^{37,38} EF skills thus develop rapidly during this time and there is evidence of malleability. ^{35,39} EF skills continue to develop across the first two decades of life generally in conjunction with brain maturation. ¹⁸ Importantly, not only brain structures but also neural organization and functional connectivity among brain regions change and develop over this time. ^{37,38} Certain "cooler" EF skills such as working memory may develop earlier than "hot" EF skills such as behavioral inhibition, which continue to develop into pre-adolescence and beyond. ^{14,18}

Importantly when considering implications for health behavior, demands on EF also change across development as a function of social context. ¹⁶ For example, the temptation for adolescents to engage in high-risk activities can increase when with friends, even if the adolescent is cognitively aware of potential negative consequences. ⁴⁰ Therefore, although adolescents generally possess more developed EF skills than younger children, they are also required to negotiate more complex contexts that test such skills to a greater degree; the

failure of EF skills in such settings may therefore be particularly costly to an adolescent's health. 41,42

Poor Executive Function is Associated with Childhood Obesity

Obesity and overweight during childhood and adolescence are associated with a wide range of cognitive skill deficits; over the past decade there has been a dramatic increase in the number of papers reporting on the association. 43_51 Given that relatively few studies have used overlapping measures or assessed the same aspects of EF in similar populations, however, the precise nature of association between different EF components and weight remains unclear. Among young children (under age 6 years), deficits in "hot" behavioral inhibition skills have been consistently associated with higher BMI and overweight as assessed using behavioral delay of gratification tasks ^{52,53} as well as cognitively-focused EF tasks. 43,54 Relatively less is known about cool EF skills in relation to weight in children younger than school-age. Among older children and adolescents, reduced EF skills in the areas of inhibitory control, attention, and working memory, as well as differences in brain activation in cortical regions associated with reward have been found in association with overweight and obesity. 46 49 50 55 56 Using longitudinal designs to study associations between EF components and weight across different developmental periods can help identify which aspects of EF are uniquely associated with weight (or other adiposity indicators) and when such associations emerge.

Possible Pathways of Association In Children

Deficits in "hot" EF skills such as behavioral inhibition have been associated with poorer emotion regulation ²¹ as well as obesogenic eating behaviors such as emotional overeating, ⁵⁹ reduced self-regulation of eating, ⁶⁰ and intake of high-calorie snack foods ⁶¹ in preschool and school-aged children, although findings are not consistent particularly in younger children. ⁶² Difficulty delaying immediate gratification in favor of long-term goals may be responsible for self-regulation failures in the context of emotional distress or in the presence of tempting foods, which may increase the level of self-regulatory effort involved to delay gratification and therefore the likelihood that a child's capacity to self-regulate will be depleted rapidly. ⁸ In particular, individuals who are higher in food reward sensitivity or who eat to calm themselves when upset may be highly susceptible to such failures and thereby more prone to obesity. ⁶³, ⁶⁴ This possibility has rarely been considered in children however; thus, research examining the inhibitory control aspect of EF with regard to food reward and

emotion regulation capacity in young children is needed in order to clarify and "unpack" these processes.

Compared to immediate delay of gratification, a hot EF skill, cooler EF capacities such as working memory and planning may operate through a longer-term pathway wherein limited capacities to plan ahead to eat healthfully or exercise, or a lack of focus on future goals could increase obesity over time. Evidence for this pathway in children is limited, particularly in young children. One study of school-age children found that cool, but not hot EF was associated with parent-reported obesogenic eating behavior ^{65,66} and another study found that children who reported more sedentary behavior and high snack food intake showed EF deficits in the areas of working memory and organization, whereas lower risk children did not show such patterns. ⁶⁷ Findings based on adolescent samples have shown that poor planning ability was associated with increased binge-eating in overweight children, ⁶⁸ and that binge-eating mediated longitudinal EF-BMI associations in girls. ⁶⁹ The implications of cooler vs. hotter EF skills for obesity risk may thus change with development. As adolescents are known to follow peer influences with regard to eating and health behaviors, ⁷⁰ deficits in either cool EF skills such as planning or hot EF skills driving affectively-loaded decision-making could increase risk as a function of the peer group.

Regarding other behavioral risk factors for obesity, both cool and hot EF skills have been associated with greater physical activity, ^{71,72} but most studies in this area are focused on how physical activity may improve EF as a pathway for intervention ^{58,73} rather than on the role of EF in promoting physical activity. Thus, future work that distinguishes the potentially unique roles of cool and hot EF skills in relation to different obesity-promoting behaviors over the short- and long-term may allow us to tailor developmentally-sensitive interventions to reduce obesity risk based on EF as well as obesity risk behavior profiles.

Mechanisms of EF - Pediatric Obesity Association are Poorly Understood

Although EF-obesity associations are increasingly recognized, the underlying mechanisms are not yet well-delineated and the causal direction of association is debated. 44,74,75 Poor EF may contribute to obesity risk by reducing self-regulation capacity, but the association could be bidirectional. 44,55,74 Experimental studies in adults have shown that EF skills, particularly working memory, can improve after dietary changes 6 and surgically-induced weight loss. This difficult to extrapolate from these studies directly to the pediatric context, as most such work has been conducted in older adults who have been overweight for years or in animal models that can identify mechanisms but only approximate human development. Yet, obesity-related biology has been proposed to contribute to reduced cognitive function through inflammatory and appetite-regulating hormone-mediated pathways (indicated by the dashed line in Figure 1). Mechanistic and experimental work is needed in children in order to determine the direction of association and inform intervention strategies. For example, intervening to enhance EF may change behavioral pathways leading from poor EF to obesity, whereas reducing adiposity-related factors that impair cognitive skills (e.g., through physical activity or surgical interventions) could interrupt the harmful effects of obesity on EF.

Intervention Implications

The above-reviewed literature suggests multiple implications and directions for intervention. Researchers have attempted to improve EF in children using a variety of approaches (see Figure 2). Group-based ⁷⁸ and classroom-based curriculum interventions ³⁵ that take a comprehensive approach to developing and supporting broad aspects of self-regulation have been shown to be effective in enhancing EF in young children. Given the known associations between parenting and EF, ²⁹ incorporating a focus on parenting in future work in this area may also be helpful. Few obesity prevention studies have used this method. However, some work using this type of approach found that improving EF-related capacities in school settings in combination with nutrition-focused content showed positive effects on eating behavior ⁷⁹ and motor skill development, ⁸⁰ though not weight.

Physical activity interventions have also shown promise in enhancing EF skills among school-aged overweight children, ^{81,82} and cognitively-engaging exercise has been suggested to be uniquely beneficial. ⁷³ Increasing physical activity may have dual benefit by not only enhancing EF but also directly reducing obesity risk through promoting physical activity. Thus, further examination and testing of such interventions is warranted.

More targeted approaches such as computer-based EF training programs that promote skills such as working memory and cognitive flexibility have also been shown improve EF among school-aged (7 to 10 years), ⁸³ and preschoolers, ⁸⁴ as well as in clinical populations of children with ADHD. ⁸⁷ There is debate regarding the level of transfer across tasks (e.g., whether training cool EF skills also changes hot EF skills), ⁹⁰ but in general such approaches can be implemented relatively easily and thus may be an exciting new direction to try in obesity prevention interventions. Finally, given the increasing evidence for EF-eating behavior associations, EF has been proposed as a method to combat obesity specifically through reducing impulsive overeating behavior pathways. ⁹² Studies in adults and older children that have enhanced EF skills in the context of obesity treatment ⁹⁴ or trained inhibitory responses specifically in relation to tempting foods ⁹³ 95 96 have shown promise in this area. Therefore, computer-mediated EF-training interventions that also take food reward sensitivity into account, particularly if they are delivered in a context that could address risk factors in the child's broader social context, could also be a helpful new tool for preventing childhood obesity.

Summary/Discussion

Overall, incorporating a focus on self-regulation processes, particularly EF skills is an exciting potential new direction for interventions that seek to prevent obesity. Important considerations for future work include identifying directional pathways of association between EF and obesity-promoting behaviors, and tailoring intervention approaches to address developmental as well as individual child needs. For example, children who are more sensitive to food reward may need an intervention that addresses the ability to inhibit behavioral responses and delay gratification in a tempting food context, whereas other children may benefit from general EF training to enhance long-range planning skills. Finally, intervention efforts that focus on multiple aspects of a child's context and include not only a

focus on the individual child but also consider parenting and school settings are likely to have the strongest impact.

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Key Points

• Incorporating a focus on self-regulation as an underlying mechanism of health behavior change may lead to better health outcomes

- Executive functioning (EF) is a central aspect of self-regulation, and EF skill
 deficits are associated with higher weight status and obesity-promoting risk
 factors in children
- Different aspects of EF may be associated with obesity risk at different points in development
- Behavioral techniques to enhance EF in children may provide a new tool for obesity prevention, particularly for children characterized by high sensitivity to food reward or social-contextual risks

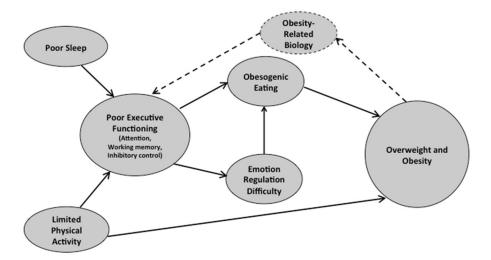


Figure 1.Potential Pathways of Association between Poor Executive Function and Obesity in Childhood

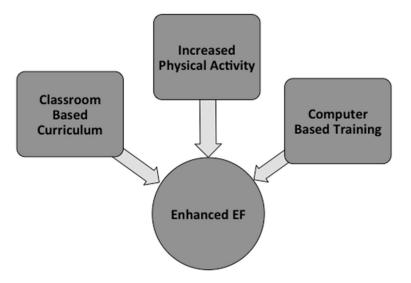


Figure 2. Effective Behavioral Strategies to Enhance Executive Functioning Capacity in Children