



Executive function in childhood obesity: Promising intervention strategies to optimize treatment outcomes



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ABSTRACT

Executive functions (EFs) are hypothesized to play a role in the development and maintenance of obesity due to their role in self-regulatory processes that manage energy-balance behaviors. Children with obesity have well-documented deficits in EF, which may impede effectiveness of current, evidence-based treatments. This review examines top-down EF processes (e.g., inhibitory control, working memory, cognitive flexibility), as well as bottom-up automatic processes that interact with EFs (e.g., attentional bias, delay discounting) and their relation to weight-loss treatment success in children. It then evaluates EF-related interventions that may improve treatment response. Empirical studies that included an intervention purported to affect EF processes as well as pre-post measurements of EF and/or relative weight in populations ages 19 or younger with overweight/obesity were reviewed. Findings indicate that poorer EF may hinder treatment response. Moreover, there is preliminary evidence that behavioral weight loss intervention and physical activity may positively affect EF and that improvements in EF are related to enhanced weight loss. Finally, novel intervention strategies, such as computer training of core EFs, attention modification programs, and episodic future thinking, show promise in influencing both EFs and EF-related skills and weight. Further research is needed to provide more conclusive evidence of the efficacy of these interventions and additional applications and settings should be considered.

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Childhood obesity is a serious public health concern due to high prevalence rates and the serious mental, physical and economic costs associated with the condition (Hannon, Rao, & Arslanian, 2005; Ogden, Carroll, Kit, & Flegal, 2014; Ogden, Carroll, & Lawman et al., 2016; Pulgaron, 2013; Schwimmer, Burwinkle, & Varni, 2003; Wang, Beydoun, Liang, Caballero, & Kumanyika, 2008). While effective treatments exist (Berge & Everts, 2011; United States Preventive Services Task Force, 2010), only one-third of children participating in family-based treatment, the “gold standard” for intervention, reach a healthy weight (Epstein, Valoski, Wing, & McCurley, 1994) and a sizeable subgroup of children do not experience clinically-significant weight change (Epstein, Paluch, Roemmich, & Beecher, 2007). Individual differences among children may impede intervention efforts. In particular, variation in cognitive processes associated with thoughts and behaviors may explain, at least in part, individual differences in child response to obesity treatment.

Executive function (EF) is an umbrella term that refers to a set of cognitive processes, supported in part by the frontal lobes, that aid in managing behavior, emotion, and thought with a consideration to future goals and outcomes (Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012; Diamond & Lee, 2011; Hall & Marteau, 2014). As such, EFs play a role in self-regulatory processes necessary to manage caloric intake and physical activity in an obesogenic environment (Appelhans, French, Pagoto, & Sherwood, 2016; Jansen, Houben, & Roefs, 2015; Liang, Matheson, Kaye, & Boutelle, 2014). If EFs are deficient, it may be difficult to employ the primary behaviors (e.g. choosing healthy foods, getting regular physical activity) as well as secondary behaviors (e.g. creating a healthy home environment) that aid in maintaining energy balance, leading to excess weight gain. Indeed, a burgeoning field of research has identified EF deficits in individuals with overweight/obesity (Fitzpatrick, Gilbert, & Serpell, 2013; Liang et al., 2014; Smith, Hay, Campbell, & Trollor, 2011) and a cognitive profile of obesity has been proposed that includes lower EF, in addition to other EF-related cognitive processes, as key components of poor self-regulation of energy-balance behaviors that ultimately leads to increased weight (Jansen et al., 2015). EF deficits would also then have implications for an individual's ability to engage in weight loss and weight loss maintenance behaviors, as these require many of the same (e.g., choosing healthy foods, etc.), as well as additional (e.g., self-monitoring, goal-setting, problem solving) self-regulatory skills (Gettens & Gorin, 2017). This review will briefly discuss EF domains and other cognitive constructs that interact with EFs and their deficits in children with obesity, examine the impact of EF deficits in children on performance in current obesity treatments, and explore traditional and novel intervention approaches that may help address EF-related issues in treatment response.

1. Executive function and obesity in children and adolescents

1.1. Core EFs

Varying theories exist as to how EFs are organized and how they function, both individually and together, to support complex cognition. The constructs at the heart of most EF models are inhibitory control, working memory, and cognitive flexibility, which have been referred to as the “core” EFs (Diamond, 2013; Diamond & Lee, 2011; Miyake et al., 2000) [see Table 1]. Core EFs begin to develop in early childhood and continue to mature through adolescence and young adulthood (Best, Miller, & Jones, 2009). Inhibitory control, or the ability to inhibit a pre-potent response and protect a desired response from disruption by competing events (Barkley, 1997; Diamond, 2013), has been assessed with regard to weight due to its theorized utility for avoiding tempting foods in an obesogenic environment. Avoiding temptation may mean saying no to cake at a birthday party, choosing an apple over chips for an afterschool snack, or choosing not to take dessert in the lunch line. Working memory allows individuals to temporarily store information and manipulate it for the execution of complex cognitive tasks, such as learning (Cowan, 2014). In the context of obesity, working memory would help children to incorporate knowledge and behavioral skills into developing diet and exercise behaviors. Cognitive flexibility supports the quick transition of thoughts and behavior in response to the environment, such as switching between activities or tasks. For children with obesity, cognitive flexibility would facilitate the use of coping strategies when faced with a novel or unexpected temptation (e.g. a classmate brings in cupcakes for his birthday at school), and more broadly would allow for strategies to be abandoned when they are not working (Hanna-Pladdy, 2007). The three core EFs work to support more complex self-regulatory skills, such as planning, decision making, and problem solving (Epstein et al., 1994).

1.2. EF-related constructs

While the three core EFs form the foundation of top down executive system, other cognitive processes interact with EF to either promote or encumber their use (Jansen et al., 2015). As such, these cognitive constructs, specifically attention/attentional bias and delay discounting, are included in this review as they may be relevant to designing interventions that support self-regulatory skills and EF development. Attention refers to the ability to concentrate on a task or item while ignoring distractors and attentional control has been proposed as an underlying factor that supports engagement of EF skills (Kaplan & Berman, 2010; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). For example, to utilize EFs, one needs to be able to notice and identify stimuli by

Table 1
EF and EF-related constructs related to weight.

Construct	Type of EF	Definition	Examples Related to Weight
Inhibitory Control	Core EF	The ability to inhibit a pre-potent response and to protect desired responses from disruption by competing events	Resisting internal and external cues for obesogenic temptations (e.g., “junk” food)
Working Memory	Core EF	The ability to temporarily store information and manipulate it for the execution of complex cognitive tasks	Integrating and utilizing nutrition and physical activity knowledge in daily life
Cognitive Flexibility	Core EF	The ability to quickly change thoughts and behavior in response to the environment	Engaging and switching coping strategies within an obesogenic environment
Attention; Attention Bias	EF-related construct	The ability to concentrate on a task or item while ignoring distractors; Preferential processing of some information above others	Attending to food cues in the environment, both consciously (attention) and subconsciously (attention bias)
Delay Discounting	EF-related construct	The subjective loss of value of a reinforcer as it becomes more temporally distant	Resisting immediate reward of a palatable food item in favor of weight maintenance/loss

directing attention to it and additionally, needs to be able to maintain this focused attention in order to achieve a goal, even if distractors are present (Kaplan & Berman, 2010). Moreover, individuals can have a predisposition to automatically focus attention on certain types of information above others, a phenomenon termed attentional bias. Attentional bias is relevant to child weight management and loss when a child has a predisposition to focusing attention on high-calorie foods at the expense of other healthier foods or non-food items. In such cases, EF skills would be needed to “override” this automatic process. Another EF-related process delay discounting refers to the subjective loss of value of a reinforcer as it becomes more temporally distant (Bickel & Yi, 2007; Odum, Baumann, & Rimington, 2006). Delay discounting may be considered a “hybrid” cognitive construct as it includes both the bottom-up influence of reward processing and the top-down need to inhibit responding to a temporally close reward. It is relevant to obesity as children engaging in weight management often need to make the decision to discount an immediate reward, such as dessert, in favor of the long-term reward of weight loss.

1.3. Deficits in children with obesity

Deficits in EF and EF-related cognitive skills are well documented in children and adolescents with obesity compared to children and adolescents with a healthy weight (for comprehensive and systematic reviews see Liang et al. (Liang et al., 2014), Reinert et al. (Reinert, Po'e, & Barkin, 2013), and Smith et al. (Smith et al., 2011)), suggesting this area may be ripe for intervention. However, the bulk of the existing literature predominately utilizes cross-sectional data, which fails to provide information on the direction of the relation between EF and EF-related deficits and obesity. It is possible that EF deficits precede obesity and increase the risk of obesity development by promoting obesogenic behaviors. However, a viable alternative explanation is that obesity development precedes EF dysfunction. Research has shown that reduced blood flow, dysregulation of glucose and insulin, and increased adipocytes associated with higher weight may negatively influence cognition and specifically EF (Boeka & Lokken, 2008; Gonzales et al., 2010; Volkow, Wang, & Telang et al., 2008). It is also possible that a bidirectional relation exists, such that EF deficits contribute to obesity development and obesity exacerbates EF deficits, or that a third variable, such as a genetic risk factor, may be the cause. This information is crucial to help understand how to best target EF deficits with interventions. For example, if deficits predate weight gain, prevention programs could be used to target children with EF deficits to prevent weight gain and proactively influence EF development. Furthermore, intervention programs could be developed for children with current obesity to specifically target EF. Alternatively, if EF deficits develop due to obesity and are reversible by weight loss, treatments most successful at

encouraging weight loss would be a sufficient focus. While this still remains largely unknown, the current treatment literature has begun to explore how EF deficits affect weight loss and what might be done to intervene. As such, this review provides an overview of the nascent literature assessing EF as a predictor of obesity treatment outcomes in children, summarizes traditional and novel EF-related interventions that have been evaluated to date, and proposes future directions based on gaps in current literature.

2. Methods

In identifying the literature reviewed, an extensive search was completed of PubMed and Google Scholar using “children OR adolescent” AND “obesity” AND “treatment OR intervention” and broad and specific terms referring to EFs of interest, specifically “executive function”, “inhibitory control”, “delay discounting OR delay of gratification”, “working memory”, “cognitive flexibility OR set-shifting OR mental flexibility OR switching”, “attention OR attention bias”, and “self-regulation”. Inclusion criteria were empirical research published in a peer-reviewed journal (e.g., no dissertations) that 1) included an intervention purported to affect EF or EF-related processes, 2) included at least a pre- and a post-invention measurement of EF/EF-related processes and/or relative weight and, 3) included EF/EF-related process measurements that were task-based (e.g., no self-report questionnaires). Participant samples must have been overweight/obese, as defined by a recognized guideline (e.g., BMI percentile equal to or greater than 85%), and be 19 years of age or younger. Studies were not included in the current review if they studied a population with health issues that may have affected results (e.g. diabetes, eating disorders, etc.). The search was completed in July 2016 and included studies published in 1995 or later.

3. Executive function as a predictor of childhood obesity treatment outcomes

Given the research supporting EF deficits in children and adolescents with obesity, their role in the treatment of obesity in this population should be considered. Current multicomponent behavioral weight loss programs teach behavioral strategies to children and families to 1) reduce calories while improving diet and 2) to increase physical activity while reducing sedentary time. As EFs facilitate goal-oriented cognition and behavior, they are important for controlling eating and activity behaviors to meet treatment weight goals and may impact treatment outcomes (Appelhans et al., 2016; Jansen et al., 2015).

Indeed, inhibitory control has been implicated as a predictor of weight loss in obesity treatments. A study conducted by Nederkoorn, Braet, Van Eijs, Tanghe, and Jansen (2006) found that 13 male and 19 female adolescents aged 12–15 who performed

more poorly on a stop-signal task, a measure of inhibitory control, lost less weight across the course of treatment ($r = -0.49$) (Nederkoorn et al., 2006). This relationship of lower inhibitory control and poorer weight outcomes was also found in a study on children ages 8–12 (9 males, 17 females) post-treatment ($r = 0.44$) and at 12 months ($r = 0.48$) following treatment, although sample sizes in both studies were small (Nederkoorn et al., 2006, 2007).

Notably, evidence showing the opposite relationship has also been found. A study of children and adolescents ($n = 111$, gender not reported) ages 7–15 participating in a one-year outpatient behavioral weight loss program with a parent component showed fast but less valid reaction times on tests of inhibitory control (e.g., the Go-NoGo task and the Incompatibility task from the Attention Assessment Battery (TAB)) positively predicted weight outcomes (R^2 change = 0.04), although found inattention (i.e., highly variable reaction times) did not relate to weight. This relation was moderated by age (R^2 change = 0.1), such that older children who were more impulsive were more successful than older children who were less impulsive while no relationship was found in younger children (Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010). The authors highlight differences in study duration, age range, setting, and cognitive tasks that potentially explain the discrepant findings with the studies completed by Nederkoorn and colleagues, although they also note the emphasis on stimulus control in their treatment program. Specifically, the authors suggest that individuals with low inhibitory control have difficulty controlling their diet in the presence of food cues, but may benefit the most when these cues are removed.

Delay discounting has also been examined as a predictor of treatment outcomes. Best, Theim, Gredysa, and et al (2012) assessed delay discounting for money and high-energy snack foods by asking children to choose between a hypothetical smaller, immediate monetary/food reward or a larger, future monetary/food award, as well as food reinforcement, at baseline on children aged 7–12 (90 males, 151 females) entering a four-month family-based behavioral weight loss treatment (FBT). Children who discounted money at higher rates upon beginning the program lost less weight than children who had lower discounting rates ($d = 0.39$), and no interaction with food reward was found. However, children who discounted food at higher rates only did more poorly in treatment when food was also found to be highly rewarding ($d = 0.75$). Thus, delay discounting of money negatively predicted weight loss in children, but discounting of food was only detrimental if it was coupled with high reinforcement of food. Previous work has demonstrated response differences to consumable and monetary rewards (Odum & Rainaud, 2003; Odum et al., 2006), so moving forward it may be important to consider the role of delay discounting for both food and money in treatment as well as how reinforcement of food versus other incentives may interact with EF constructs to influence outcomes.

Although a relatively new area of research, preliminary literature suggests that inhibitory control and delay discounting are related to weight loss outcomes in treatment and may account for individual factors driving the poorer response of some children to current interventions. More research is needed to concretely identify the relation of inhibitory control and delay discounting to weight loss in children, particularly given small sample sizes and the contradictory finding by Pauli-Pott and colleagues that higher impulsivity was associated with greater weight loss. Notably, research of other EFs (i.e., cognitive flexibility and working memory) and EF-related domains (i.e., attention) are absent, but would be worthy of investigation given their associations to weight status and potential influence on weight control behaviors. Additional work is needed to identify the role of each domain, both separately and together, on treatment success. In the meantime, development

and testing of interventions to strengthen EFs in the context of obesity treatment may provide greater insight into whether EFs can be changed and if so, if this change promotes improved weight outcomes.

4. Executive function-related interventions for children and adolescents

This section reviews research into interventions that may enhance EF skills in childhood obesity. The impact current treatments may have on EFs is explored, including general multicomponent behavioral programs and more specifically, physical activity, as well as novel treatment strategies being developed or newly applied to childhood obesity that target enhanced developed of specific EFs [see Table 2 for summary of treatments and Table 3 for specific study information].

4.1. Traditional child obesity treatments

4.1.1. Multicomponent behavioral weight loss interventions

Currently, there is some evidence to suggest that established multicomponent behavioral weight loss programs already help children and adolescents develop EF skills. By definition, these programs teach self-regulatory cognitive and behavioral strategies that would recruit EFs. These strategies include goal-setting, planning for behavior change, self-monitoring, inhibition of consumption of high-calorie foods in high risk situations, and problem-solving. Use of these strategies recruit and challenge the executive system and when used on a regular basis, should develop EF skills both for specific use in weight-loss treatment, but also for more general cognitive development. Many self-regulatory weight-loss strategies mirror those taught in programs that are empirically-supported to contribute to EF growth (Diamond, Barnett, Thomas, & Munro, 2007; Lillard & Else-Quest, 2006; Riggs, Greenberg, Kusché, & Pentz, 2006), thus it is likely the strategies will be effective in impacting EF in children participating in obesity treatment.

A pre-post treatment study supports this claim. Adolescents ($n = 42$) participating in a 12-week outpatient behavioral weight loss intervention completed tasks of inhibitory control and cognitive flexibility (Stroop Task), working memory (Letter-Number Sequencing Task) and decision-making, a complex cognitive process supported by core EFs that also relates to delay discounting (Iowa Gambling Task) pre- and post-intervention (Delgado-Rico, Rio-Valle, & Albein-Urios et al., 2012). The intervention provided a psychosocial module that was dedicated to the training of specific skills including cognitive skills (inhibitory control, planning, and conflict resolution) and affective skills (emotional expression and regulation), a nutritional module, which consisted of the prescription and monitoring of personalized diets for weight loss, and a physical activity module, which included the prescription and monitoring of a physical activity program to achieve at least 1 h of physical activity a day. Improvements were seen on the response inhibition and switching subscale of the Stroop ($d = 0.4$) and improvements on the response inhibition ($R^2 = 0.09$) and the response inhibition and switching subscales of the Stroop ($R^2 = 0.17$) were related to weight, suggesting program-related improvements in inhibitory control and cognitive flexibility influence weight outcomes. Working memory and decision-making did not change across treatment.

Similar effects regarding inhibitory control have also been noted in more intensive treatment settings. Children and adolescents ages 10–17 ($n = 53$) participating in up to eight weeks of a residential obesity treatment camp were measured pre- and post-intervention using the stop-signal task and a computerized monetary delay

Table 2
EF-related interventions for children and adolescents.

Treatment	EF and EF-related Targets	Treatment Mechanisms
Multicomponent Behavioral Weight Loss	Global	Skill development of self-regulatory strategies related to weight management (e.g., goal-setting, planning, self-monitoring, inhibition of desires). Programs also include physical activity, which likely also benefits EF (see below)
Physical Activity	Global	Utilization of self-regulatory skills related to goal-oriented exercise, complex motor movements that engage EF skills, and physiological changes in the brain
EF Computer Training	Inhibitory Control, Working Memory	Practice of EF skills on computer-based tasks
Attention Modification Program	Attention Bias	Practice redirecting attention away from food stimuli
Episodic Future Thinking	Delay Discounting	Mentally project oneself into the future to increase subjective value of future rewards

discounting task (Kulendran, Vlaev, & Sugden et al., 2014). The program components included stimulus control, monitoring, behavior shaping, alternative responses, goal setting, planning, problem solving, and time management. Participants also had a daily routine that included playing a team sport. At baseline, scores on both the stop-signal task and the delay discounting task predicted degree of overweight/obesity. Post-intervention, significant improvements were seen on inhibitory control and delay discounting and in follow-up analyses, age, number of weeks in camp, and improvement on an exercise task were related to the change in inhibitory control while improvement on the exercise task was related to the change in delay discounting. Finally, a stepwise regression showed number of weeks participating in camp as well as both initial and change inhibitory control scores were related to weight-loss outcomes, such that children who were in camp longer, who initially demonstrated superior inhibitory control skills, and who improved the most in inhibitory control lost the most weight. Initial scores or change in delay discounting did not predict weight change. Thus, inhibitory control and delay discounting improved across the course of the program and improvements in inhibitory control were related to weight loss.

4.1.2. Physical activity interventions

Improvements of EFs in multicomponent treatments may not be due to curriculum alone, but may also be influenced by increasing physical activity, which is a primary treatment goal in most behavioral weight loss interventions for increasing calorie expenditure (Jeffery, Wing, Sherwood, & Tate, 2003) and improving cardiovascular health (Poirier, Giles, & Bray et al., 2006). However, both chronic and acute aerobic exercise has also been shown to positively affect cognition, and more specifically, EFs (Best, 2010; Davis, Tomporowski, McDowell, & et al., 2011; Tomporowski, Lambourne, & Okumura, 2011). While a complete discussion of the mechanisms in which exercise aids in EF development is outside the scope of the review (and detailed in Best, 2010 (Best, 2010)), three main influences have been identified. First, particularly in group games and sports, EF skills are required to facilitate exercise behaviors, such as creating, monitoring, and updating a plan to complete a goal (e.g. avoid being caught in tag). Thus, by engaging in exercise, children are practicing these EF skills, which may transfer to other EF tasks. Second, complex motor movement used for exercise can be considered a cognitive task. Studies show complex movements activate several areas involved in EF, such as the dorsolateral prefrontal cortex, and require individuals to override “default” motor responses to initiate novel movements (Diamond, 2009). Finally, both chronic and acute exercise cause physiological changes in the brain that impact functioning as well as performance on cognitive tasks (Colcombe, Erickson, & Scaif et al., 2006; Davis et al., 2011; Winter, Breitenstein, & Mooren et al., 2007).

While the effect of exercise on weight loss is well-studied in obesity (see Swift et al. (Swift, Johannsen, Lavie, Earnest, & Church,

2014) and Catenacci et al. (Catenacci & Wyatt, 2007) for reviews), most studies have not separated the role of exercise on weight via physiological processes compared to the potential role of exercise on weight via EF. There are only two studies in children that provide insight into this relationship. The first study was completed by Davis et al., 2011, who intervened for approximately 13 weeks with 171 sedentary, overweight children aged 7 to 11. Participants were randomized to one of three conditions: 20 or 40 min of exercise per day in an afterschool program, or a no treatment control. Exercise occurred through activities that were game or sport based and meant to be both enjoyable and cardiovascularly strenuous, with a target average heart rate of 150 or above. Results showed positive dose-response effects of exercise on scores on planning, which is generally considered a higher-order self-regulatory skill supported by EFs and is sometimes included EF taxonomies, although not on attention, as measured by the modules of the Cognitive Assessment System (Best et al., 2009; Bickel et al., 2012; Diamond, 2013). The findings demonstrate that aerobic exercise over time improves planning in children with overweight/obesity, although weight outcomes as well as the relationship between EF and weight is not reported, so it is unclear how change in planning performance contributed to weight change, if at all.

A study in older, African-American adolescents ages 15–19 ($n = 54$) using “exergames” did assess both EF and weight (Staiano, Abraham, & Calvert, 2012). Exergames are videogames that combine game play with physical activity. They incorporate many of the benefits for cognitive training from sedentary videogames (Green & Bavelier, 2003), but additionally lead to greater calorie expenditure (Graves, Stratton, Ridgers, & Cable, 2007), and have previously been shown to positively influence EF in children and adolescents (Best, 2012; Flynn, Richert, Staiano, Wartella, & Calvert, 2013). In the study, adolescents in the intervention were randomized to a no-play control group or either competitive exergame or collaborative exergame play using the Wii EA Sports Active exergame routines, for which 30-min sessions were offered every school day. EF was measured pre- and post-intervention using the Delis-Kaplan Executive Function System Design Fluency and Trail Making tasks. From these, a combined total EF score was created. Adolescents in the competitive exergame condition improved in EF more than those in the cooperative or no-play control group and improvements in the competitive group were significantly correlated with weight loss. No differences in EFs were found between the cooperative and no-play control groups, and scores did not predict weight loss in either condition.

Notably, the results described above were only significant when exercise was competitive. Competition is thought to increase demands on the prefrontal cortex, as it requires an individual to be able to mentalize both himself and the opponent, which utilizes and likely enhances EF (Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004). Additionally, competitive exergaming in particular has previously been shown to increase energy expenditure (Peng & Crouse, 2013) potentially through greater motivation to

Table 3
EF-related interventions for children and adolescents.

Study	Sample Size (M/F)	Age Range (Avg±SD)	Design	Intervention Groups; Length	EF and EF-related Tasks	Measurement Time points	Findings
Delgado-Rico et al. (2012)	42 (14/28)	12–17 (14.19 ± 1.38)	Pre-post	Outpatient BWL; 12 weeks	Stroop (IC, CF); Letter-Number Sequencing (LNS; WM); Iowa Gambling Task (IGT)	Bl, 12 wks	Adolescents significantly improved on the response inhibition and switching subscale of the Stroop ($d = 0.4$), but did not improve on the other subscales (response inhibition and response switching) nor the LNS or IGT. Response inhibition ($R^2 = 0.09$) and the response inhibition and switching subscale improvement ($R^2 = 0.17$) were associated with weight loss.*
Kulendran et al. (2014)	42 (20/32)	10–17 (14.7 ± 1.7)	Pre-post	Residential BWL; 8 weeks	CANTAB Stop Signal (IC); Monetary Delay Discounting (DD)	Bl, 2–8 wks	Children and adolescents significantly improved on the stop signal and monetary delay discounting tasks across treatment. Changes on the stop signal task, but not the delay discounting task, were related to weight change ($R^2 = 0.32$).*
Davis et al. (2011)	171 (75/96)	7–11	RCT	20 vs. 40 vs. 0 min/day exercise; ~13 weeks	CAS: Planning and Attention	Bl, ~13 wks	Children exhibited a significant dose-response to exercise for improvement on the planning task ($d = 0.39^a$), but not the attention task.
Staiano et al. (2012)	54 (23/31)	15–19 (16.46)	RCT	Exergames: competitive vs. collaborative vs. no treatment; 10 weeks	D-KEFS: Design Fluency and Trail Making (CF)	Bl, 10 wks	Adolescents in the competitive group showed significant improvements on an EF summary score compared to the collaborative group or no physical activity control group ($\eta^2 = 0.145$). Improvements were positively correlated with weight loss ($r = 0.48$).*
Verbeken et al. (2013)	44 (22/22)	8–14 (9.79 ± 1.04)	RCT	IC and WM computer training + inpatient BWL vs. inpatient BWL; 6 weeks	Corsi Block-Tapping Task (WM); Stop-Signal (IC)	Bl, 6 wks	Children significantly improved on the block-tapping task forwards ($\eta^2 = 0.13$) and backwards ($\eta^2 = 0.12$) compared to a control group, but no changes were seen on the stop signal task. Changes in working memory were related to weight loss maintenance at the eight-week follow-up ($\eta^2 = 0.16$), but no effects were seen post-treatment or at 12-weeks follow-up*
Boutelle et al. (2014)	29 (16/13)	8-12 (10.8 ± 1.3)	RCT: pilot	Attention modification (AMP) vs. Attention control (ACC); 1 session	Modified (Food) Dot-Probe (ATTB)	Pre- and post-intervention	A trend level effect showed children in AMP decreased in attention bias compared to a no-treatment control. Children in AMP ate significantly fewer kilocalories in an <i>ad libitum</i> taste test compared to control ($d = 0.68^a$). Changes in attentional bias did not moderate treatment outcomes.
Daniel et al. (2015)	42 (21/21)	9–14	Cont. lab exprmt.	EFT vs. ERT; 1 session	Monetary Delay Discounting (DD)	Pre- and post-intervention	Children in the EFT condition significantly decreased delay discounting ($d = 1.069$) and reduced energy intake ($d = 0.27$) compared to the control condition.
Sze et al. (2015)	20 (11/9)	(11 ± 1.3)	RCT: pilot	EFT + outpatient FBT vs. FBT alone; 4 weeks	Not Assessed	Bl, 4 wks	Children in the FBT+EFT condition ate significantly fewer mean calories per day than children in the FBT control condition ($d = 0.891^a$). No group differences were found with weight.*

*EF change and weight change were measured across time and their relationship assessed.

RCT: Randomized controlled trial; BWL: Multicomponent behavioral weight loss treatment; EFT: Episodic Future Thinking; FBT: Family-based behavioral weight loss treatment; IC: Inhibitory control; CF: Cognitive flexibility; WM: Working memory; DD: Delay discounting; ATTB: Attention Bias; CANTAB: Cambridge Neuropsychological Test Automated Battery; CAS: Cognitive Assessment System; D-KEFS: Delis-Kaplan Executive Function System; Bl: Baseline.

^a Effect size calculated based on study data.

improve performance (Marker & Staiano, 2015). Therefore, adolescents in the study described above may have been exercising with greater intensity in the competitive condition, which may have also contributed to differential results between the two active conditions, although this was not assessed. While the sample size is small, the results provide support for competitive exercise as an intervention for EF skill enhancement in adolescents with obesity, as well as an association between EF improvement and weight loss. Moreover, these effects were seen with approximately 10 exercise sessions spread over 10 weeks, a remarkably smaller number than the Davis et al. (Davis et al., 2011) study, indicating that even small amounts of exercise may have significant effects.

4.2. Targeted EF interventions

Interventions targeted at improving EF may aid in obesity treatment. The following interventions have been developed to enhance specific EFs and have either been developed for or recently applied to obesity-specific treatment contexts. Preliminary work in this area has primarily begun with adult populations, thus each section below begins with a short review of the intervention protocol and initial work in adults before moving onto the review of empirical research in child samples.

4.2.1. Computer training: EF training protocols

Computer training has children engage in tasks or activities meant to improve a specific EF domain. Studies show existing training programs are efficacious for typically developing children and individuals with EF deficits (e.g. ADHD, poor working memory spans) (Diamond & Lee, 2011; Melby-Lervåg & Hulme, 2013), and similar training programs targeting inhibitory control and working memory have been newly applied for populations with obesity.

Specifically, inhibitory control training has shown short-term changes in food-related behaviors in adult laboratory studies (Forman, Shaw, & Goldstein et al., 2016; Lawrence, Verbruggen, Morrison, Adams, & Chambers, 2015; Stice, Lawrence, Kemps, & Veling, 2016; Veling, Aarts, & Stroebe, 2013; van Koningsbruggen, Veling, Stroebe, & Aarts, 2014). Inhibitory control training uses an inhibitory control task, such as a Go-NoGo task that asks participants to respond to a target object on a computer (a “go” signal) and to inhibit response to a “no go” signal, repeatedly over time to train individuals to inhibit their responses. These tasks will often use foods as targets, thus individuals practice inhibiting response to obesogenic food items. A meta-analysis suggests significant short-term effects of inhibitory control training on appetitive behavior in adults (Jones, Di Lemma, & Robinson et al., 2016). Longer interventions have assessed weight effects of inhibitory control training in adults with one four week study showing positive results (Veling, van Koningsbruggen, Aarts, & Stroebe, 2014) and another 10-day study demonstrating null results with empirical height and weight measures (Allom & Mullan, 2015). Long-term working memory training has also shown promise for dietary behavior change, although has not shown weight effects in adults (Houben, Dassen, & Jansen, 2016).

Only one study to date has looked at computer training in children with obesity for weight change. The completed study randomized 44 children ages 8–14 who were finishing a 10-month inpatient treatment program to a six-week, 25 session combined inhibitory control and working memory training program or to a usual care control group. The training was presented as a computer game, the first 20 min of which included the working memory training consisting of tasks that targeted short-term memory, updating and manipulating information, and keeping information online, and the second 20 min of which was targeted to inhibitory control training consisting of an adapted stop-signal task. After

each block of training tasks, the difficulty of the tasks was adjusted to meet the level of the child. Results showed that children in the training condition had greater improvements post-treatment in working memory, as measured by the Corsi Block-Tapping task, than the control group, but that there were no time nor time by interaction effects for inhibitory control, as measured by a stop-signal task. Moreover, group effects were seen for follow-up weight outcomes, such that children in the training group were better able to maintain weight-loss from post-training to eight week follow-up; however, this effect was not seen pre to post training when children were still in inpatient treatment and it dissipated by the 12 week follow-up.

This study showed that the computerized cognitive training was most helpful for the initial maintenance of weight loss following treatment. A conceptual model of the role of EFs on successful long-term weight control proposes the benefit of EFs not only for weight loss, but also for helping to self-regulate behaviors necessary for long-term weight loss maintenance (Gettens & Gorin, 2017). These weight loss maintenance behaviors include flexible dietary restraint, spontaneous meal planning, and continued inhibition of unhealthy weight-related behaviors, among others. In the current study, the positive finding on weight loss maintenance suggests the computer training may have worked to alter the underlying EF mechanisms that facilitate these weight-loss maintenance behaviors. Measurements of the EF improvement in the experimental group support this conclusion, although inhibitory control did not change, suggesting that working memory may be driving the effect. However, the study design did not allow the disentanglement of the specific contributions of the training tasks themselves, as they were not assessed independently and potential carry-over may have occurred. Effects of the training were also short-term and dissipated by the third month. It is unclear if this is due to diminution of working memory improvements or just as failure of working memory enhancements to facilitate long-term weight change (EFs were not assessed at the follow-up time points).

Results from the study also showed that concurrent training did not enhance weight loss during active, inpatient treatment. This is perhaps unsurprising, as prior to study initiation, children had participated in at least 6 months of intensive, inpatient treatment and continued to do so across the course of the active training. Inpatient settings provide standardized meals and physical activity routines specialized for weight loss, thus its possible training effects may be too subtle to further promote weight loss in this controlled environment. Potentially, the training may be most beneficial for active weight loss in an outpatient setting, where children and families will be making their own daily diet and activity choices, and should be a future area of research.

4.2.2. Computerized training: attention modification programs

Given the underlying role of attention in EF processes, interventions have also been developed to target attention processes. Both children and adults with obesity have been found to have an attentional bias, or an increased attention for, palatable food cues. Specifically, children with obesity, compared to children of normal weight, show greater response latencies to food words than neutral words in a Stroop task, which demonstrates an increased bias towards these words (Braet & Crombez, 2003) and BMI has been found to be predictive of attentional bias to food but not neutral stimuli in a sample of adolescent females (Yokum, Ng, & Stice, 2011), although another study in adolescents did not show this effect (Soetens & Braet, 2007). Attention modification programs, originally developed to help individuals with anxiety disorders, work to train individuals to disengage attention from threatening cues, such as a snake in a reptile-related specific phobia or negative emotion faces in social anxiety, and to retrain that attention toward

neutral cues in the environment. As such, these programs do not work to train EFs per se, but instead train the underlying, bottom-up attentional bias toward distracting stimuli so that less top-down EF control is necessary. More recently, attention modification programs have been developed to aid individuals who have attentional biases for appetitive, as opposed to threatening, cues, such as alcohol, cigarettes, and food. A meta-analysis published in 2012 primarily focused on adults indicates that attention modification training using appetitive and neutral stimuli can be effective for producing changes in attentional bias; however, results are less clear as to whether they are able to change subjective experience or behavior in response to a challenge (Beard, Sawyer, & Hofmann, 2012). While none of the studies in the meta-analysis assessed attention modification for weight or weight-control behaviors, more recent studies have indicated that an attention modification program can reduce attentional bias for chocolate as well as chocolate consumption in adults (Kemps, Tiggemann, & Elford, 2015) and that an eight-week attention modification program reduced attention bias and weight in adults with overweight or obesity that engaged in binge eating (Boutelle, Monreal, Strong, & Amir, 2016).

No long-term intervention study on changing attention bias to reduce weight has been completed yet in children; however, Boutelle, Kuckertz, Carlson, and Amir (2014) have assessed the use of a single-session attention modification program in children with overweight and obesity (Boutelle et al., 2014). Children ages 8–12 with overweight/obesity were randomized to an attention modification control or an attention control condition. In the modification program, children completed 288 trials in which two words, a food and a neutral word, were presented on the screen. Following presentation of these words, the child was asked to respond to a probe, which always was in the location of the neutral word. Thus, over the course of the intervention, children were trained to direct their attention to the neutral word. In the control condition, the probe appeared equally in the position of the food and neutral words. Results showed that children in the experimental group ate the same amount at an *ad libitum* taste test pre-post, whereas children in the control group ate significantly more than they had at baseline; however, no effects of group or time were found for cravings, liking, or salivary response across the experiment. The dot-probe task showed a marginal time by group interaction, such that children in the experimental group showed a slight decrease in attentional bias towards food, whereas children in the control group increased in attentional bias.

Overall, results suggest attention modification training can positively affect eating behaviors. While this pilot study indicated the promise of attention modification training, this study was one session in a small sample and eating behaviors were measured directly before and after. Thus it remains to be seen if attention modification training can affect weight, and if so, how many sessions at what frequency and duration may be necessary to produce real-world results. Additionally, the increases in consumption and attentional bias should be noted in the control condition. By splitting the probe location equally between the food and neutral words, children were actually being trained toward the food word on 50% of the trials, which may have induced increased eating. Had a more neutral task been selected for the comparison group, it's possible no effects of the training would have been observed, as children in the training condition did not actually change their caloric consumption.

Approach-avoidance training is a similar training paradigm in which participants practice “approaching” healthy foods, generally by pulling joystick towards themselves when viewing healthy food images, and “avoiding” unhealthy foods, generally by pushing a joystick away from themselves. It is similar to attention

modification programs as it trains underlying automatic processes away from tempting foods. In adults, studies have shown positive effects of a single session of training on food choices (Fishbach & Shah, 2006) and chocolate consumption (Schumacher, Kemps, & Tiggemann, 2016); however, another set of three studies did not show any effects on explicit or implicit preferences or eating behavior (Becker, Jostmann, Wiers, & Holland, 2015). No food-related approach-avoidance training studies have been conducted in children, although one is currently underway (Warschburger, 2015).

4.2.3. Episodic future thinking

Another intervention that has been developed to target EF- and EF-related deficits is episodic future thinking (EFT). EFT targets delay discounting by asking an individual to mentally project himself into the future and to “pre-experience” a future event through detailed visualization (Atance & O'Neill, 2001). Theoretically, this increases the salience of the future and subsequently, the subjective value of future events and rewards. Laboratory studies have shown that EFT interventions reduce monetary discounting rates (Daniel, Stanton, & Epstein, 2013; Sheffer, Mackillop, & Fernandez et al., 2016) and eating behaviors (Dassen, Jansen, Nederkoorn, & Houben, 2016) in adults following single session applications, although some have only found EFT to be effective for appetitive behaviors when future events are food-specific (Dassen et al., 2016). A child's ability to engage in EFT develops between the ages of 3 and 5, therefore it may also be applicable for child intervention.

An EFT intervention has been tested against a control group (episodic recent thinking; ERT) in a laboratory study of 42 9–14 year olds with overweight/obesity. Individuals in the EFT group listed and rated positive future events for valence, salience, arousal, and vividness, while individuals in the control group rated positive current events. Both groups then participated in a monetary delay discounting task and an *ad libitum* eating task during which each group was reminded of the events they previously specified. Results showed individuals in the EFT group had lower delay discounting rates and lower energy consumption than children in the ERT group (Daniel, Said, Stanton, & Epstein, 2015).

EFT has also been piloted as an intervention for weight loss in a randomized controlled study of 20 parent-child dyads over a period of four weeks (Sze, Daniel, Kilanowski, Collins, & Epstein, 2015). Both groups received behavioral diet change strategies and were asked to audio-record prompts for themselves to remember to engage in the healthy eating and activity behaviors recommended by the program. In addition, children and parents assigned to the EFT condition created descriptive prompts of future events they were able to vividly imagine, which were also recorded. Participants in both groups developed four prompts each week in their weekly meeting with an interventionist and between these sessions, participants were supposed to listen to the prompts at least twice per day.

Results showed that children's weight loss did not vary by condition post-intervention, but that beneficial effects were seen in diet, as measured by 24-h recalls at pre- and post-intervention, with children in the EFT condition showing a trend-level effect toward eating fewer daily calories, approximately 400 fewer calories, than the control FBT group. The diet effects mirror those seen in laboratory studies in children (Daniel et al., 2013) and point to the potential of EFT to impact obesogenic behaviors in children. In contrast, parents in the EFT condition lost one BMI point while the comparison group only lost 0.2 BMI points, a significant difference; however, no diet effects were seen in parents. A potential explanation for the differential effects in children and parents is access to the electronic devices that housed EFT prompts. Parents were

presumably able to access their recordings for most of the day via electronic devices, while children likely had more limited access, given school and other obligations, so potentially a shorter, more inconsistent dose of EFT may explain results. Notably, delay discounting was not assessed before or following the intervention, thus it is unclear if the intervention produced any change on this variable and if it did, how the changes were related to weight outcomes.

5. General discussion

Research in the field of EF intervention for weight loss in children is nascent, but existing research supports deficits in EF and cognitive processes that interact with EF are related to more negative treatment outcomes in children with obesity participating in obesity interventions. Additionally, skills taught within current childhood obesity treatments, physical activity, and targeted EF interventions show promise in affecting child EF and weight loss and weight loss maintenance. Yet, findings are not exclusively positive and many existing studies lack experimental rigor.

Preliminary evidence supports improvement in inhibitory control and cognitive flexibility across current multicomponent behavioral weight loss treatments, as well as related changes in weight that suggest improvements in EF are enhancing weight loss outcomes. It is hypothesized that the self-regulatory strategies taught in these programs for weight management (e.g., goal-setting, self-monitoring, etc.) recruit and challenge the executive system, which leads to EF development. However, with small sample sizes and no control groups, extant studies of the role of multicomponent treatments in developing EFs and affecting weight through EFs are methodologically lacking; it is difficult to say whether these changes are the result of the interventions tested, particularly as EFs will develop across childhood and adolescence. Furthermore, other EFs (e.g. working memory) and EF-related cognitive processes (e.g. delay discounting) did not show change across treatment (Delgado-Rico et al., 2012; Kulendran et al., 2014). Moreover, it is currently unclear which components of multifaceted interventions specifically facilitate change in EFs. Dismantling studies could provide insight into which treatment components enhance EFs. With this information, it would be possible to tailor interventions to meet the needs of children low in certain EF domains by focusing on treatment elements that have the greatest effect. Finally, none of the existing studies assess how much weight loss in behavioral treatments are explained by changes in EF, which makes it impossible to understand the magnitude of the effect of EF change on weight loss.

Physical activity is a key component of most multicomponent treatments and may produce changes in EF independently of the general treatment. Current research of the effects of physical activity on EFs in children with overweight/obesity showed that experimental paradigms aimed at increasing physical activity resulted in improvements in EF, although results were dependent on duration and type of physical activity. Moreover, in the study that also provided weight outcomes, improvements in EF functioning were related to weight changes (Staiano et al., 2012). However, only two studies were found, only one of which included weight outcomes, and neither included follow-up assessments of EF skills or weight. The initial positive effects of exercise on EF and weight short-term may inform treatment approaches. Most obesity treatments do encourage physical activity and provide duration and/or intensity goals (Janicke, Steele, & Gayes et al., 2014), but more specific guidance on activities may be beneficial. For example, recommendations regarding engagement in physical activity that is competitive (e.g., team sports) or that incorporates cognitive components (e.g., exergames) could be given. Furthermore,

interventions may offer physical activity sessions as part of the treatment protocol to ensure children are getting physical activity and would have the additional benefit of offering group exercise, which also enhances EF (Pesce, Crova, Cereatti, Casella, & Bellucci, 2009).

Finally, newly developed or newly applied interventions that target specific EFs show promise for positively impacting eating behaviors and weight in children with obesity. A combined inhibitory control and working memory intervention added to a traditional inpatient treatment showed improvements in working memory as well as short-term weight-loss maintenance, but not immediate weight-loss or longer-term weight-loss maintenance, compared to a control group (Verbeken, Braet, Goossens, & Van der Oord, 2013). An attention modification intervention and an EFT intervention resulted in reduced calorie consumption in an *ad libitum* taste test compared to control groups (Boutelle et al., 2014; Daniel et al., 2015). Finally, a pilot EFT intervention, in combination with a family-based multicomponent behavioral weight loss treatment, showed a trend-level reduction in daily calorie consumption in children (Sze et al., 2015). However, the findings from these studies were not all positive. The inhibitory control/working memory intervention did not change inhibitory control skills or result in post-treatment weight loss or longer-term weight-loss maintenance, the attention modification intervention finding was due to an *increase* in caloric consumption in the control group and changes in attention modification were trend-level and not moderators of the treatment effect, and the pilot study of an additional EFT treatment component did not actually lead to additional weight loss in children, nor did it measure change in delay discounting.

As with studies assessing the effects of traditional treatment approaches on EF, only a small number of studies of targeted treatments are currently available and many questions still remain. First, it is unknown whether these types of interventions could be effectively employed as stand-alone interventions in children and adolescents. To date, studies targeting weight change have only utilized targeted EF interventions in the context of a multicomponent behavioral weight-loss program as a supplementary treatment (Sze et al., 2015; Verbeken et al., 2013). Second, if treatments are combined with multicomponent interventions, research is needed to determine if it may be able to effectively replace time currently spent on the intervention or if additional time would need to be added. Child weight loss programs already require a heavy participant time commitment to see reliable results (i.e., 26 or more contact hours (United States Preventive Services Task Force, 2010) in addition to other treatment activities such as planning and self-monitoring, exercising, etc.) and additional time may not be feasible for translation, particularly if only small effects are gained. Third and relatedly, it is currently unclear how long training or other intervention methods reviewed may need to be formally practiced to have long-lasting effects. The studies reviewed did not show long-term effects (Sze et al., 2015; Verbeken et al., 2013), which may be due to time period of intervention, or may reflect other study factors (e.g., lack of power). However, literature regarding targeted EF training in other populations highlights the lack of long-lasting effects of EF changes as a major issue (Diamond & Lee, 2011; Melby-Lervåg & Hulme, 2013), thus it may be a more general limitation of these types of interventions. Finally, different interventions target different EF domains; however, it is unclear which domain may be most potent in affecting weight change.

6. Future directions

As the research field of EF interventions for weight loss moves

Table 4
Future directions for EF-Related intervention research.

Research Themes	Topics of Further Inquiry
Improve and Increase Empirical Evidence	<ul style="list-style-type: none"> o Increased sample sizes and randomized controlled designs are needed to improve evidence base o Optimal dose and frequency of EF-related interventions to produce clinically-significant weight change remain unknown
Examine Tailored Use of EF Interventions	<ul style="list-style-type: none"> o Unique contribution of EF change to weight loss and identification of specific EF domains that affect weight o Evidence of directionality of relationship between EF change and weight loss should be explored o Use of EF interventions for specific subpopulations of children with obesity that have indicators of EF deficits may enhance weight-loss outcomes o ADHD is a disorder characterized by impulsivity and inattention and children with ADHD have increased rates of overweight/obesity o Binge eating and loss of control eating has been associated with EF deficits and children engaging in these behaviors have higher rates of obesity
Consider Developmental Stages	<ul style="list-style-type: none"> o Periods of relative plasticity during child development may be optimal times for intervention o EF interventions may be more relevant in childhood than adulthood
Explore Additional Promising Interventions	<ul style="list-style-type: none"> o Mindfulness-based interventions may improve EF skills and also aid in weight loss, but have yet to be tested in children for this purpose o Neurological interventions, such as transcranial magnetic stimulation and transcranial direct-current stimulation, have shown initial promise in affecting eating behavior in adults
Broaden Applications of EF Interventions	<ul style="list-style-type: none"> o Classrooms and other venues may viable settings for EF interventions o EF interventions may be useful for prevention of childhood obesity as well as treatment
Assess Translation Issues	<ul style="list-style-type: none"> o Obesity interventions should be accessible, scalable, and cost-effective o Some EF-related interventions (e.g., physical activity, EFT prompts via mobile phones, etc.) may promote these objectives, although this remains to be tested

forward, researchers may consider the following future research areas [see [Table 4](#)].

6.1. Improve and increase empirical evidence

Many of the studies reviewed have designs that could be improved upon. Small sample sizes in nearly all studies and the lack of control groups in the more intensive interventions (e.g., multi-component behavioral weight loss studies) severely limit conclusions. For example, it is unclear whether null results reflect a true null finding, or if the studies were not powered to find effects. More rigorous experimental obesity treatment designs will be necessary to determine the efficacy and feasibility of augmenting current obesity treatment strategies to include EF-related intervention strategies for the purpose of improving EF skills. To this point, information about specific treatment protocols should be determined, including the individual effects of global treatment (e.g., behavioral weight loss) components on EF and weight and the utility of targeted interventions alone at affecting weight change. Dose and frequency of EF interventions should also be considered with regard to producing clinically-significant weight change in children with obesity in the short- and long-term. To date, limited studies provide an indication of the unique contribution of EF-related strategies to weight loss and which EF domain may be most relevant to weight change. Moreover, in existing studies, even if weight losses with EF-related interventions are statistically-significant, they may be small and difficult to maintain long term ([Sze et al., 2015](#); [Verbeken et al., 2013](#)). Thus, future studies should assess long-term efficacy, particularly as EFs have been implicated for their importance for not only weight loss, but weight loss maintenance ([Gettens & Gorin, 2017](#)).

The directionality of the relationship between EF and obesity also remains a question. In the current review, many of the studies showed that EF change was related to weight change. While it is possible that changes in EF resulted in weight loss, the opposite may also be true; that the weight loss resulted in change in EF. Research supporting the latter assertion exists in bariatric surgery populations, which has found that post-surgery, measures of EF improved, suggesting the rapid weight loss may lead to cognitive improvements, although the biological mechanisms of these effects are not currently well understood ([Alosco, Galioto, & Spitznagel](#)

[et al., 2014](#)). Moreover, neither causality hypothesis must be mutually exclusive; it is possible a bidirectional relationship exists. As the science moves forward, future studies may address this question of directionality more specifically and may also explore third factors potentially affecting results.

6.2. Examine tailored use of EF interventions

Individual differences exist in childhood obesity treatment response and many children may have limited or no weight loss ([Epstein et al., 1994](#)). As noted earlier, decreased inhibitory control skills and increased delay discounting are predictors of poorer response ([Best et al., 2012](#); [Nederkoorn et al., 2006, 2007](#)). In light of this, it is likely that children exhibiting these characteristics would benefit most from supplementary treatment, such as EF training to target deficits in particular EF processes, additional exercise recommendations, or training in specific strategies to overcome these deficits to aid in self-regulatory treatment tasks. To this end, there are specific subgroups of children with obesity with comorbid conditions, such as attention deficit hyperactivity disorder (ADHD) and binge eating difficulties, related to EF deficits. It may be that these subgroups will see increased benefit from obesity treatment in EF skills are specifically targeted.

ADHD is a disorder typically diagnosed in childhood that is characterized by behavioral impulsivity and inattention and EF deficits are frequently associated with the condition ([Pliszka, 2007](#)). Children with ADHD are 40% more likely to be overweight/obese ([Cortese et al., 2016](#)) and EF skills are poorer in children with ADHD with obesity than with ADHD alone ([Graziano et al., 2012](#)), suggesting children with ADHD and obesity have particular difficulty with EF tasks and may do more poorly in a weight loss program. This subgroup may then see greater benefit from the inclusion of program components aimed at the development of EF, such as a greater physical activity prescription or a targeted EF intervention.

Children with obesity with comorbid binge eating or loss of control eating would be another population of interest. Binge eating is defined as consumption of an objectively large amount of food with a concurrent feeling of loss control over eating ([Association AP, 2013](#)), while loss of control (LOC) only requires the feeling of loss of control, regardless of the amount consumed ([Tanofsky-Kraff, Faden, Yanovski, Wilfley, & Yanovski, 2005](#)). Data

suggest LOC eating or binge eating occurs in 2%–10% of children and 30% (Tanofsky-Kraff et al., 2005) to 37% (Tzischinsky & Latzer, 2006) of children with overweight/obesity report at least one lifetime episode of LOC eating. Binge eating and LOC eating have been associated with EF deficits (Duchesne, Mattos, & Appolinário et al., 2010; Manasse et al., 2014) and a recent longitudinal study in adolescents indicates that binge eating may be a partial mediator of the relation between EF deficits and increased weight (Goldschmidt, Hipwell, Stepp, McTigue, & Keenan, 2015). As such, children with obesity and LOC/binge eating may see greater benefit from weight loss interventions designed to address EF deficits. Future studies experimentally assessing this, as well as studies including LOC or binge eating as a potential moderator to EF intervention response are warranted.

6.3. Consider developmental stages

As discussed previously, age plays a role in the development of EF and different EFs have unique developmental progressions (Best et al., 2009; Wass, Scerif, & Johnson, 2012; Zelazo & Carlson, 2012). As such, children of certain ages may respond best to particular types of interventions. For example, younger children have been shown to improve inhibitory control relative to older children when participating in a behavioral weight loss program (Kulendran et al., 2014). Knowing that inhibitory control is one of the first EFs to emerge, it may be easier to enhance skills at younger ages during a period of greater growth. Indeed, certain ages have been highlighted as periods of relative plasticity, when brain regions may be more vulnerable to outside influence. The preschool age has been identified as important due to rapid and substantial changes occur in the prefrontal cortex (Zelazo & Carlson, 2012). Additionally, with adolescence comes a period of reorganization and synaptic refinement in the prefrontal cortex, resulting in substantial changes in white and gray matter volume (Brenhouse & Andersen, 2011). Thus, these times may be optimal periods to maximize the effects of an EF intervention program for obesity prevention or treatment.

Moreover, given the recent proliferation of EF studies in adults with obesity, it is also worthwhile to understand how interventions affect individuals across the lifespan. Studies indicate that younger (e.g., children and adolescents), compared to older individuals gain the most improvement from working memory and attention interventions (Wass et al., 2012). This has not been looked at in populations with obesity and future studies should assess the relative efficacy of EF interventions for obesity in children compared to adults. Obesity treatment in children has been highlighted for its preventative potential for adult obesity, and if EF interventions have better outcomes in children, this may be further reason why childhood obesity intervention is beneficial.

6.4. Explore additional promising interventions

In addition to the interventions reviewed above, others have been highlighted for their potential for intervention with EF deficits, but have even more limited research in children with obesity and were therefore not included. Mindfulness-based interventions are growing area of research, for their applications in promoting EF development and in reducing obesogenic behaviors. Mindfulness-based interventions ask participants to engage in meditation, which involves paying attention, on purpose and non-judgmentally, to the goings-on of the present moment (Kabat-Zinn, 2003). Interventions that incorporate mindfulness training have been used for weight loss in adults, with results showing significantly better weight loss with an acceptance-based intervention utilizing mindfulness than in a standard behavioral weight loss program (Forman, Butryn, & Manasse et al., 2016). Mindfulness

may likely be effective for weight loss in part due to its ability to influence the executive system. Studies in adults (Moynihan, Chapman, & Klorman et al., 2013) and children (Flook, Smalley, & Kitiil et al., 2010; Tang, Yang, Leve, & Harold, 2012) support the positive role of mindfulness in improving EFs, as individuals need to utilize cognitive flexibility and inhibitory control skills to maintain attention in the present and keep their minds from wandering (Heeren, Van Broeck, & Philippot, 2009). Indeed, individuals with greater disinhibition in eating and poorer inhibitory control respond better to these types of treatments compared to traditional weight loss treatments (Forman, Butryn, & Manasse et al., 2013; Manasse et al., 2017; Niemeier, Leahey, Reed, Brown, & Wing, 2012). Thus, mindfulness interventions can be used to alter EF in children and could potentially be used in weight loss programs to augment outcomes, although this has yet to be assessed.

Neuroimaging research has also highlighted functional and molecular brain processes unique to individuals with obesity, specifically as they relate to processes in the prefrontal cortex and striatum, thus neurological interventions have been proposed as potential next steps in developing more effective obesity interventions. Transcranial magnetic stimulation (TMS) and transcranial direct-current stimulation (tDCS) are two non-invasive neuromodulation methods that involve the application of magnetic fields or mild currents, respectively, to specific areas on the scalp to affect the neuronal firing in the brain area below. Experimentally, no large scale studies have been done assessing the use of TMS or tDCS for weight loss, but preliminary work in eating behavior suggests these non-invasive neuromodulation methods can increase inhibitory control (Lapenta, Di Sierve, de Macedo, Fregni, & Boggio, 2014) and decrease cravings (Uher, Yoganathan, & Mogg et al., 2005) and food intake (Lapenta et al., 2014). Additionally, developments have been made with functional magnetic resonance imaging such that the neuroimaging process can now be used to assess brain processes and give feedback in real time (rtfMRI). Cognitive interventions have been shown to change brain functioning, and with regard to EFs, have been shown to increase activation of inhibitory control regions and decrease activation of attention regions in response to images of palatable foods in individuals at risk for weight gain (Stice et al., 2015). As such, the potential usefulness of neurofeedback about brain processes has been highlighted for clinical implications in eating and obesity research (Val-Laillet, Aarts, & Weber et al., 2015). While these treatments have just started to be tested in adults and much still needs to be learned about their efficacy and potential side effects, it is possible there will be future applications in children.

6.5. Broaden applications of EF interventions

Applications of EF treatments, while currently being tested in specialized clinical settings, may be applicable to more general settings, such as the classroom, for prevention of obesity in childhood and adulthood. To this end, Riggs, Sakuma, and Pentz (2007) adapted the curriculum Promoting Alternative Thinking Strategies (PATHS) (Greenberg, Mihalic, & Kusché, 1998), which teaches self-regulatory and problem-solving strategies and has been shown to enhance inhibitory control (Riggs et al., 2006), into PATHWAYS to healthy behavior, which uses the same curriculum activities, but focuses the content on healthy eating and activity choices. Elementary students were assessed in two pilot studies and pre-post results showed improvements in attitudes towards self-regulation of eating and activity and some behavioral improvements in TV watching and appetitive decision-making pre- to post-intervention (Riggs et al., 2007). Notably, these studies were not controlled and no behavioral measures of EF or eating were used, but classroom and community applications may be future areas for

research. Another study is currently underway to assess an intervention that combines both self-regulatory training and obesity prevention in preschoolers to examine if the addition of the self-regulatory training enhances obesity-related outcomes (Miller, Horodynski, & Herb et al., 2012).

6.6. Assess translation issues

As with any treatment study, consideration should be given to implementation of novel interventions for real-world applications. Currently, access to childhood obesity treatment is limited, as multicomponent behavioral weight loss programs are primarily offered in specialty care centers and are not well-reimbursed by many insurance plans (Tershakovec, Watson, Wenner, & Marx, 1999; Lee, Sheer, Lopez, & Rosenbaum, 2010; Association of Children's Hospitals, 2013). Accessible, scalable treatment options are needed. Relatedly, multicomponent behavioral treatments are time-intensive for both families and interventionists, making them expensive and difficult to implement. Consideration should be given to intervention strategies that reduce participant and interventionist burden and maximize cost-savings. The EF-related interventions discussed may meet these criteria. Physical activity interventions could likely be completed outside the treatment setting for low-cost. Children can join sports leagues, play active games with friends at recess, or go to a park or ride bikes after school. Additionally, low-cost technology offers a unique avenue for targeted EF interventions to be completed outside of a clinic with little additional time from an interventionist. Children may engage with computer training at home, at school, or potentially through a mobile device, receive EFT prompts via technology, and create and carry-out implementation intentions themselves. Future research should assess the logistical aspects of EF-related interventions and the practicality of their implementation outside of the research domain.

7. Conclusions

Children and adolescents with obesity generally demonstrate poorer EF and EF-related skills compared to children and adolescents of normal weight. These deficits may play a role in inhibiting treatment response as the few available studies suggest poorer inhibitory control skills, as well as greater delay discounting rates, are connected to lower weight loss following treatment. By enhancing EF skills, treatment outcomes may be optimized. Preliminary treatment studies of EF-related interventions suggest that typically recommended multicomponent behavioral treatments and physical activity as well as novel treatment strategies to train or target specific EFs, have some research to support that they may change EFs and promote weight loss and weight loss-related behaviors (e.g., reduced calorie consumption). However, results of these preliminary studies are varied, do not show changes in all EF domains that were assessed, and do not consistently demonstrate positive findings on weight and weight-related behaviors. As such, more research with more rigorous and diverse designs are necessary to improve understanding of how EF skills contribute to treatment response as well as the dose and intensity of intervention necessary to see clinically-significant effects on both EFs and weight. Future research should work to clarify these issues as well as identify in what settings and for whom EF interventions may be most advantageous.

References

Allom, V., & Mullan, B. (2015). Two inhibitory control training interventions designed to improve eating behaviour and determine mechanisms of change.

- Appetite*, 89, 282–290.
- Alonso, M. L., Galioto, R., Spitznagel, M. B., et al. (2014). Cognitive function after bariatric surgery: Evidence for improvement 3 years after surgery. *The American Journal of Surgery*, 207(6), 870–876.
- Appelhans, B. M., French, S. A., Pagoto, S. L., & Sherwood, N. E. (2016). Managing temptation in obesity treatment: A neurobehavioral model of intervention strategies. *Appetite*, 96, 268–279.
- Association AP. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.
- Association of Children's Hospitals. (2013). *Survey findings of Children's hospitals obesity Services*, 2013.
- Atance, C. M., & O'Neill, D. K. (2001). Episodic future thinking. *Trends in Cognitive Sciences*, 5(12), 533–539.
- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, 121(1), 65.
- Beard, C., Sawyer, A. T., & Hofmann, S. G. (2012). Efficacy of attention bias modification using threat and appetitive stimuli: A meta-analytic review. *Behavior Therapy*, 43(4), 724–740.
- Becker, D., Jostmann, N. B., Wiers, R. W., & Holland, R. W. (2015). Approach avoidance training in the eating domain: Testing the effectiveness across three single session studies. *Appetite*, 85, 58–65.
- Berge, J. M., & Everts, J. C. (2011). Family-based interventions targeting childhood obesity: A meta-analysis. *Childhood Obesity*, 7(2), 110–121.
- Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*, 30(4), 331–351.
- Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology*, 48(5), 1501–1510.
- Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review*, 29(3), 180–200.
- Best, J. R., Theim, K. R., Gredysa, D. M., et al. (2012). Behavioral economic predictors of overweight children's weight loss. *Journal of Consulting and Clinical Psychology*, 80(6), 1086.
- Bickel, W. K., Jarmolowicz, D. P., Mueller, E. T., Gatchalian, K. M., & McClure, S. M. (2012). Are executive function and impulsivity antipodes? A conceptual reconstruction with special reference to addiction. *Psychopharmacology*, 221(3), 361–387.
- Bickel, W., & Yi, R. (2007). Temporal discounting as a measure of executive function: Insights from the competing neuro-behavioral decision system hypothesis of addiction. *Advances in Health Economics and Health Services Research*, 20, 289–309.
- Boeka, A. G., & Lokken, K. L. (2008). Neuropsychological performance of a clinical sample of extremely obese individuals. *Archives of Clinical Neuropsychology*, 23(4), 467–474.
- Boutelle, K. N., Kuckertz, J. M., Carlson, J., & Amir, N. (2014). A pilot study evaluating a one-session attention modification training to decrease overeating in obese children. *Appetite*, 76, 180–185.
- Boutelle, K. N., Monreal, T., Strong, D. R., & Amir, N. (2016). An open trial evaluating an attention bias modification program for overweight adults who binge eat. *Journal of Behavior Therapy and Experimental Psychiatry*, 52, 138–146.
- Braet, C., & Crombez, G. (2003). Cognitive interference due to food cues in childhood obesity. *Journal of Clinical Child and Adolescent Psychology*, 32(1), 32–39.
- Brenhouse, H. C., & Andersen, S. L. (2011). Developmental trajectories during adolescence in males and females: A cross-species understanding of underlying brain changes. *Neuroscience & Biobehavioral Reviews*, 35(8), 1687–1703.
- Catenacci, V. A., & Wyatt, H. R. (2007). The role of physical activity in producing and maintaining weight loss. *Nature Clinical Practice Endocrinology & Metabolism*, 3(7), 518–529.
- Colcombe, S. J., Erickson, K. I., Scalf, P. E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(11), 1166–1170.
- Cortese, S., Moreira-Maia, C. R., St Fleur, D., Morcillo-Penalver, C., Rohde, L. A., & Faraone, S. V. (2016). Association between ADHD and obesity: A systematic review and meta-analysis. *The American Journal of Psychiatry*, 173(1), 34–43.
- Cowan, N. (2014). Working memory underpins cognitive development, learning, and education. *Educational Psychology Review*, 26(2), 197–223.
- Daniel, T. O., Said, M., Stanton, C. M., & Epstein, L. H. (2015). Episodic future thinking reduces delay discounting and energy intake in children. *Eating Behavior*, 18, 20–24.
- Daniel, T. O., Stanton, C. M., & Epstein, L. H. (2013). The future is now: Comparing the effect of episodic future thinking on impulsivity in lean and obese individuals. *Appetite*, 71, 120–125.
- Dassen, F. C., Jansen, A., Nederkoorn, C., & Houben, K. (2016). Focus on the future: Episodic future thinking reduces discount rate and snacking. *Appetite*, 96, 327–332.
- Davis, C. L., Tomporowski, P. D., McDowell, J. E., et al. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychology*, 30(1), 91–98.
- Decety, J., Jackson, P. L., Sommerville, J. A., Chaminade, T., & Meltzoff, A. N. (2004). The neural bases of cooperation and competition: An fMRI investigation. *NeuroImage*, 23(2), 744–751.
- Delgado-Rico, E., Rio-Valle, J. S., Albein-Urios, N., et al. (2012). Effects of a multicomponent behavioral intervention on impulsivity and cognitive deficits in adolescents with excess weight. *Behavioural Pharmacology*, 23(5–6), 609–615.

- Diamond, A. (2009). All or none hypothesis: A global-default mode that characterizes the brain and mind. *Developmental Psychology*, 45(1), 130.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135.
- Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science (New York, NY)*, 318(5855), 1387.
- Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, 333(6045), 959–964.
- Duchesne, M., Mattos, P., Appolinário, J. C., et al. (2010). Assessment of executive functions in obese individuals with binge eating disorder. *Revista Brasileira de Psiquiatria*, 32(4), 381–388.
- Epstein, L. H., Paluch, R. A., Roemmich, J. N., & Beecher, M. D. (2007). Family-based obesity treatment, then and now: Twenty-five years of pediatric obesity treatment. *Health Psychology*, 26(4), 381.
- Epstein, L. H., Valoski, A., Wing, R. R., & McCurley, J. (1994). Ten-year outcomes of behavioral family-based treatment for childhood obesity. *Health Psychology*, 13(5), 373.
- Fishbach, A., & Shah, J. Y. (2006). Self-control in action: Implicit dispositions toward goals and away from temptations. *Journal of Personality and Social Psychology*, 90(5), 820.
- Fitzpatrick, S., Gilbert, S., & Serpell, L. (2013). Systematic review: Are overweight and obese individuals impaired on behavioural tasks of executive functioning? *Neuropsychology Review*, 23(2), 138–156.
- Flook, L., Smalley, S. L., Kitil, M. J., et al. (2010). Effects of mindful awareness practices on executive functions in elementary school children. *Journal of Applied School Psychology*, 26(1), 70–95.
- Flynn, R. M., Richert, R. A., Staiano, A. E., Wartella, E., & Calvert, S. L. (2013). Effects of exergame play on EF in children and adolescents at a summer camp for low income youth. *Journal of Educational and Developmental Psychology*, 4(1), 209–225.
- Forman, E. M., Butryn, M. L., Juarascio, A. S., et al. (2013). The mind your health project: A randomized controlled trial of an innovative behavioral treatment for obesity. *Obesity*, 21(6), 1119–1126.
- Forman, E. M., Butryn, M. L., Manasse, S. M., et al. (2016). Acceptance-based versus standard behavioral treatment for obesity: Results from the mind your health randomized controlled trial. *Obesity*, 24(10), 2050–2056.
- Forman, E. M., Shaw, J. A., Goldstein, S. P., et al. (2016). Mindful decision making and inhibitory control training as complementary means to decrease snack consumption. *Appetite*, 103, 176–183.
- Gettens, K. M., & Gorin, A. A. (2017). Executive function in weight loss and weight loss maintenance: A conceptual review and novel neuropsychological model of weight control. *Journal of Behavioral Medicine*, 1–15.
- Goldschmidt, A. B., Hipwell, A. E., Stepp, S. D., McTigue, K. M., & Keenan, K. (2015). Weight gain, executive functioning, and eating behaviors among girls. *Pediatrics*, 136(4), e856–e863.
- Gonzales, M. M., Tarumi, T., Miles, S. C., Tanaka, H., Shah, F., & Haley, A. P. (2010). Insulin sensitivity as a mediator of the relationship between BMI and working memory-related brain activation. *Obesity*, 18(11), 2131–2137.
- Graves, L., Stratton, G., Ridgers, N. D., & Cable, N. T. (2007). Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: Cross sectional study. *BMJ*, 335(7633), 1282–1284.
- Graziano, P. A., Bagner, D. M., Waxmonsky, J. G., Reid, A., McNamara, J. P., & Geffken, G. R. (2012). Co-occurring weight problems among children with attention deficit/hyperactivity disorder: The role of executive functioning. *International Journal of Obesity*, 36(4), 567–572.
- Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, 423(6939), 534–537.
- Greenberg, M. T., Mihalic, S. F., & Kusché, C. A. (1998). *Promoting alternative thinking strategies (PATHS)*. Center for the study and prevention of violence. Institute of Behavioral Science, University of Colorado at Boulder.
- Hall, P. A., & Marteau, T. M. (2014). Executive function in the context of chronic disease prevention: Theory, research and practice. *Preventive Medicine*, 68, 44–50.
- Hanna-Pladdy, B. (2007). Dysexecutive syndromes in neurologic disease. *Journal of Neurologic Physical Therapy*, 31(3), 119–127.
- Hannon, T. S., Rao, G., & Arslanian, S. A. (2005). Childhood obesity and type 2 diabetes mellitus. *Pediatrics*, 116(2), 473–480.
- Heeren, A., Van Broeck, N., & Philippot, P. (2009). The effects of mindfulness on executive processes and autobiographical memory specificity. *Behaviour Research and Therapy*, 47(5), 403–409.
- Houben, K., Dassen, F. C., & Jansen, A. (2016). Taking control: Working memory training in overweight individuals increases self-regulation of food intake. *Appetite*, 105, 567–574.
- Janicke, D. M., Steele, R. G., Gayes, L. A., et al. (2014). Systematic review and meta-analysis of comprehensive behavioral family lifestyle interventions addressing pediatric obesity. *Journal of Pediatric Psychology*, 39(8), 809–825.
- Jansen, A., Houben, K., & Roefs, A. (2015). A cognitive profile of obesity and its translation into new interventions. *Frontiers in Psychology*, 6.
- Jeffery, R. W., Wing, R. R., Sherwood, N. E., & Tate, D. F. (2003). Physical activity and weight loss: Does prescribing higher physical activity goals improve outcome? *The American Journal of Clinical Nutrition*, 78(4), 684–689.
- Jones, A., Di Lemma, L. C., Robinson, E., et al. (2016). Inhibitory control training for appetitive behaviour change: A meta-analytic investigation of mechanisms of action and moderators of effectiveness. *Appetite*, 97, 16–28.
- Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice*, 10(2), 144–156.
- Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, 5(1), 43–57.
- Kemps, E., Tiggemann, M., & Elford, J. (2015). Sustained effects of attentional retraining on chocolate consumption. *Journal of Behavior Therapy and Experimental Psychiatry*, 49(Part A), 94–100.
- van Koningsbruggen, G. M., Veling, H., Stroebe, W., & Aarts, H. (2014). Comparing two psychological interventions in reducing impulsive processes of eating behaviour: Effects on self-selected portion size. *British Journal of Health Psychology*, 19(4), 767–782.
- Kulendran, M., Vlaev, I., Sugden, C., et al. (2014). Neuropsychological assessment as a predictor of weight loss in obese adolescents. *International Journal of Obesity*, 38(4), 507–512.
- Lapenta, O. M., Di Sierve, K., de Macedo, E. C., Fregni, F., & Boggio, P. S. (2014). Transcranial direct current stimulation modulates ERP-indexed inhibitory control and reduces food consumption. *Appetite*, 83, 42–48.
- Lawrence, N. S., Verbruggen, F., Morrison, S., Adams, R. C., & Chambers, C. D. (2015). Stopping to food can reduce intake. Effects of stimulus-specificity and individual differences in dietary restraint. *Appetite*, 85, 91–103.
- Lee, J. S., Sheer, J. L. O., Lopez, N., & Rosenbaum, S. (2010). Coverage of obesity treatment: A state-by-state analysis of medicaid and state insurance laws. *Public Health Reports*, 125(4), 596–604.
- Liang, J., Matheson, B. E., Kaye, W. H., & Boutelle, K. N. (2014). Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *International Journal of Obesity*, 38(4), 494–506.
- Lillard, A., & Else-Quest, N. (2006). The early years: Evaluating Montessori education. *Science*, 313(5795), 1893–1894.
- Manasse, S. M., Flack, D., Dochat, C., Zhang, F., Butryn, M. L., & Forman, E. M. (2017). Not so fast: The impact of impulsivity on weight loss varies by treatment type. *Appetite*, 113, 193–199.
- Manasse, S. M., Juarascio, A. S., Forman, E. M., Berner, L. A., Butryn, M. L., & Ruocco, A. C. (2014). Executive functioning in overweight individuals with and without loss-of-control eating. *European Eating Disorders Review*, 22(5), 373–377.
- Marker, A. M., & Staiano, A. E. (2015). Better together: Outcomes of cooperation versus competition in social exergaming. *Games for Health Journal*, 4(1), 25–30.
- McCabe, D. P., Roediger, H. L., III, McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology*, 24(2), 222.
- Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, 49(2), 270.
- Miller, A. L., Horodyski, M. A., Herb, H. E., et al. (2012). Enhancing self-regulation as a strategy for obesity prevention in Head Start preschoolers: The growing healthy study. *BMC Public Health*, 12, 1040.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49–100.
- Moynihan, J. A., Chapman, B. P., Klorman, R., et al. (2013). Mindfulness-based stress reduction for older adults: Effects on executive function, frontal alpha asymmetry and immune function. *Neuropsychobiology*, 68(1), 34–43.
- Nederkoorn, C., Braet, C., Van Eijs, Y., Tanghe, A., & Jansen, A. (2006). Why obese children cannot resist food: The role of impulsivity. *Eating Behavior*, 7(4), 315–322.
- Nederkoorn, C., Jansen, E., Mulken, S., & Jansen, A. (2007). Impulsivity predicts treatment outcome in obese children. *Behaviour Research and Therapy*, 45(5), 1071–1075.
- Niemeier, H. M., Leahey, T., Reed, K. P., Brown, R. A., & Wing, R. R. (2012). An acceptance-based behavioral intervention for weight loss: A pilot study. *Behavior Therapy*, 43(2), 427–435.
- Odum, A. L., Baumann, A. A., & Rimington, D. D. (2006). Discounting of delayed hypothetical money and food: Effects of amount. *Behavioral Processes*, 73(3), 278–284.
- Odum, A. L., & Rainaud, C. P. (2003). Discounting of delayed hypothetical money, alcohol, and food. *Behavioral Processes*, 64(3), 305–313.
- Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA*, 311(8), 806–814.
- Ogden, C. L., Carroll, M. D., Lawman, H. G., et al. (2016). Trends in obesity prevalence among children and adolescents in the United States, 1988–1994 through 2013–2014. *JAMA*, 315(21), 2292–2299.
- Pauli-Pott, U., Albayrak, O., Hebebrand, J., & Pott, W. (2010). Association between inhibitory control capacity and body weight in overweight and obese children and adolescents: Dependence on age and inhibitory control component. *Child Neuropsychology*, 16(6), 592–603.
- Peng, W., & Crouse, J. (2013). Playing in parallel: The effects of multiplayer modes in active video game on motivation and physical exertion. *Cyberpsychology, Behavior, and Social Networking*, 16(6), 423–427.
- Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity*, 2(1), 16–22.
- Pliszka, S. (2007). Practice parameter for the assessment and treatment of children and adolescents with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, 46(7), 894–921.
- Poirier, P., Giles, T. D., Bray, G. A., et al. (2006). Obesity and cardiovascular disease:

- Pathophysiology, evaluation, and effect of weight loss: an update of the 1997 American heart association scientific statement on obesity and heart disease from the obesity committee of the council on nutrition, physical activity, and metabolism. *Circulation*, 113(6), 898–918.
- Pulgaron, E. R. (2013). Childhood obesity: A review of increased risk for physical and psychological comorbidities. *Clinical Therapeutics*, 35(1), A18–A32.
- Reinert, K. R., Po'e, E. K., & Barkin, S. L. (2013). The relationship between executive function and obesity in children and adolescents: A systematic literature review. *Journal of Obesity*, 2013, 820956.
- Riggs, N. R., Greenberg, M. T., Kusché, C. A., & Pentz, M. A. (2006). The mediational role of neurocognition in the behavioral outcomes of a social-emotional prevention program in elementary school students: Effects of the PATHS curriculum. *Prevention Science*, 7(1), 91–102.
- Riggs, N. R., Sakuma, K. L., & Pentz, M. A. (2007). Preventing risk for obesity by promoting self-regulation and decision-making skills: Pilot results from the PATHWAYS to health program (PATHWAYS). *Evaluation Review*, 31(3), 287–310.
- Schumacher, S. E., Kemps, E., & Tiggemann, M. (2016). Bias modification training can alter approach bias and chocolate consumption. *Appetite*, 96, 219–224.
- Schwimmer, J. B., Burwinkle, T. M., & Varni, J. W. (2003). Health-related quality of life of severely obese children and adolescents. *JAMA*, 289(14), 1813–1819.
- Sheffer, C. E., Mackillop, J., Fernandez, A., et al. (2016). Initial examination of priming tasks to decrease delay discounting. *Behavioral Processes*, 128, 144–152.
- Smith, E., Hay, P., Campbell, L., & Trollor, J. (2011). A review of the association between obesity and cognitive function across the lifespan: Implications for novel approaches to prevention and treatment. *Obesity Reviews*, 12(9), 740–755.
- Soetens, B., & Braet, C. (2007). Information processing of food cues in overweight and normal weight adolescents. *British Journal of Health Psychology*, 12(Pt 2), 285–304.
- Staiano, A. E., Abraham, A. A., & Calvert, S. L. (2012). Competitive versus cooperative exergame play for African American adolescents' executive function skills: Short-term effects in a long-term training intervention. *Developmental Psychology*, 48(2), 337–342.
- Stice, E., Lawrence, N. S., Kemps, E., & Veling, H. (2016). Training motor responses to food: A novel treatment for obesity targeting implicit processes. *Clinical Psychology Review*, 49, 16–27.
- Stice, E., Yokum, S., Burger, K., Rohde, P., Shaw, H., & Gau, J. M. (2015). A pilot randomized trial of a cognitive reappraisal obesity prevention program. *Physiology & Behavior*, 138, 124–132.
- Swift, D. L., Johannsen, N. M., Lavie, C. J., Earnest, C. P., & Church, T. S. (2014). The role of exercise and physical activity in weight loss and maintenance. *Progress in Cardiovascular Diseases*, 56(4), 441–447.
- Sze, Y. Y., Daniel, T. O., Kilanowski, C. K., Collins, R. L., & Epstein, L. H. (2015). Web-based and mobile delivery of an episodic future thinking intervention for overweight and obese families: A feasibility study. *JMIR MHealth and UHealth*, 3(4), e97.
- Tang, Y. Y., Yang, L., Leve, L. D., & Harold, G. T. (2012). Improving executive function and its neurobiological mechanisms through a mindfulness-based intervention: Advances within the field of developmental neuroscience. *Child Development Perspectives*, 6(4), 361–366.
- Tanofsky-Kraff, M., Faden, D., Yanovski, S. Z., Wilfley, D. E., & Yanovski, J. A. (2005). The perceived onset of dieting and loss of control eating behaviors in overweight children. *International Journal of Eating Disorders*, 38(2), 112–122.
- Tershakovec, A. M., Watson, M. H., Wenner, W. J., Jr., & Marx, A. L. (1999). Insurance reimbursement for the treatment of obesity in children. *The Journal of Pediatrics*, 134(5), 573–578.
- Tomporowski, P. D., Lambourne, K., & Okumura, M. S. (2011). Physical activity interventions and children's mental function: An introduction and overview. *Preventive Medicine*, 52, S3–S9.
- Tzischinsky, O., & Latzer, Y. (2006). Sleep–wake cycles in obese children with and without binge-eating episodes. *Journal of Paediatrics and Child Health*, 42(11), 688–693.
- Uher, R., Yoganathan, D., Mogg, A., et al. (2005). Effect of left prefrontal repetitive transcranial magnetic stimulation on food craving. *Biological Psychiatry*, 58(10), 840–842.
- United States Preventive Services Task Force. (2010). Screening for obesity in children and adolescents: US preventive Services task Force recommendation statement. *Pediatrics*, 125(2), 361–367.
- Val-Laillet, D., Aarts, E., Weber, B., et al. (2015). Neuroimaging and neuromodulation approaches to study eating behavior and prevent and treat eating disorders and obesity. *NeuroImage Clinical*, 8, 1–31.
- Veling, H., Aarts, H., & Stroebe, W. (2013). Using stop signals to reduce impulsive choices for palatable unhealthy foods. *British Journal of Health Psychology*, 18(2), 354–368.
- Veling, H., van Koningsbruggen, G. M., Aarts, H., & Stroebe, W. (2014). Targeting impulsive processes of eating behavior via the internet. Effects on body weight. *Appetite*, 78, 102–109.
- Verbeken, S., Braet, C., Goossens, L., & Van der Oord, S. (2013). Executive function training with game elements for obese children: A novel treatment to enhance self-regulatory abilities for weight-control. *Behaviour Research and Therapy*, 51(6), 290–299.
- Volkow, N. D., Wang, G.-J., Telang, F., et al. (2008). Low dopamine striatal D2 receptors are associated with prefrontal metabolism in obese subjects: Possible contributing factors. *NeuroImage*, 42(4), 1537–1543.
- Wang, Y., Beydoun, M. A., Liang, L., Caballero, B., & Kumanyika, S. K. (2008). Will all Americans become overweight or obese? Estimating the progression and cost of the US obesity epidemic. *Obesity*, 16(10), 2323–2330.
- Warschburger, P. (2015). SRT-joy - computer-assisted self-regulation training for obese children and adolescents: Study protocol for a randomized controlled trial. *Trials*, 16, 566.
- Wass, S., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory—is younger, better? *Developmental Review*, 32(4), 360–387.
- Winter, B., Breitenstein, C., Mooren, F. C., et al. (2007). High impact running improves learning. *Neurobiology of Learning and Memory*, 87(4), 597–609.
- Yokum, S., Ng, J., & Stice, E. (2011). Attentional bias to food images associated with elevated weight and future weight gain: An fMRI study. *Obesity (Silver Spring)*, 19(9), 1775–1783.
- Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, 6(4), 354–360.