Title

The relationship between executive functioning and weight loss and maintenance in children and parents participating in family-based treatment for childhood obesity

Permalink

https://escholarship.org/uc/item/9z60d6m0

Authors

Eichen, Dawn M
Matheson, Brittany E
Liang, June
et al.

Publication Date

2018-06-01

DOI

10.1016/j.brat.2018.03.010

Peer reviewed

# The relationship between executive functioning and weight loss and maintenance in children and parents participating in family-based treatment for childhood obesity

Dawn M. Eichen[a,*], Brittany E. Matheson[b,c], June Liang[a], David R. Strong[d], Kyung Rhee[a], Kerri N. Boutelle[a,c,d]

[a] Department of Pediatrics, University of California, San Diego, 9500 Gilman Drive #0874, La Jolla, CA, 92093, United States
[b] San Diego State University / University of California, San Diego, Joint Doctoral Program in Clinical Psychology, 6363 Alvarado Court, San Diego, CA, 92120, United States
[c] Department of Psychiatry, University of California, 9500 Gilman Dr, La Jolla, CA, 92093, United States
[d] Department of Family Medicine and Public Health, University of California, San Diego, 9500 Gilman Drive #0725, 92093, La Jolla, CA, United States

## ARTICLE INFO

## ABSTRACT

We examined the relationship between executive function and weight loss among children (8–12 years) and parents enrolled in a behavioral weight-loss program. 150 overweight/obese children and their parents participated in a 6-month family-based weight-loss intervention and completed baseline (month 0), post-treatment (month 6) and 18-month follow-up assessments (month 24), which included Digit Span (DS), Stop Signal Task (SST), and Wisconsin Card Sorting Test (WCST). Anthropometrics were additionally measured at mid-treatment (month 3) and 6-month follow-up (month 12). Children with more baseline WCST perseverative errors regained more weight ($p = .002$) at 18-month follow-up. Change in child BMIz was not associated with change in child executive function ($p > .05$) or parent executive function ($p > .05$). Among parents, baseline measure of DS-backward ($p < .001$) and post-treatment changes in WCST perseverative errors ($p < .001$) were associated with post-treatment changes in parent BMI. SST was not related to parent or child weight loss. Thus, children's baseline set-shifting was associated with weight regain during follow-up whereas changes in parent set-shifting was associated with changes in parent weight. Future research is needed to examine the relationship between executive function and weight loss and how this translates to intervention success for both overweight/obese children and participating parents.

## 1. Introduction

Approximately one-third of children in the United States have overweight or obesity (Ogden, Carroll, Kit, & Flegal, 2014) which is defined as having a BMI percentile ≥ 85th percentile (Kuczmarski et al., 2000). Children with overweight and obesity demonstrate deficits in neurocognitive functioning, particularly in executive functioning (Liang, Matheson, Kaye, & Boutelle, 2014; Reinert, Po'e, & Barkin, 2013). Broadly speaking, executive function is an umbrella term that refers to higher-level cognitive control processes that dictate goal-oriented behaviors (Miller & Cohen, 2001). Theoretical frameworks posit three core executive function domains: inhibitory control, working memory and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). These three core domains interact to support higher-level functions involved in self-regulation of behavior like planning, problem solving and reasoning (Diamond, 2013; Munakata et al., 2011) and interact with automatic processes of attention and reward to determine ability to delay gratification (Appelhans, French, Pagoto, & Sherwood, 2016; Jansen, Houben, & Roefs, 2015).

Compared to healthy weight youth, youth with overweight or obesity may exhibit deficits in inhibition, set-shifting, delay of gratification, planning or decision making (Liang et al., 2014). Similar deficits in executive and higher level cognitive functions are observed among adults with overweight and obesity (Smith, Hay, Campbell, & Trollor, 2011). Among children, poorer executive function is linked to obesity-related behaviors such as high calorie snack consumption and sedentary behavior (Liang et al., 2014). Interventions to overcome executive functioning deficits with physical exercise show promise in improving executive functioning among children with overweight and obesity (Davis et al., 2011) and have demonstrated sustained effects among

children up to 9-months following the exercise intervention (Hillman et al., 2014). While not targeting executive functioning skills directly, behavioral weight-loss treatments for pediatric obesity also may indirectly strengthen and enhance executive function in overweight children through a broad range of self-regulatory skills training (Hayes, Eichen, Barch, & Wilfley, 2017).

Weight-loss treatment success relies on self-regulatory skills and goal-directed actions benefiting from higher level executive functioning (Hayes et al., 2017). The most successful treatments to date for children with overweight or obesity are family-based programs (FBT) that deliver weekly group-based behavioral treatment to the parent and child separately over a 6-month period (Epstein & Wrotniak, 2010). A meta-analysis demonstrates that on average FBT programs result in reduction of BMI (Ho et al., 2012); however individual responses vary. Long-term follow-up suggests that only one-third of children who participate in FBT no longer have obesity in adulthood (Epstein, Valoski, Wing, & McCurley, 1990). FBT includes dietary and physical activity recommendations, parenting techniques, and behavior therapy skills. Moreover, the major tenets of FBT include self-monitoring of all food intake, inhibitory control of food intake to adhere to a calorie recommendation, scheduling physical activity, and planning for high-risk situations. These behaviors depend on executive functions as executive functions command behaviors needed for weight-directed goals to control eating and activity (Appelhans et al., 2016; Jansen et al., 2015). Deficits in executive function could impact the ability of parents and children to adhere to treatment recommendations and are likely to impact weight loss results. Since only one-third of children who participate in FBT are no longer obese in adulthood (Epstein et al., 1990), unaddressed mechanisms, such as executive functioning, may play a role in treatment success or failure. Successful weight-loss maintenance may be impacted by how parents and children utilize executive functioning skills to effectively respond to the obesogenic environment and make behavior changes that limit excess weight gain.

Parents are considered the major agents of change in reference to weight-related behaviors of children (Boutelle, Cafri, & Crow, 2011; Boutelle et al., 2017; Golan, 2006; Janicke et al., 2008). In FBT, parents are expected to participate with their children and model the recommended physical activity and eating behaviors. Research shows that parents on average lose weight when participating with their child in FBT (Epstein, Wing, Koeske, Andrasik, & Ossip, 1981) and that parent weight change is significantly related to child weight loss (Boutelle, Cafri, & Crow, 2012; Wrotniak, Epstein, Paluch, & Roemmich, 2004). Since parent executive function influences parent weight loss behaviors and facilitates parental management of the home environment (e.g., what foods enter the house), it is likely that parent executive function may be related to child weight loss.

To date, only one study examined executive function and weight loss in children participating in FBT (Best et al., 2012). This study found that 7-12-year-old children who demonstrated greater impairments in delay discounting (i.e., propensity to choose smaller immediate rewards vs. larger future rewards) had poorer weight-loss outcomes after FBT. Although interesting, this study focused on only one facet related to executive function (delay discounting) and did not examine the executive function skills of parents, the major agents of change in FBT (Boutelle et al., 2011, 2017; Golan, 2006; Janicke et al., 2008). Another study with 26 children ages 8–12 shows that children who were the most impulsive lost the least weight following weight-loss treatment (Nederkoorn, Jansen, Mulkens, & Jansen, 2007). Studies among older children and adolescents also show that baseline measures of executive function moderate weight loss such as those with the poorest executive function have less weight-loss success after intervention (Naar-King et al., 2016; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006). However, one study in children 7.5–15 years of age shows the opposite: more impulsivity predicted success in a 1-year weight-loss program, with age moderating the effect such that success was predicted by more impulsivity in older adolescents while there was no effect in younger

children (Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010). The proposed explanation for the contradictory findings provided by Pauli-Pott et al. (2010) is that older adolescents may benefit the most from the recommendation of stimulus control (i.e., keeping high calorie, tempting foods out of the house) provided in the program and thus were more successful (Pauli-Pott et al., 2010).

In adults, a few studies demonstrate that poorer executive function prior to treatment is related to poorer weight-loss outcomes following bariatric surgery and a medically-supervised lifestyle intervention (Galioto et al., 2016; Spitznagel et al., 2014; Spitznagel, Alosco, et al., 2013; Spitznagel, Garcia, et al., 2013). Two prospective studies suggest that impairments in executive function and related higher-level cognitive function like impaired delay of gratification predict higher weight at a later age (Groppe & Elsner, 2017; Seeyave et al., 2009). Further, cognitive trainings, targeting improving executive function, show there may be some benefits in aiding weight loss maintenance although effects do not always persist over time (Jones, Hardman, Lawrence, & Field, 2017; Verbeken, Braet, Goossens, & van der Oord, 2013). While this initial evidence supports the relationship of executive function and weight change, more studies are needed to fully evaluate the relationships between various executive function factors and weight-loss outcomes in youth and adults to better understand the underlying mechanisms in weight loss and maintenance.

Thus, the purpose of this study was to complete a secondary data analysis to examine the relationship between three key facets of executive function (working memory, inhibition, and flexible decision making) and weight-loss outcomes among children and parents participating in a FBT or FBT-based intervention with only parents attending treatment (PBT) (Boutelle et al., 2017). In particular, this study examined three questions about weight loss among children: 1) Was child baseline executive functioning related to child weight loss and weight-loss maintenance over time?; 2) Was parent baseline executive functioning related to child weight loss and maintenance over time?; 3) Were post-treatment changes in child executive functioning related to changes in child weight loss over time? We then addressed two additional questions regarding parent weight loss: 4) Was parent baseline executive functioning related to their own weight loss and maintenance over time?; and 5) Were post-treatment changes in parent executive functioning related to changes in their own weight over time? We hypothesized that both parent and child executive function would be related to weight loss outcomes in the child and that parent executive function would be related to parent weight loss. We also evaluated whether baseline executive function would be associated with weight loss and maintenance or whether executive function and weight appeared to change together over time. By elucidating these relationships, this study will contribute to the research base regarding the role of child and parent executive function on weight change in FBT-based programs and explore a potential mechanism by which parents serve as the agent of change in child weight loss.

## 2. Methods

### 2.1. Participants

One-hundred and fifty children with overweight and obesity (10.4 ± 1.3 years; 66.7% female; 43% non-Hispanic White, 31% Hispanic, 24% non-Hispanic other race; Body Mass Index (BMI): 26.4 ± 3.6 kg/m$^2$; BMI z-score: 2.0 ± 0.34) and their parents (42.9 ± 6.4 years; 87.3% female; 49% non-Hispanic White, 31% Hispanic, 20% non-Hispanic other race; BMI: 31.9 ± 6.3 kg/m$^2$) participated in a six-month Family-based Behavioral Treatment (FBT) weight-loss intervention. Children and parent dyads were enrolled in the study for 2 years and followed for 18-months after treatment [anthropometric assessment time points: 0 months (baseline), 3 months (mid-treatment), 6 months (post-treatment), 12 months (6-month follow-up) 24 months (18-month follow-up)]. Executive function was

assessed at baseline, post-treatment and 18-month follow-up. Details regarding dropout rates and assessment participation are published elsewhere (Boutelle et al., 2017) but the overall retention rate at the final assessment was 87%.

Half of the families were randomized to FBT (parent and child attended) and the other half were randomized to PBT (Parent-Based Treatment; FBT for parents without their child). Both treatments focus on changing both the child and the parent's weight-related behaviors. The treatment components and main outcome results of this larger clinical trial (NCT01197443) are described in detail elsewhere (Boutelle et al., 2015, 2017). In summary, PBT was non-inferior to FBT on child and parent weight loss, child and parent energy intake, child and parent physical activity, parenting style and parent feeding behaviors. Prior to enrolling in the study, all families completed informed consent and assent. This study was approved by the University of California, San Diego and Rady Children's Hospital Institutional Review Boards.

### 2.2. Measures

This study was a secondary data analysis of a larger clinical trial with additional measures detailed elsewhere (Boutelle et al., 2015, 2017). The specific measures used in this study included:

*Anthropometrics*. Weight and height were measured in duplicate. BMI (kg/m$^2$) was calculated using the mean height and weight values for adults. For children, a standardized BMI z-score (BMIz) was calculated from the Centers for Disease Control growth charts (Kuczmarski et al., 2000).

*Wisconsin Card Sorting Test (WCST)*. The computerized version of the WCST (Heaton, 2003) was administered to assess for flexibility in decision making in both children and parents in this study. Participants are shown a card and asked to sort it to one of four category cards that differ on color, shape and number (the possible sorting categories). Participants are only told whether they are right or wrong and are to use trial and error to determine how to sort the cards. The category switches unbeknownst to the participant. Perseverative errors occur when the participant continues to make a response to the wrong sorting rule. The number of perseverative errors was used as the measure of cognitive flexibility or set-shifting with fewer errors indicating better performance.

*Digit Span*. The Digit Span subtest was administered from the WISC-IV for children (Wechsler, 2003) and from the WAIS-IV for parents (Wechsler, 2008). In the backward subtest, an examiner reads the participant increasingly longer strings of numbers and then the participant repeats them in the reverse order. The Digit Span Backward raw score was used as a measure of working memory (Baddeley & Hitch, 1974; Ramsay & Reynolds, 1995).

*Stop Signal Task (SST)*. The SST (Matthews, Simmons, Arce, & Paulus, 2005; Matthews et al., 2009) was administered to assess behavioral inhibition. Both children and parents completed the SST. Participants were instructed to press the left arrow key on the keyboard if they saw an "X" or the down arrow key if they saw an "O" as quickly as possible, but to withhold their response if they heard a tone (stop trial). The SST consisted of 288 trials delivered in 6 blocks with 72 total stop trials. A practice session was completed prior to the task to establish a mean reaction time (RT) for each participant so that the stop trials could be individualized for each person to be either hard (delivered at RT, or 100 ms or 200 ms less than RT) or easy (delivered 300, 400, or 500 ms less than RT). For each stop time, the percent of trials participants failed to inhibit was calculated. These were averaged across all stop times to create a single score representing the total percentage of trials participants failed to inhibit such that higher scores represent a greater number of trials with failed inhibition. As the version used was not based on the "horse-race model" (Logan & Cowan, 1984), a stop signal reaction time (SSRT) was not calculated.

*Demographics*. Parents self-reported demographic variables of interest, including age, date of birth, race, and ethnicity on survey measures administered at baseline about themselves and their child.

### 2.3. Statistical analysis

Descriptive statistics were conducted for the main variables and Cohen's d values were calculated to provide an estimate of the effect of change in variables over time. Spearman correlations were conducted to elucidate the relationship between parent and child executive function and as independent potential influences of child weight loss. Linear mixed effects models (LME) with maximum likelihood estimation for missing data were used for all analyses and all analyses were conducted as intent-to-treat. All models had planned covariates of age, gender, treatment condition (FBT or PBT), the corresponding baseline value of the primary outcome variable, and three dummy coded indices to assess BMIz or BMI changes at post-treatment, 6- and 18- month follow-ups with mid-treatment as the reference. Age and gender were used as covariates since these are commonly used in reporting weight-loss results and to be consistent with the primary trial analyses. A dummy coded term for allocation to condition was included to account for randomization in the original study design. With no mid-treatment or 6-month assessment, models examining time-varying effects of executive function on BMIz/BMI included a dummy code for time using post-treatment as a reference to reflect change at 18-month assessment.

LME models of child BMIz over time evaluated the main effect of baseline executive function on changes in BMIz (question 1) and assessed any differences in the strength of relationship between executive function and levels of BMIz (interaction of executive function X time) across assessments (Model 1). We evaluated question 2 by using model 1 as the base model and adding a term reflecting baseline executive function of the parent followed by the interaction of parent executive function and time (Model 2). We next assessed question 3 by adding the time-varying effect of post-treatment executive functioning assessments from each corresponding assessment to the standard covariates (Model 3). To assess the effects of parent executive function on changes in their own BMI (questions 4 and 5), parallel LME models with planned covariates first assessed main effects of baseline executive function (Model 4) and then the effect of time-varying executive function (Model 5). Analyses for this study were conducted in R version 3.2.2 (Team, 2015) using the nlme package. GGPLOT and EFFECTS were used to display results. Effect size estimates for the multivariate associations between fixed effects and predictors for LME models were reflected using the semi-partial correlation ($r_s$) (Jaeger, Edwards, Das, & Sen, 2017) of the r2glmm package (Jaeger, 2017). Statistical significance for all analyses was set at the $p < .05$ level. Altogether, 83–93% of participants were retained in the WCST models, 53–81% of participants were retained in SST models and 85–94% in digit span backwards models. Some SST data were lost due to computer malfunction, resulting in less available data and decreased the number of participants in the SST models. To address this, we evaluated missing baseline data of the SST and there was no relation to any of the covariates in the child model; however, parent missing SST data was related to treatment condition ($p = .004$) with more data missing from parents in PBT.

## 3. Results

A summary of the means and standard deviations for all variables included in analyses are provided in Table 1. Correlations between concurrent baseline parent and child executive function indices were small and not significant for WCST ($r_s = 0.05$ $p = .52$) and Stop Signal ($r_s = 0.09$, $p = .42$) and approached significance for Digit Span Backward ($r_s = 0.14$, $p = .08$).

### 3.1. Child Wisconsin Card Sorting Test (WCST) perseverative errors

The first LME model (Model 1) showed that the interaction term

**Table 1**
Child and parent descriptive anthropometric and executive function data at each assessment point.

| Variable | Baseline | | Mid-Tx | | Post-Tx | | 6-mo f/u | | 18 – mo f/u | | Cohen's $d$[a] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Child | Parent | Child | Parent | Child | Parent | Child | Parent | Child | Parent | Child | Parent |
| BMI | 26.35 (3.62) | 31.91 (6.3) | 25.39 (6.12) | 30.98 (3.53) | 24.98 (3.77) | 30.56 (6.28) | 26.14 (4.08) | 31.1 (6.24) | 27.44 (4.38) | 31.9 (6.68) | -0.27 -0.11 0.30 0.31 | -0.15 -0.07 0.09 0.12 |
| BMIz | 2 (.34) | - | 1.85 (.39) | - | 1.73 (.44) | - | 1.79 (.46) | - | 1.81 (.46) | - | -0.41 -0.29 0.13 0.04 | - |
| WCST Perseverative Errors | 15.66 (10.92) | 10.71 (8.54) | - | - | 9.73 (7.58) | 6.62 (4.89) | - | - | 8.73 (6.82) | 6.65 (5.1) | -0.63 -0.14 | 0.59 0.01 |
| DS Backward | 15.46 (2.90) | 17.23 (3.5) | - | - | 16.21 (3.14) | 17.84 (3.87) | - | - | 16.93 (3.32) | 18.02 (4.16) | 0.25 0.22 | 0.17 0.04 |
| SST % Trials of Failed Inhibition | 48.59% (16.98) | 45.64% (14.5) | - | - | 51.85% (16.05) | 44.13%(14.3) | - | - | 50.18% (15.39) | 40.11% (16.18) | 0.20 -0.11 | -0.10 -0.26 |

Note: Tx-treatment; mo = month; f/u = follow-up; WCST = Wisconsin Card Sorting Test; DS = Digit Span; SST = Stop Signal Task.

[a] Cohen's $d$ presented for each variable evaluating effects between each timepoint and the subsequent timepoint starting with pre-treatment. Effects are presented with the later timepoint first such that a negative effect indicates a decrease from time 1 to time 2.

**Table 2**
Child Wisconsin Card Sorting Test linear mixed effects model estimates.

| Model Term | B | SE | $p$ | $r$ |
|---|---|---|---|---|
| Treatment Condition | 0.018 | 0.034 | .600 | 0.045 |
| Time Post | -0.094 | 0.035 | .008 | 0.089 |
| Time 6-month | -0.088 | 0.035 | .013 | 0.084 |
| Time 18-month | -0.126 | 0.035 | < .001 | 0.118 |
| Perseverative Errors (PE) | -0.003 | 0.002 | .086 | 0.084 |
| Time Post x PE | 0.0002 | 0.002 | .927 | 0 |
| Time 6-month x PE | 0.003 | 0.002 | .077 | 0.084 |
| Time 18-month x PE | 0.006 | 0.002 | < .001 | 0.110 |

Note: Model presented also adjusted for child age, gender, baseline BMIz.

between baseline WCST and the set of three time dummy codes was significant, $F_{(3,342)} = 5.15$, $p = .002$. Planned follow-up analyses (Table 2) showed that the relationship between WCST and BMIz at the post-treatment ($p = .927$) or the 6-month follow-up time points (t = 1.77, $p = .077$) was not significant but was significant at the 18-month follow-up time point (t = 3.40, $p < .001$). Children with fewer perseverative errors in the baseline assessment had similar weight loss/maintenance at post-treatment and 6-month follow-up but maintained lower BMIz at 18-month than those with more perseverative errors at

baseline (See Fig. 1). This interaction effect was small ($r = 0.110$). Overall, child WCST performance at post-treatment was better on average (fewer perseverative errors) than when measured at baseline (d = −0.63). Minimal change in WCST was observed between post-treatment and follow-up (Table 1). In Model 2, assessment of parents baseline perseverative errors was not associated significantly with change in child BMIz ($F_{(1,126)} = 2.646$, $p = .106$) and the interaction between time and parent errors approached significance ($F_{(3,336)} = 2.461$, $p = .063$). We explored whether parent executive function differentially affected child BMIz in the two conditions (PBT or FBT). None of these interactions were significant ($p$'s > 0.05). Lastly, in Model 3, the time-varying effect of perseverative errors at each follow-up assessment was not significantly related to corresponding changes in BMIz ($p = .914$).

### 3.2. Child Digit Span Backward

In Models 1 and 2 we found no significant relationships between the change in child BMIz and baseline Digit Span Backward of the child or parent. Further, in Model 3, the time-varying assessment of Digit Span Backward on changes in BMIz was not significant ($p > 05$).
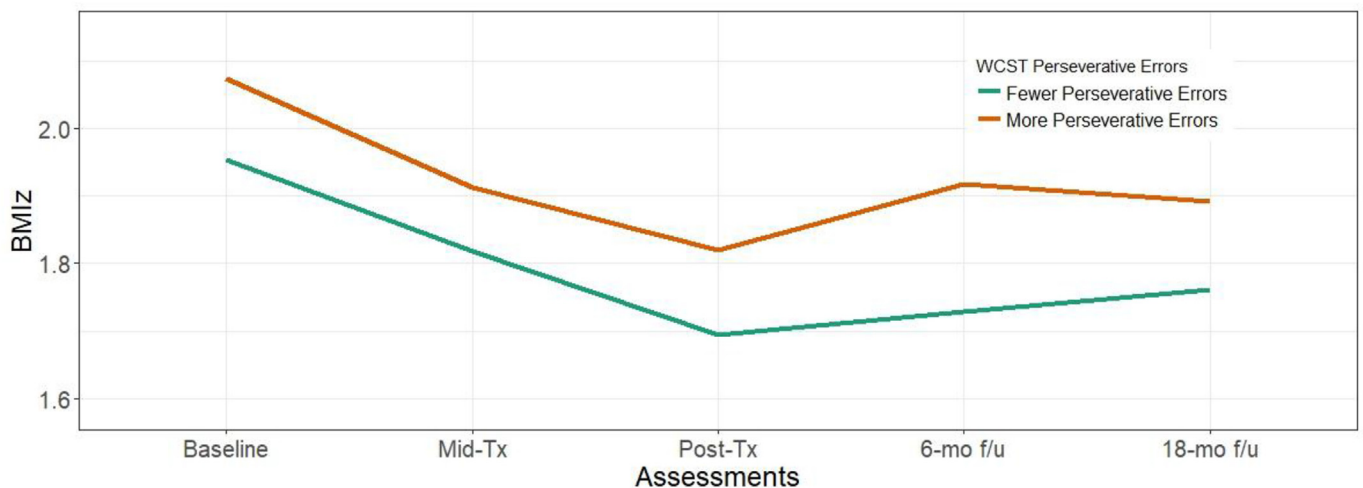


**Fig. 1.** More perseverative errors on the WCST at baseline in children resulted in weight regain at 18-month follow-up. A median split of perseverative errors was used to define more and fewer perseverative errors.

**Table 3**
Parent Wisconsin Card Sorting Test time-varying effects predict parent BMI.

| Model Term | B | SE | $p$ | $r$ |
|---|---|---|---|---|
| Treatment Condition | -0.811 | 0.499 | .106 | 0.114 |
| Time 18-month | 1.418 | 0.323 | < .001 | 0.200 |
| Baseline Perseverative Errors | -0.071 | 0.038 | .066 | 0.122 |
| Perseverative errors change term | 0.214 | 0.053 | < .001 | 0.245 |

Note: Model presented also adjusted for parent age, gender, baseline BMI.

### 3.3. Child Stop Signal Task

There were no significant relationships found between percent of trials failed to inhibit on the SST and BMIz in any of the three models ($p$'s > .05).

### 3.4. Parent Wisconsin Card Sorting Test perseverative errors (Table 3)

In Model 4 for WCST, there was no significant interaction between baseline parent perseverative errors and time ($F_{(3,356)} = 0.129$, $p = .943$). However, in Model 5, the time-varying effect of parent perseverative errors was significantly related to the corresponding change in parent BMI ($F_{(1,88)} = 16.425$, $p < .001$); see Table 3. This time-varying effect suggested a small to medium effect of WCST on parent BMI over time ($r = 0.245$). Parent WCST perseverative errors decreased between baseline and post-treatment and minimally changed between post-treatment and follow-up; see Table 1.

### 3.5. Parent Digit Span Backward

In parents, Model 4 suggested there was a main effect of baseline Digit Span Backward ($F_{(1,135)} = 11.61$, $p < .001$; $r = 0.077$) on BMI across assessments and a non-significant interaction with time suggested this relationship did not change over assessments. There were no time-varying effects of Digit Span Backward in Model 5.

### 3.6. Parent Stop Signal Task

Neither Model 4 nor Model 5 detected a relationship between percent of trials inhibited on SST and parent BMI change ($p$'s > .05).

## 4. Discussion

This study is the first to longitudinally evaluate the relation of three domains of executive function (inhibitory control, set-shifting/flexible decision making, and working memory) and weight loss in both children and parents participating in a FBT-based program. Results show that child baseline levels of set-shifting was associated with weight-loss maintenance at the 18-month follow-up time point, such that children with poorer performance on the WCST were less successful at retaining their weight losses from treatment. Baseline or time-varying measures of child working memory or inhibitory control were not related to child weight loss outcomes. Contrary to our hypothesis, none of the parent executive functions measured were associated with child weight outcomes. Further, there was no significant association between parent and child measures of executive function although one approached significance. Parent baseline performance on working memory was associated with parent weight across the study while inhibition was not related to any parent weight outcomes. In parents, time-varying effects of set-shifting were related to time-varying effects of weight loss, such that if set-shifting was improving, concurrent assessment of weight was decreasing across each time point when looking at performance on the WCST. Lastly, treatment condition (FBT or PBT) was not significant in any analysis suggesting that the relationship between executive function and weight change did not differ across treatment conditions.

Taken together, this study provides further evidence that some domains of executive function are related to weight loss and weight loss maintenance in children and parents participating in FBT-based programs. Of clinical importance, our findings suggest that flexible decision-making may be a predictor of successful treatment outcome which may help identify children who are likely to have long-term success following FBT or PBT. Accordingly, future weight-loss interventions may want to provide skills to support children with poorer executive function or identify the specific aspects of child obesity treatment with which children with low executive function have difficulty. Clinically, as the WCST findings were significant, it may be that flexible decision making is an essential characteristic to success. It would make sense that parents and children, who are less perseverative in their responses, are more likely to try new alternatives when behavioral strategies are not working. Thus, these individuals may find solutions to barriers to their healthy behaviors and more efficiently increase weight-loss facilitating behaviors. It is important to continue investigating the relationship between executive function and weight as directionality of this relationship remains unclear. If future research shows that deficits in executive function precede initial and continued weight gain, it is possible that targeting improvements in skills like inhibition, set-shifting, delay of gratification, planning, and decision making (Liang et al., 2014) around food choices could be useful in obesity prevention programs. This field is still in its nascent stages and additional research in this area can help develop more effective weight-loss and obesity prevention programs, which are huge public health priorities, given the detrimental health and societal effects of obesity.

It is interesting that parent executive function did not impact child weight loss and this pattern did not differ between PBT and FBT, although child and parent weight loss was comparable across treatments (Boutelle et al., 2017). It is possible that other facets related to executive function than were measured in this study have a greater impact on treatment, such as organization or problem solving. Alternatively, there may be alternative mechanisms, which interact with executive function or are more salient than executive function in predicting success in treatment. It is important to continue to identify traits that predict success in child obesity treatments in order to apply targeted treatments and improve outcomes.

Overall, our results closely align with previous studies (Best et al., 2012; Naar-King et al., 2016) that also found support for the relationship between executive functioning and weight outcomes in weight-loss treatment studies. In particular, our study found similar results in that children with poorer set-shifting executive functioning at baseline lost less weight over the course of treatment. One possible explanation for why set-shifting was related to weight loss maintenance and not initial weight loss in children could be that once treatment is over, families lose the personalized advice from their coach in FBT or PBT and more onus is on the family itself to continue to carry out these behaviors. Further, as children are getting older more responsibility may be passed directly to the child to maintain healthy behaviors and children with better set-shifting may be better at flexible decision making in high-risk situations, making them more likely to maintain their weight-loss promoting behaviors and thus maintain their weight loss. As the pattern of results differed between parents and children, it is also important to understand how executive function and weight change interact in children and adults. Improvement in parents' set-shifting following treatment were related to further weight loss in this period. Since treatment encourages parents to model weight-loss behaviors, parents are encouraged to model thinking through high-risk situations. It is likely that parent who were able to continue to improve their flexible decision making or set-shifting would be more successful in losing weight.

It is interesting that our study did not find a significant relationship with baseline working memory or inhibitory control skills. Our lack of findings on inhibition may be because our SST measure did not provide as sensitive of a measure as previous studies since we could not

calculate a SSRT (Nederkoorn et al., 2006, 2007). Further, had we used a measure that allowed us to concurrently evaluate multiple facets of executive function, rather than examine them separately (Naar-King et al., 2016) perhaps our findings wuould have been different. Additionally, non-significant findings with digit span may be the result that working memory may not be as essential to weight loss compared to other executive functions as it is may be easier to compensate for working memory deficits by using tools like calendars and reminders. Lastly, all of our tasks utilized general, non-food stimuli. Some research suggests that deficits in individuals with obesity are exacerbated or perhaps only deficient in response to food (Houben, Nederkoorn, & Jansen, 2014; Svaldi, Naumann, Trentowska, & Schmitz, 2014) so it is possible that food-specific measures may provide different results and should be examined in the future.

Interventions that aim to strengthen executive function skills exist though these interventions are highly variable in terms of outcomes measures and improvements in executive function (Karbach & Unger, 2014). Studies suggest that children with executive functioning difficulties benefit more from these targeted interventions than do children whose executive functioning is largely intact (Diamond & Lee, 2011). To date, there are no systematic reviews of executive function training in middle childhood and adolescence. Thus, conclusions about the impact of such executive function trainings during this period of development are largely unknown. However, research suggests that training executive function constructs such as working memory and inhibitory control in preschool populations (Diamond, Barnett, Thomas, & Munro, 2007; Dowsett & Livesey, 2000; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009) may be a critical time in development to strengthen these skills. It is unknown what impact, if any, strengthening executive function skills at an early age may have on weight outcomes and weight trajectories into middle childhood, adolescence, and adulthood. Longitudinal research should continue to investigate the impact of improvement on executive function skills and the impact on weight over time as one potential key prevention strategy to limit excess weight gain, particularly among children with poor executive function skills or those that may be at-risk for overweight/obesity.

Currently, behavioral weight-loss programs do not include executive function training components that could potentially improve intervention results in terms of weight loss and weight maintenance. Perhaps executive function training should be conducted as a lead in prior to enrollment in child obesity treatment to enhance skills like set-shifting which may improve treatment effects and promote greater – and longer lasting – weight-loss results. Given that no differences in the relationship of executive function and weight change were found between PBT and FBT, it may be important to train executive function in children even in a parent-only treatment.

Our study had a number of strengths and limitations to consider. First, this study included a large, diverse treatment-seeking sample of overweight and obese children and their parents. We examined several facets of executive function longitudinally at various time points. Executive function is an umbrella term for higher-level cognitive functions with varying definitions and related constructs. In the current study, results varied depending on the measure so future studies should consider utilizing more comprehensive standardized batteries such as the NIH toolbox (Weintraub et al., 2013) or the NIH EXAMINER (Kramer et al., 2014) to continue to tease apart the relation between executive function and weight-loss outcomes. Using a battery would allow researchers to examine individual executive function domains as well as a composite measure in a standardized way to evaluate executive function across domains. Also, utilizing a version of SST that allows calculation of SSRT may produce different results. It is possible that parent executive function may have been a stronger predictor of child weight loss if other measures of executive function were utilized. We cannot say whether our results will extend to community samples of non-treatment seeking children and parents, as participating in

treatment may impact executive function (Hayes et al., 2017), or extend to adults seeking treatment for themselves. Further, we did not use imaging or other techniques that may provide additional information related to the neural mechanisms that may contribute to weight loss. Lastly, we did not have a measure of general cognitive functioning (e.g., IQ) to include as a covariate and poor executive function may be related to poorer cognitive functioning.

## 5. Conclusion

In conclusion, this study is the first to evaluate the relation between executive function and weight loss among children and their parents participating in FBT-based programs for weight loss. This study adds to the growing literature trying to understand the relative importance of child and parent executive function in implementing behavioral weight-loss skills. In this study, children's set-shifting executive function, and not parent executive function, was related to child weight-loss outcomes. Changes in the assessed set-shifting executive function of parents over time were associated with parent weight changes over corresponding assessments. This pattern may suggest that one's own set-shifting has the strongest relation to one's own weight change. Future research should examine whether targeting executive function directly as part of obesity treatment or prevention can help improve current treatment and prevention efforts.

## Acknowledgements

## References

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. https://doi.org/10.1016/j.appet.2015.09.035.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Vol. Ed.), *Psychology of learning and motivation: Vol. 8*, (pp. 47–89). Academic Press.

Best, J. R., Theim, K. R., Gredysa, D. M., Stein, R. I., Welch, R. R., Saelens, B. E., ... Wilfley, D. E. (2012). Behavioral economic predictors of overweight children's weight loss. *Journal of Consulting and Clinical Psychology, 80*(6), 1086–1096. http://dx.doi.org/10.1037/a0029827.

Boutelle, K. N., Braden, A., Douglas, J. M., Rhee, K. E., Strong, D., Rock, C. L., ... Crow, S. (2015). Design of the fresh study: A randomized controlled trial of a parent-only and parent-child family-based treatment for childhood obesity. *Contemporary Clinical Trials, 45*(Pt B), 364–370. http://dx.doi.org/10.1016/j.cct.2015.09.007.

Boutelle, K. N., Cafri, G., & Crow, S. J. (2011). Parent-only treatment for childhood obesity: A randomized controlled trial. *Obesity, 19*(3), 574–580. http://dx.doi.org/10.1038/oby.2010.238.

Boutelle, K. N., Cafri, G., & Crow, S. J. (2012). Parent predictors of child weight change in family based behavioral obesity treatment. *Obesity, 20*(7), 1539–1543. http://dx.doi.org/10.1038/oby.2012.48.

Boutelle, K. N., Rhee, K. E., Liang, J., Braden, A., Douglas, J., Strong, D., ... Crow, S. J. (2017). Effect of attendance of the child on body weight, energy intake, and physical activity in childhood obesity treatment: A randomized clinical trial. *JAMA Pediatrics.* http://dx.doi.org/10.1001/jamapediatrics.2017.0651.

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., ... Naglieri, J. A. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychology, 30*(1), 91–98. http://dx.doi.org/10.1037/a0021766.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. http://dx.doi.org/10.1146/annurev-psych-113011-143750.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318*(5855), 1387–1388. http://dx.doi.org/10.1126/science.1151148.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4–12 years old. *Science, 333*(6045), 959–964. http://dx.doi.org/10.1126/science.1204529.

Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in

preschool children: Effects of "executive skills" training. *Developmental Psycholbiology, 36*(2), 161–174.

Epstein, L. H., Valoski, A., Wing, R. R., & McCurley, J. (1990). Ten-year follow-up of behavioral, family-based treatment for obese children. *Journal of the American Medical Association, 264*(19), 2519–2523.

Epstein, L. H., Wing, R. R., Koeske, R., Andrasik, F., & Ossip, D. J. (1981). Child and parent weight loss in family-based behavior modification programs. *Journal of Consulting and Clinical Psychology, 49*(5), 674–685. https://doi.org/10.1037/0022-006X.49.5.674.

Epstein, L. H., & Wrotniak, B. H. (2010). Future directions for pediatric obesity treatment. *Obesity, 18*(Suppl 1), S8–S12. http://dx.doi.org/10.1038/oby.2009.425.

Galioto, R., Bond, D., Gunstad, J., Pera, V., Rathier, L., & Tremont, G. (2016). Executive functions predict weight loss in a medically supervised weight loss programme. *Obesity Science & Practice, 2*(4), 334–340. http://dx.doi.org/10.1002/osp4.70.

Golan, M. (2006). Parents as agents of change in childhood obesity–from research to practice. *International Journal of Pediatric Obesity, 1*(2), 66–76.

Groppe, K., & Elsner, B. (2017). Executive function and weight status in children: A one-year longitudinal perspective. *Child Neuropsychology, 23*(2), 129–147. http://dx.doi.org/10.1080/09297049.2015.1089981.

Hayes, J. F., Eichen, D. M., Barch, D. M., & Wilfley, D. E. (2017). Executive function in childhood obesity: Promising intervention strategies to optimize treatment outcomes. *Appetite.* http://dx.doi.org/10.1016/j.appet.2017.05.040.

Heaton, R. K. (2003). *Wisconsin card sorting test: Computer version 4 [wcst: Cv4].* Psychological Assessment Resources.

Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N. A., Raine, L. B., Scudder, M. R., ... Kamijo, K. (2014). Effects of the fitkids randomized controlled trial on executive control and brain function. *Pediatrics, 134*(4), e1063–1071. http://dx.doi.org/10.1542/peds.2013-3219.

Ho, M., Garnett, S. P., Baur, L., Burrows, T., Stewart, L., Neve, M., & Collins, C. (2012). Effectiveness of lifestyle interventions in child obesity: Systematic review with meta-analysis. *Pediatrics, 130*(6), e1647–e1671. http://dx.doi.org/10.1542/peds.2012-1176.

Houben, K., Nederkoorn, C., & Jansen, A. (2014). Eating on impulse: The relation between overweight and food-specific inhibitory control. *Obesity, 22*(5), E6–E8. http://dx.doi.org/10.1002/oby.20670.

Jaeger, B. C. (2017). *R2glmm: Computes r squared for mixed (multilevel models) (Version R package version 0.1.2).* Retrieved from: https://CRAN.R-project.org/package=r2glmm.

Jaeger, B. C., Edwards, L. J., Das, K., & Sen, P. K. (2017). An r2 statistic for fixed effects in the generalized linear mixed model. *Journal of Applied Statistics, 44*(6), 1086–1105. http://dx.doi.org/10.1080/02664763.2016.1193725.

Janicke, D. M., Sallinen, B. J., Perri, M. G., Lutes, L. D., Huerta, M., Silverstein, J. H., & Brumback, B. (2008). Comparison of parent-only vs family-based interventions for overweight children in underserved rural settings: Outcomes from project story. *Archives of Pediatrics and Adolescent Medicine, 162*(12), 1119–1125. http://dx.doi.org/10.1001/archpedi.162.12.1119.

Jansen, A., Houben, K., & Roefs, A. (2015). A cognitive profile of obesity and its translation into new interventions. *Frontiers in Psychology, 6*(1807), http://dx.doi.org/10.3389/fpsyg.2015.01807.

Jones, A., Hardman, C. A., Lawrence, N., & Field, M. (2017). Cognitive training as a potential treatment for overweight and obesity: A critical review of the evidence. *Appetite.* https://doi.org/10.1016/j.appet.2017.05.032.

Karbach, J., & Unger, K. (2014). Executive control training from middle childhood to adolescence. *Frontiers in Psychology, 5*, 390. http://dx.doi.org/10.3389/fpsyg.2014.00390.

Kramer, J. H., Mungas, D., Possin, K. L., Rankin, K. P., Boxer, A. L., Rosen, H. J., ... Widmeyer, M. (2014). Nih examiner: Conceptualization and development of an executive function battery. *Journal of the International Neuropsychological Society, 20*(1), 11–19. http://dx.doi.org/10.1017/s1355617713001094.

Kuczmarski, R. J., Ogden, C. L., Grummer-Strawn, L. M., Flegal, K. M., Guo, S. S., Wei, R., ... Johnson, C. L. (2000). Cdc growth charts: United States. *Advance Data, 314*, 1–27.

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. http://dx.doi.org/10.1038/ijo.2013.142.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91*(3), 295.

Matthews, S., Simmons, A., Arce, E., & Paulus, M. (2005). Dissociation of inhibition from error processing using a parametric inhibitory task during functional magnetic response imaging. *NeuroReport, 16*, 755–760. http://dx.doi.org/10.1097/00001756-200505120-00020.

Matthews, S., Simmons, A., Strigo, I., Gianaros, P., Yang, T., & Paulus, M. (2009). Inhibition-related activity in subgenual cingulate is associated with symptom severity in major depression. *Psychiatry Research: Neuroimaging, 172*(1), 1–6. https://doi.org/10.1016/j.pscychresns.2008.08.006.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*(1), 167–202. http://dx.doi.org/10.1146/annurev.neuro.24.1.167.

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. https://doi.org/10.1006/cogp.1999.0734.

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences, 15*(10), 453–459. http://dx.doi.org/10.1016/j.tics.2011.07.011.

Naar-King, S., Ellis, D. A., Idalski Carcone, A., Templin, T., Jacques-Tiura, A. J., Brogan Hartlieb, K., ... Jen, K. L. (2016). Sequential multiple assignment randomized trial (smart) to construct weight loss interventions for african american adolescents. *Journal of Clinical Child and Adolescent Psychology, 45*(4), 428–441. http://dx.doi.org/10.1080/15374416.2014.971459.

Nederkoorn, C., Braet, C., Van Eijs, Y., Tanghe, A., & Jansen, A. (2006). Why obese children cannot resist food: The role of impulsivity. *Eating Behaviors, 7*(4), 315–322. https://doi.org/10.1016/j.eatbeh.2005.11.005.

Nederkoorn, C., Jansen, E., Mulkens, S., & Jansen, A. (2007). Impulsivity predicts treatment outcome in obese children. *Behaviour Research and Therapy, 45*(5), 1071–1075. https://doi.org/10.1016/j.brat.2006.05.009.

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. *Journal of the American Medical Association, 311*(8), 806–814. http://dx.doi.org/10.1001/jama.2014.732.

Pauli-Pott, U., Albayrak, Ö., Hebebrand, J., & Pott, W. (2010). Does inhibitory control capacity in overweight and obese children and adolescents predict success in a weight-reduction program? *European Child & Adolescent Psychiatry, 19*(2), 135–141. http://dx.doi.org/10.1007/s00787-009-0049-0.

Ramsay, M. C., & Reynolds, C. R. (1995). Separate digits tests: A brief history, a literature review, and a reexamination of the factor structure of the test of memory and learning (tomal). *Neuropsychology Review, 5*(3), 151–171. http://dx.doi.org/10.1007/bf02214760.

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. http://dx.doi.org/10.1155/2013/820956.

Seeyave, D. M., Coleman, S., Appugliese, D., Corwyn, R. F., Bradley, R. H., Davidson, N. S., ... Lumeng, J. C. (2009). Ability to delay gratification at age 4 years and risk of overweight at age 11 years. *Archives of Pediatrics and Adolescent Medicine, 163*(4), 303–308. http://dx.doi.org/10.1001/archpediatrics.2009.12.

Smith, E., Hay, P., Campbell, L., & Trollor, J. N. (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. http://dx.doi.org/10.1111/j.1467-789X.2011.00920.x.

Spitznagel, M. B., Alosco, M., Galioto, R., Strain, G., Devlin, M., Sysko, R., ... Gunstad, J. (2014). The role of cognitive function in postoperative weight loss outcomes: 36-month follow-up. *Obesity Surgery, 24*(7), 1078–1084. http://dx.doi.org/10.1007/s11695-014-1205-2.

Spitznagel, M. B., Alosco, M., Strain, G., Devlin, M., Cohen, R., Paul, R., ... John Gunstad, P. D. (2013a). Cognitive function predicts 24-month weight loss success after bariatric surgery. *Surgery for Obesity and Related Diseases, 9*(5), 765–770. https://doi.org/10.1016/j.soard.2013.04.011.

Spitznagel, M. B., Garcia, S., Miller, L. A., Strain, G., Devlin, M., Wing, R., ... Gunstad, J. (2013b). Cognitive function predicts weight loss after bariatric surgery. *Surgery for Obesity and Related Diseases, 9*(3), 453–459. https://doi.org/10.1016/j.soard.2011.10.008.

Svaldi, J., Naumann, E., Trentowska, M., & Schmitz, F. (2014). General and food-specific inhibitory deficits in binge eating disorder. *International Journal of Eating Disorders, 47*(5), 534–542. http://dx.doi.org/10.1002/eat.22260.

Team, R. C. (2015). *R: A language and enivornment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. Retrieved from: http://www.R-project.org/.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106–113. http://dx.doi.org/10.1111/j.1467-7687.2008.00745.x.

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. https://doi.org/10.1016/j.brat.2013.02.006.

Wechsler, D. (2003). *Wechsler intelligence scale for children - fourth edition (WISC-IV).* San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler adult intellgience scale - fourth edition (WAIS-IV).* San Antonio, TX: NCS Pearson.

Weintraub, S., Dikmen, S. S., Heaton, R. K., Tulsky, D. S., Zelazo, P. D., Bauer, P. J., ... Gershon, R. C. (2013). Cognition assessment using the nih toolbox. *Neurology, 80*(11 Suppl 3), S54–S64. http://dx.doi.org/10.1212/WNL.0b013e3182872ded.

Wrotniak, B. H., Epstein, L. H., Paluch, R. A., & Roemmich, J. N. (2004). Parent weight change as a predictor of child weight change in family-based behavioral obesity treatment. *Archives of Pediatrics and Adolescent Medicine, 158*(4), 342–347. http://dx.doi.org/10.1001/archpedi.158.4.342.