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REGULAR ARTICLE

Executive Functioning as a Predictor of Weight Loss and Physical Activity Outcomes

Meghan L. Butryn, PhD • Mary K. Martinelli, MA • Jocelyn E. Remmert, MS • Savannah R. Roberts, BS • Fengqing Zhang, PhD • Evan M. Forman, PhD • Stephanie M. Manasse, PhD

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Abstract

Background Executive functioning, which is fundamental for carrying out goal-directed behaviors, may be an underappreciated predictor of outcomes in lifestyle modification programs for adults with obesity.

Purpose This study tested the hypotheses that higher levels of baseline executive functioning would predict greater weight loss and physical activity after 6 months of behavioral treatment.

Methods Participants (N = 320) were recruited from the community and provided with 16 treatment sessions. Executive functioning was measured with the tower task component of the Delis-Kaplan Executive Function System (D-KEFS). At months 0 and 6, weight was measured in the clinic and physical activity was measured with tri-axial accelerometers.

Results Baseline D-KEFS achievement score, rule violations, and completion time significantly predicted weight loss at 6 months. For example, among participants without any rule violations (n = 162), weight loss averaged 11.0%, while those with rule violations (n = 158) averaged 8.7% weight loss. Rule violations also significantly predicted physical activity at 6 months. Among participants without any rule violations, physical activity at 6 months averaged 169.8 min/week, versus 127.2 min/week among those with rule violations.

Conclusions Particular aspects of executive functioning may predict the relative ease or difficulty of changing eating and exercise-related behaviors, albeit with small effect sizes. This study is the first to our knowledge to detect a predictive relationship between components of executive functioning and objectively measured physical activity in adult lifestyle modification, and one of the first to predict weight loss in adults using an objective measure of executive functioning.

ClinicalTrials.gov registration number NCT02363010

Keywords Obesity • Behavioral weight loss • Executive function • Neuropsychology

Introduction

Lifestyle modification is recommended as a first line of intervention for individuals with obesity, but changing diet and exercise behaviors is quite challenging [1, 2]. More research is needed to identify factors that facilitate or hinder weight-related behavior change. A growing body of literature suggests that a subset of top–down cognitive processes, known as executive functions, are implicated in the development and maintenance of obesity. These higher-level cognitive processes are critical for regulating behavior [3], and include planning, working memory, attention, and inhibitory control [4, 5]. In the modern environment, highly palatable foods are omnipresent and sedentary lifestyles are common (i.e., transportation, occupation, leisure, and food acquisition typically require little physical activity). As such, weight regulation may be challenging if an individual has weaknesses in executive functioning. For example, to limit calorie intake, an individual may need to regularly enact inhibitory control by refraining from eating good-tasting foods that are available. To achieve adequate energy expenditure, an individual may regularly need to create opportunities (e.g., plan) for physical activity. Attention and working memory are likely required to keep one's eating and physical activity goals in mind.

Cross-sectional findings suggest that, compared to normal weight controls, individuals with obesity demonstrate poorer performance on a range of executive functioning tasks [6–9]. Longitudinal studies have

✉ Meghan L. Butryn
mlb34@drexel.edu

Department of Psychology, Drexel University, Stratton Hall 119, 3141 Chestnut Street Philadelphia, PA 19104, USA

detected a bidirectional relationship between obesity and executive functioning, with poor executive function representing both a risk factor and a consequence of obesity [10]. There also is evidence that executive functioning improves following weight loss [11], suggesting that weight loss may have cognitive benefits.

Executive functioning facilitates self-control and is fundamental for planning and carrying out goal-directed behaviors [12]. As such, it is likely that executive functioning is a key factor in determining how challenging or feasible it is to make changes in diet or physical activity. Lifestyle modification programs typically recommend that participants self-monitor their food intake (requiring attention and working memory), select and prepare healthy foods that are consistent with a calorie goal (requiring planning and inhibitory control), and make time to engage in aerobic exercise (requiring planning and problem solving).

A growing body of literature has examined executive functioning as a prospective predictor of weight loss outcomes, but important gaps in this research remain. Some of this research has been conducted with children and adolescents [13–15], who may differ from adults in developmentally important ways. In adults, research has tended to focus on food-specific measurement of inhibitory control. For example, in a behavioral treatment study, baseline inhibitory control, measured by a food-specific Go-No-Go task, interacted with hedonic liking of food to predict weight loss outcomes (but did not independently predict 13-week or 52-week weight loss) [16]. In another study of adults entering behavioral weight loss, baseline inhibitory control was measured by a food-specific Stop Signal task and was found to predict weight loss at 12 months [17]. More research is needed to examine executive processes that are related to other facets of executive functioning, rather than food-specific inhibition of behavior. One such study did measure multiple facets of executive functioning in adults with obesity, and found that baseline set-shifting and inhibitory control, but not planning or working memory, predicted post-treatment weight losses [18]. However, participants in that study were provided with meal replacements to achieve weight loss; it is unclear how the role of executive functioning might differ when eating a diet of self-selected foods.

While experimental studies have established that engaging in physical activity can improve executive functioning [19, 20], it is less clear to what extent executive functioning facilitates the adoption and maintenance of physical activity among adults with obesity. Planning and inhibitory control may be critical for following a physical activity prescription, in order to successfully integrate this behavior into one's lifestyle and follow through on intentions to exercise even when there is a temptation to engage in an alternate behavior that is perceived as more enjoyable [21, 22]. In several studies of older adults (i.e., age 60 and older), executive functioning components such as inhibitory control, mental set-shifting, attentional flexibility, and overall cognitive ability have positively predicted the acquisition of physical activity [23–27]. However, individuals with obesity who attempt lifestyle modification may differ from these samples of older adults in important ways beyond age, including mobility, physical functioning, and cognitive health.

In summary, conceptual models of lifestyle modification highlight the important role of executive functioning in inhibiting and initiating key weight-related behaviors [21, 22, 28, 29]. Prospective research is needed to examine how executive functioning might predict treatment outcomes in adults with obesity. Identifying pre-treatment predictors of weight loss and physical activity may lead to the development of personalized interventions for individuals who are at risk for suboptimal outcomes. The primary aim of the present study was to test the hypotheses that in a sample of overweight or obese adults entering a lifestyle modification program, better executive functioning at baseline would predict greater weight loss and physical activity after 6 months of treatment. The study methods were designed to make a unique contribution to the literature by (a) using a baseline measure of executive functioning that was standardized, objective, and multi-faceted (as opposed to only measuring food-related inhibitory control) and (b) objectively measuring changes in weight and physical activity.

Method

Participants

This project was conducted as a sub-study, collecting data from participants recruited from the community for a clinical trial of weight loss treatment. The study is registered with ClinicalTrials.gov (NCT02363010). This research was approved by the Institutional Review Board and informed consent was obtained from all participants enrolled in the study. Eligible participants had a body mass index (BMI) between 27 and 45 kg/m^2, were 18–70 years old, had no medical contraindications to participating and were physically able to begin exercising. A history of bariatric surgery, the use of weight-affecting medication, substantial (>5%) weight loss in the past 6 months, and a diagnosis of major medical or psychiatric condition that would interfere with participation were all exclusion criteria. Women who were currently nursing, pregnant,

or planning to become pregnant over the course of the study were also ineligible.

Intervention

Over the course of 6 months, all participants were provided with 16 sessions of group-based, standard behavioral treatment designed to induce a 10% weight loss (as the parent clinical trial was focused on experimentally testing strategies for weight loss maintenance, intervention content was uniform during this period of weight loss induction). The treatment protocol was adapted from Look AHEAD [30] and the Diabetes Prevention Program [31]. The program emphasized self-monitoring of calorie intake as a core skill. Participants also learned stimulus control, problem solving, goal setting, and social support skills. A progression was prescribed for gradually increasing days and minutes of moderate-to-vigorous physical activity (i.e., aerobic exercise), with the ultimate goal of 250 min of moderate-to-vigorous physical activity per week.

Measures

Participant characteristics

Participants reported age, gender, race, and ethnicity at baseline.

Weight

Blinded research staff used a Tanita model WB-3000 digital scale to weigh participants (measured in street clothes) at baseline and 6 months.

Moderate-to-vigorous physical activity

Moderate-to-vigorous physical activity was measured using ActiGraph GT3X tri-axial, solid state accelerometers. Accelerometers were distributed at baseline and 6 months to participants, with the instruction to wear them for the following seven consecutive days for all waking hours; participants who wore the devices for a minimum of 4 days were included in analyses. Moderate-to-vigorous physical activity in bouts of at least 10 min was extracted using ActiLife software and analyzed using established cut-points [32].

Executive functioning

Participants completed the tower task component of the Delis-Kaplan Executive Function System (D-KEFS) [33] during their baseline assessment. We chose this task because it captures facets of planning, inhibitory control, and flexibility, and because successful weight control likely requires multiple interacting facets of executive functioning. Participants were instructed to build a designated tower using disks of various sizes in as few moves as possible across three pegs, with the rules that (a) they may only move one disk at a time and (b) they may never place a larger disk over a smaller disk. Participants were given an opportunity to build nine towers that increased in difficulty and time limit as the participant progressed. The task was discontinued after three consecutive tower failures. Each tower was given an achievement score based on the number of moves used to complete it, such that failed towers earn 0 points and towers that are correct within the time limit earn more points with fewer moves. The achievement score represents overall executive functioning. Prior research has shown that process measures from the tower task, such as rule violations, may be useful for distinguishing groups based on neurocognitive deficits [34, 35]. Thus, several process measures also were calculated: mean first-move time (representing impulsive initial responding), time-per-move ratio (representing deliberateness of behavioral responses), move accuracy ratio (representing planning ability), and total rule violations (representing the ability to keep a rule set in mind and behave consistently with it).

Data Analysis Plan

Baseline relationships between D-KEFS scores and age, BMI, and moderate-to-vigorous physical activity were examined with Pearson's correlations. Nonparametric correlation analysis (Kendall's tau) was used when assumptions were violated. Multiple linear regression was used to evaluate whether baseline D-KEFS scores predicted weight loss after 6 months of treatment controlling for baseline BMI, age, and baseline moderate-to-vigorous physical activity. Each of the D-KEFS scores was examined separately. Due to the zero-inflated distribution of moderate-to-vigorous physical activity, compound Poisson linear model was chosen to examine whether baseline D-KEFS scores predicted moderate-to-vigorous physical activity at 6 months, controlling for baseline moderate-to-vigorous physical activity, baseline BMI, age, and 6-month weight loss [36]. The compound Poisson linear model has been applied in many different areas including actuarial science, animal studies, rainfall modeling and fishery research to handle continuous data with extra zeros. The R add-on package cplm was used to implement the compound Poisson linear model [33]. Additionally, a set of analyses was run without controlling for physical activity in weight prediction and without controlling for weight in physical activity prediction. Men and women significantly differed in 6-month weight loss and moderate-to-vigorous physical activity outcomes, and thus models also were run, where

noted, with gender as a covariate. African American and non-Hispanic white participants differed significantly in 6-month weight loss but not in 6-month moderate-to-vigorous physical activity, thus where noted race was included as a covariate for predicting weight loss at 6 months (Other race categories were not examined as covariates because they accounted for less than 5% of the data.). Post-hoc exploratory mediation analysis was used to examine whether moderate-to-vigorous physical activity at 6 months mediated the effect of baseline D-KEFS scores on weight loss after 6 months of treatment. Retention at the 6-month assessment was 90%. All analyses were based on an intent-to-treat approach. Multiple imputation was conducted to handle missing data using MCMC algorithms known as chained equations imputation available in SPSS [37]. Results from multiply imputed data were combined using Rubin's rules [38, 39]. Effect sizes were reported as Cohen's f^2 in regression analysis and Cohen's d in t-tests. Influential points and residual plots were examined in all the analyses. The residuals were randomly scattered around zero, which suggested that assumptions (e.g., equal variance and linearity) were satisfied.

Results

Sample Characteristics at Baseline

Participants (N = 320) were 78% female with a mean age of 52.6 years (SD = 10.74) and an average BMI of 35.1 kg/m^2 (SD = 4.63) at baseline. Racial composition of the sample was 70.0% White, 25.0% Black, 1.6% Asian, 0.6% American Indian/Alaskan Native, and 2.8% multi-racial. Four percent of participants were Hispanic or Latino. At baseline, participants engaged in an average of 62.20 min per week of moderate-to-vigorous physical activity (SD = 89.83). As shown in Table 1, baseline moderate-to-vigorous physical activity was negatively associated with D-KEFS time per move; no other D-KEFS scores were associated with baseline moderate-to-vigorous physical activity or BMI. Age was significantly associated with mean first-move time, time per move, and move accuracy ratio. There were no significant differences between men and women for any D-KEFS scores.

D-KEFS as a Predictor of Weight Loss

Total achievement score (f^2 = 0.015, p = .043,), rule violations (f^2 = 0.031, p = .002), and total completion time (f^2 = 0.028, p = .005) significantly predicted weight loss at 6 months, controlling for baseline moderate-to-vigorous physical activity, baseline BMI, age, and 6-month moderate-to-vigorous physical activity. These analyses were re-run without controlling for physical activity. The same three predictors were found to be statistically significant. When gender was added as a covariate, total achievement score (p = .031), rule violations (p = .005), and total completion time (p = .0096) remained significant predictors of weight loss at 6 months. When race was added as a covariate (African American vs. non-Hispanic white), rule violations (p = .01) and total completion time (p = .01) remained significant predictors of weight loss at 6 months.

To illustrate the clinical significance of the observed relationships, rule violations and completion time were examined categorically in post-hoc analysis. The distribution of rule violations was positively skewed with a median of 0. We chose to split the sample categorically based on whether participants committed any greater than zero rule violations so that the number of participants without any rule violations was about the same as the

Table 1 D-KEFS Descriptive Statistics and Baseline Associations Between D-KEFS Performance, MVPA, BMI, and Age

			Correlations with D-KEFS at baseline					
			MVPA min/week		BMI		Age	
D-KEFS scores	*M*	*SD*	*r*	*p*	*r*	*p*	*r*	*p*
Total achievement score	16.59	4.02	0.03	.48	−0.06	.16	−0.04	.35
Mean first-move time	5.66	3.32	−0.05	.19	0.04	.28	0.08*	.03
Time per move	4.32	2.19	−0.09*	.02	0.04	.28	0.09**	.01
Total rule violations	1.11	1.73	−0.01	.77	0.01	.76	0.08	.08
Move accuracy ratio	1.59	0.47	0.07	.08	0.01	.89	−0.12***	.00
Total completion time (s)	531.89	158.39	0.00	.99	0.04	.27	−0.01	.81

D-KEFS Delis-Kaplan Executive Function System; *MVPA* moderate-to-vigorous physical activity; *BMI* body mass index; *min/week* minutes per week. Associations were examined using Pearson's correlation (or nonparametric correlation analysis [Kendall's tau] when appropriate).

*p < .05, **p < .01, ***p < .001.

number of participants with at least one rule violation. This is consistent with evidence that 44.4% of a normed sample committed no rule violations on the tower task [33]. As shown in Fig. 1, among participants without any rule violations (n = 162), weight loss averaged 11.0%, while those with rule violations (n = 158) averaged 8.7% weight loss ($t(313) = -3.78$, $p < .001$, $d = 0.43$). Among participants in the lowest quartile of total completion time (n = 80), weight loss at 6 months averaged 11.0%, while those in the highest quartile (n=80) averaged 9.0% weight loss ($t(153) = -2.32$, $p = .022$, $d = 0.37$), as shown in Fig. 2. Mean first-move time ($p = .717$), time per move ($p = .388$), and move accuracy ratio ($p = .165$) were not significant predictors of weight loss.

D-KEFS as a Predictor of Moderate-to-Vigorous Physical Activity

Rule violations ($f^2 = 0.002$, $p = .036$) significantly predicted moderate-to-vigorous physical activity at 6 months, controlling for baseline moderate-to-vigorous physical activity, baseline BMI, age, and 6-month weight loss. As shown in Fig. 3, among participants without any rule violations (n = 162), 6-month moderate-to-vigorous physical activity averaged 169.8 min/week, while those with rule violations (n = 158) averaged 127.2 min/week of moderate-to-vigorous physical activity ($t(313) = 2.15$, $p = .032$, $d = 0.33$). Total completion time ($p = .055$) was a marginally significant predictor of 6-month moderate-to-vigorous physical activity. Total achievement score ($p = .255$), mean first-move time ($p = .822$), time per move ($p = .489$), and move accuracy ratio ($p = .373$) were not significant predictors of 6-month moderate-to-vigorous physical activity. Rule violations remained the only significant predictor of 6-month moderate-to-vigorous physical activity when the analyses were re-run without controlling for weight. Rule violations remained a significant predictor of 6-month moderate-to-vigorous physical activity when gender was added as a covariate ($p = .036$).

As an exploratory aim, a mediation model also was tested. Mediation analysis showed that 6-month physical activity significantly mediated the effect of rule violations on weight loss at 6 months (effect size = .11, bootstrap confidence intervals [0.04, 0.25]). This suggests participants with fewer rule violations on average were more physically active at 6 months, which in turn had a positive effect on 6-month weight loss.

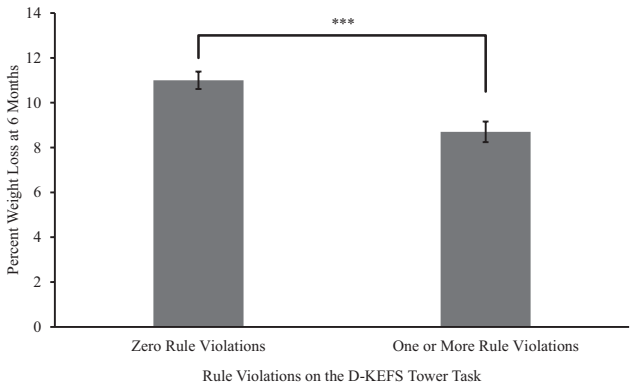

Fig. 1. Mean percent weight loss at 6 months by category of number of rule violations on the D-KEFS tower task. *D-KEFS* Delis-Kaplan Executive Function System. Error bars represent standard errors. ***$p < .001$.

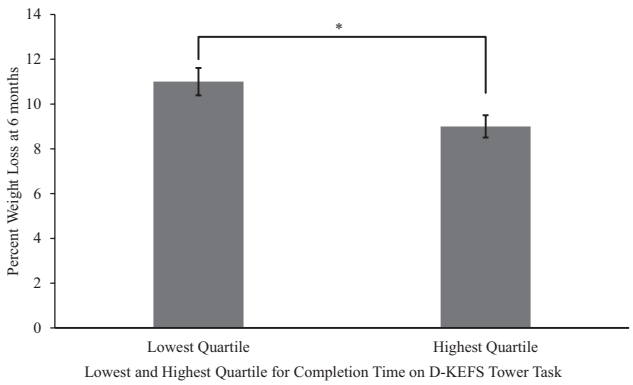

Fig. 2. Mean percent weight loss at 6 months for participants in the lowest and highest quartile for completion time on the D-KEFS tower task. *D-KEFS* Delis-Kaplan Executive Function System. Error bars represent standard errors. *$p < .05$.

Discussion

This study was designed to prospectively examine baseline executive functioning as a predictor of weight loss and physical activity among adults with overweight or obese BMIs who were entering a lifestyle modification program. Pre-treatment performance on several aspects of an executive functioning task significantly predicted

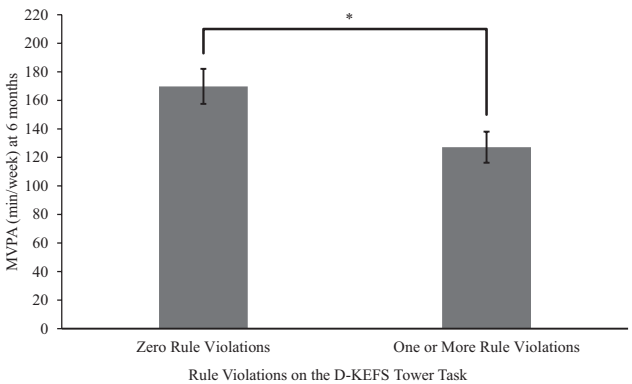

Fig. 3. Mean moderate-to-vigorous physical activity at 6 months by category of number of rule violations on the D-KEFS tower task. *D-KEFS* Delis-Kaplan Executive Function System; *MVPA* moderate-to-vigorous physical activity; *min/week* minutes per week. Error bars represent standard errors. *$p < .05$.

these outcomes at 6 months, providing further evidence that particular executive functioning abilities may influence the relative ease or difficulty with which an individual changes his or her eating and exercise-related behaviors. This study is the first to our knowledge to detect a predictive relationship between any aspect of executive functioning and objectively measured physical activity in a sample of adults seeking weight loss treatment, and it is one of the first to predict weight loss in adults using an objective measure of executive functioning that was broader than inhibitory control.

Weight loss at 6 months was significantly predicted by total achievement score, which can be interpreted as a representation of overall executive functioning. However, when race was added as a covariate to the model, this prediction became nonsignificant; additional research is needed to understand the complex relationships between executive functioning, race, and behavior change. Weight loss also was significantly predicted by two of the four process measures that were examined (total rule violations and total completion time), and exploratory analyses indicated that the size of this effect was clinically notable. These results build on previous research that has shown that aspects of objectively measured executive function predict weight loss outcomes in adults [17, 18]. These data are consistent with the theory that limiting calorie intake in the modern food environment requires strong planning and inhibitory control skills [40, 41]. The finding that rule violations were associated with less weight loss suggests that individuals with weaknesses in planning and inhibitory control at the start of treatment may find it more challenging to override impulsive eating and initiate eating related changes. It is possible that individuals with weaker executive functioning are more prone to dietary lapses or overeating episodes because of deficits in inhibitory control [42, 43]. Because executive functioning is also critical for initiating behaviors, individuals with poorer executive functioning might have lower utilization of skills that are designed to facilitate dietary restraint, such as following a regular schedule of eating, weighing and measuring foods, self-monitoring of calorie intake, eliminating tempting food cues in the environment, and ensuring that healthy snacks and meals are readily available. It is less clear why longer total completion time was associated with lower weight loss. Previous research in patients with prefrontal cortex (i.e., the brain region associated with executive functioning) lesions indicated that prefrontal cortex damage was associated with slower tower task performance compared to healthy controls [34]. Thus, it is possible that slow performance is indicative of global executive functioning weaknesses.

Effect sizes reported in this study were small, but still clinically meaningful as evidenced by the size of the differences in weight loss observed categorically. Similar previous literature has not reported effect sizes. Therefore, direct comparisons of effect sizes observed in other studies are not possible [17, 18]. The relative importance of executive function may depend on an individual's environment, other psychological or neurocognitive factors, or biology [44, 45]. Future research utilizing models that examine such interactions may provide additional insight into how the relationship between executive function and weight loss may be moderated by other factors [44, 45].

Moderate-to-vigorous physical activity at 6 months, controlling for moderate-to-vigorous physical activity at baseline, also was significantly predicted by total rule violations. The size of this effect was small but appeared clinically meaningful (i.e., a difference of approximately 40 min/week in 6-month moderate-to-vigorous physical activity for those with vs. without rule violations at baseline). Physical activity significantly mediated the effect of rule violations on weight loss at 6 months. These results are consistent with previous research demonstrating that individuals with poorer executive functioning are less likely to adhere to physical activity intentions or prescriptions [27, 46, 47]. Weaknesses in executive functioning may be an underappreciated barrier to the adoption and maintenance of moderate-to-vigorous physical activity among adults with overweight or obese BMIs. The rule violations process measure of the tower task is thought to reflect poorer self-monitoring, inhibition, and planning abilities [34, 35]. Previous research supports the link between these abilities and physical activity outcomes. Many individuals with obesity also report relatively low enjoyment of exercise [48], and thus they may frequently experience the temptation to engage in other behaviors rather than exercise. Inhibitory control may be necessary to overcome these temptations [24]. Engagement in physical activity requires prioritizing long-term benefits of the behavior, such as weight loss and fitness, over short-term desires, such as preferring to engage in an alternate activity (e.g., watching television or sleeping) rather than exercising [24, 45]. In the modern environment, it typically takes purposeful effort to engage in moderate-to-vigorous physical activity, given that the defaults for transportation, leisure, and labor are sedentary [49]. Thus planning, a core component of executive functioning, may be necessary in order to form intentions to engage in exercise and to determine what sequence of behaviors is necessary to carry out those intentions [24]. In this environment, remaining mindful of physical activity goals also may be critical for success, tapping into a working memory component of executive functioning [4].

Notably, total achievement score was not a significant predictor of 6-month moderate-to-vigorous physical

activity. It is possible that some of the abilities that influence total achievement score are unrelated to ability to adopt and maintain physical activity, and that the predictive relationship between executive functioning and physical activity can most readily be detected with process measures that tap into particular executive functioning domains, such as those represented by rule violations on the D-KEFS. Rule violations are thought to reflect self-monitoring, inhibition, and planning abilities, while achievement scores also can be influenced by visual attention, visual-spatial skills, and spatial planning [34, 35]. Additionally, rule violations can be thought of as a marker of inflexibility, that is, difficulties with breaking out of certain behavioral patterns even when the rules specify to do so (In the case of the tower task, the rules involve specifications such as never placing a bigger disc on top of a smaller disc, and never moving more than one disc at a time). Executive functioning ability may determine how flexibly individuals are able to incorporate new ideas and strategies while striving to meet goals [50]. Despite being given a new set of rules to follow (e.g., a prescription for moderate-to-vigorous physical activity), an individual who has difficulty flexibly applying new rules may also have difficulty breaking out of habitual behavioral patterns (e.g., watching TV after dinner).

Other null results were observed in this study. As a preliminary analysis, baseline relationships between D-KEFS scores and weight and moderate-to-vigorous physical activity were examined. All but one of these relationships were nonsignificant (baseline moderate-to-vigorous physical activity was negatively associated with D-KEFS time per move). It is possible that the restricted range of weight (all participants had a BMI over 27 kg/m^2) and moderate-to-vigorous physical activity (participants generally were engaging in modest amounts of exercise) at baseline limited the ability to detect relationships that might be observed in a more representative sample of the population, as opposed to those seeking weight loss treatment. It also is possible that executive functioning is less important in explaining natural variability in BMI and moderate-to-vigorous physical activity than in predicting response to behavioral interventions. In other words, it is possible that executive functioning is more influential in predicting how one eats and exercises when attempting to change these weight-related behaviors than in explaining how one behaves when not in a lifestyle modification program.

Experimental research is warranted to explore the clinical implications of these findings. For example, in obesity treatment programs, weight loss and physical activity outcomes might be improved by providing cognitive training to directly bolster executive functioning abilities among individuals who exhibit deficits at baseline [12, 51]. It also is possible that treatment protocols might be more efficacious if they include strategies for managing weaknesses in domains such as planning or inhibitory control, or teach behavioral skills that are designed to compensate for or accommodate such weaknesses. For instance, it is possible that individuals with weaker executive functioning might benefit more from interventions that rely on habit-learning (i.e., to make eating and exercise behaviors more automatic), thus requiring fewer executive resources [50]. On the other hand, it is important to note that the size of the observed effects in the present study was generally small, and thus modest effect may ultimately be observed for such intervention adaptations. The modest size of the observed effects suggests that physical activity and weight loss outcomes are predominantly determined by factors other than the aspects of executive functioning measured in this study.

This study had several key strengths that increase the impact of the findings. Whereas much of the previous research examining executive functioning has been conducted with children and older adults, this sample was predominantly comprised of participants in young adulthood or middle age. The sample had a moderate amount of racial diversity. On average, participants made clinically significant improvements in their weight and physical activity over the 6-month observation period, which provided a rich context in which to examine executive functioning as a predictor of change. Data on age and baseline and 6-month weight and moderate-to-vigorous physical activity were available to include as covariates, which increased the rigor of the statistical analyses. The ability to examine weight loss and adoption of physical activity in the same sample was especially important, to establish that aspects of executive functioning independently predicted both of these outcomes. Moderate-to-vigorous physical activity, weight, and executive functioning were measured objectively, rather than relying on self-report. There is evidence that executive function has distinct components corresponding to initiatory and inhibitory behaviors [52]; the D-KEFS was chosen as a measure of executive functioning because it taps into both of those components, rather than only one of them.

This study has several limitations that should be addressed with future research. The D-KEFS measure does not provide an exhaustive or domain-specific assessment of executive functioning, and some aspects of executive functioning, such as sustained attention, may not have been adequately captured by performance on this task. This study was limited by the use of only one measure of executive functioning, and future studies should include multiple, alternate measures. Executive functioning also can be confounded with other variables that were not measured or controlled for in this study,

such as general cognitive ability or other aspects of physical health. Ideally, future research would measure and covary global cognitive functioning and years of education to better interpret the specificity of results. Finally, because research examining the relationship between executive functioning and lifestyle modification is relatively new, a *p*-value of .05 was chosen for analyses to reduce risk of failing to detect potentially important findings. As a result, given that multiple comparisons were conducted, it is possible that one or more findings were the result of type II error. Replication of results will be necessary to address this possibility.

For many years, it has been clear that individuals with overweight or obese BMIs attempting lifestyle modification have a very difficult time adopting and maintaining changes in their eating and exercise behaviors. This study adds to a growing body of research suggesting that particular facets of executive functioning may be modest but novel predictors of the relative success or failure an individual experiences when attempting lifestyle modification. Because individuals who have obesity and are physically inactive are more likely than healthy adults to have poor executive functioning [6–9], the efficacy of treatments that target or account for weaknesses in these abilities should be explored.

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Compliance with Ethical Standards

Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors Meghan L. Butryn, Mary K. Martinelli, Jocelyn E. Remmert, Savannah R. Roberts, Fengqing Zhang, Evan M. Forman, and Stephanie M. Manasse declare that they have no conflict of interest. All procedures, including the informed consent process, were conducted in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

Primary Data Primary data were collected as part of clinical trial NCT02363010.

Authors' Contributions Meghan L. Butryn designed the research and directed the project, Fengqing Zhang conducted statistical analyses, and all authors contributed to the primary aims, interpretation of results, and drafting and critically revising the manuscript.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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