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Executive Function in Weight Loss Maintenance: The Moderating Role of Socioeconomic Status

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Few individuals with overweight/obesity maintain weight loss. Executive function (EF) and socioeconomic status (SES) contribute to weight loss maintenance (WLM). This study examined whether the relationship between EF and WLM differs across SES. Forty-four participants between 32-78 years of age were assessed ≥ 1-year post- behavioral obesity intervention. Those who achieved >5% weight loss during the program were recruited for the present study. Participants (N = 44) previously lost >5% of initial body weight. Hierarchical regressions tested the moderating role of SES in the relationship between performance-based EF [Iowa Gambling Task (IGT)] or self-report EF [Behavior Rating Inventory of Executive Function (BRIEF-A)] and %WLM. The relationship between performance-based EF and %WLM varied across SES ($p < .05$). For those with high SES, a 1-point T-score increase on IGT corresponded with 4.5% greater %WLM ($\beta = .52$, $p = .03$). No association was observed for those with low SES ($\beta = -.12$, $p = .54$). For those with low SES, greater EF may not benefit WLM. For those with high SES, greater EF may benefit WLM. Personalized WLM interventions accounting for levels of SES and EF may best facilitate WLM.
Keywords: executive function, weight loss maintenance, socioeconomic status, obesity

Approximately one-third of U.S. adults have obesity, with prevalence estimates increasing each year (Lundeen et al., 2018). Behavioral treatment for obesity is the gold-standard approach (Butryn et al., 2011). However, only half of the individuals achieve clinically significant weight loss (i.e., >5%) through these interventions (Ball & Crawford, 2002; Christian et al., 2010; Kraschnewski et al., 2010; Montesi et al., 2016). Further, only 20% of individuals maintain clinically significant weight loss >1-year post-treatment (Wing & Phelan, 2005), highlighting the significant challenge of weight loss maintenance (WLM).

A multitude of factors contribute to WLM, many of which relate to patients' socioeconomic and demographic characteristics (Fitzgibbon et al., 2012; Goode et al., 2017). One review demonstrated that occupation, education, and income all predicted weight change over time, with more socioeconomically disadvantaged participants having a greater risk of weight gain (Ball & Crawford, 2005). Because each of these constructs was related to poorer weight maintenance, it may be advantageous to utilize a measure of SES that captures the broader construct of SES related to weight maintenance (Ball & Crawford, 2005). These findings point toward the importance of identifying the combined influence of several measures of SES to understand the holistic influence of a disadvantaged background on WLM.

Additionally, several psychological variables, including executive function (EF), have been implicated in weight regain. EF refers to neuropsychological processing that controls and coordinates behaviors and cognitive abilities (Diamond, 2013). This typically includes skills pertaining to organization and regulation such as problem solving, decision making, reasoning, attention, planning, and time management. Deficits in impulse control (Giel et al., 2017) and related EF constructs have been repeatedly associated with reduced obesity treatment efficacy and greater weight regain (Montesi et al., 2016; Wing & Phelan, 2005; Elfhag & Rössner, 2005; Varkevisser et al., 2019). Further, constructs consistently related to executive dysfunction, such as binge eating (Boggiano et al., 2014; Striegel-Moore et al., 1998), eating in the absence of hunger, and emotional eating, have been associated with a greater weight regain (Giel et al., 2017; Elfhag & Rössner, 2005). Together, these studies suggest that EF plays a critical role in WLM.

SES and EF may interact to affect health outcomes as well. For example, in an intervention that trained EF skills, SES moderated improvement in EF skills, such that those from low SES families experienced greater improvement than those from high SES families, emphasizing the importance of including SES as a mod erator, rather than simply a covariate when examining the effects of EF on treatment (Schubert, 2016). Evidence from qualitative research supports this notion as well. One study exploring factors associated with dietary behavior indicated that low and mid-SES women emphasized the effect of employment-related time constraints on food preparation more than high-SES women (Inglis et al., 2005). Similarly, low-SES women, but not mid or high-SES women, named the cost of healthy food most frequently among food purchasing considerations (Inglis et al., 2005). These emphases reflect a high demand for resource management via organization and planning when preparing and purchasing foods (Inglis et al., 2005). Indeed, healthy food preparation can require a great deal of time and EF. Those with greater SES resources may be able to compensate for EF constraints by utilizing higher cost strategies (e.g., eating healthier quickly prepared foods due to lack of cost barrier and endorsing more opportunities to cook from home; Inglis et al., 2005) to accomplish EF-demanding health behaviors. Thus, these individuals may not experience the same degree of negative effects of EF on their WLM. Conversely, those with low SES may not be able to employ more costly coping strategies (Inglis et al., 2005) and subsequently experience greater negative effects of EF difficulties on WLM.

Although initial evidence suggests that SES may interact with EF to influence health behavior or WLM, the literature has yet to examine this moderation effect. Evaluating the interaction between SES and EF on WLM would elucidate risk and resilience factors in WLM and has the potential to inform precision medicine approaches to WLM (e.g. identifying who may benefit from interventions targeting resources and/or EF skills). As such, the present paper aims to examine whether SES moderates the relationship between EF and WLM in a racially-diverse group of individuals who lost a clinically significant amount of weight via lifestyle modification. We hypothesized that higher EF will be associated with greater WLM among those with low SES, but be unrelated to WLM among those with high SES.

Method

Participants

Forty-four participants between 32-78 years of age (M = 57.43 years, SD = 11.71) were recruited from previous participants of a behavioral obesity intervention. The original intervention, Improving Weight Loss Maintenance Through Alternative Schedules of Treatment (ImWeL, NCT02487121), consisted of weekly sessions involving evidence-based dietary modifications, increased physical activity, and behavioral strategies designed to promote adherence to these lifestyle changes, delivered by trained interventionists (for more information, see Gowey et al., 2021). For the original intervention, participants were recruited through the local newspaper, television, flyers, and the university-affiliated website and e-newsletter advertisements. For the current study, participants were contacted 2-4 years post-intervention on a rolling basis for six months. Individuals were eligible for recruitment if ≥ 5% weight loss was achieved during ImWeL. Eligibility was confirmed based on study records of weight loss history. Participants were excluded if they had (a) a history of bariatric surgery, (b) unintentional weight loss since participating in the previous weight loss trial, or (c) a medical condition influencing body weight. The current sample was predominantly female and racially diverse (93% female, 55% African American/other, 45% White, see Table 1). The study was approved by the university's Institutional Review Board.

Procedure

Individuals were recruited via mailed letters and telephone calls to assess eligibility. All 44 participants contacted for this study were interested and eligible to enroll in the study. They were scheduled for a two-hour study visit where informed consent procedures were conducted, after which anthropometry measurements were taken, surveys were completed, and EF testing was conducted by a trained graduate student under the supervision of a PhD-level clinical psychologist.

Measures

Demographic information

Participants self-reported their age, educational attainment, medical history, race, ethnicity, marital status, and household income.

Socioeconomic Status

SES was measured by averaging standardized income and education variables (e.g., Pu & Rodriguez, 2021; Rodriguez et al., 2021; Gardner et al., 2017). Education was reported on a 5-point scale, ranging from (1) Less than a high school diploma to (5) Graduate school. Annual total gross family income was reported on an 11-point scale, with the following values: 0) Under $10,000, 1) $10-20,000, 2) $20-30,000, 3) $30-40,000, 4) $40-50,000, 5) $50-60,000, 6) $60-70,000, 7) $70-80,000, 8) $80-90,000, 9) $90-100,000, 10) Over $100,000. For interaction analyses, simple slopes were calculated at 1 standard deviation above and below the mean according to best practices for moderation analyses when there are no meaningful cut points available (Memon et al., 2019). Thus, "High SES" refers to an SES level one standard deviation above the mean, or the 84th percentile. "Low SES" refers to an SES level at one standard deviation below the mean, or the 16th percentile. For reference, an income one SD above the mean would be an income between $80-90,000 and an income one SD below the mean would be an income of about $30,000. For education, one SD above the mean represents a doctoral or professional degree, while one SD below the mean represents some college, but no degree.

Anthropometric measurements

Trained staff measured participants' height and weight with shoes removed using a wall-mounted stadiometer and digital scale.

Percent weight loss maintenance (%WLM)

To determine %WLM, the following data were self-reported by participants: the most weight they lost in their lifetime (initial weight loss; Krueger & Reither, 2015; Santos et al., 2017) how much they weighed prior to losing that weight (start weight), how much they weighed after losing that weight (post weight), and their current weight which was measured objectively (see anthropometric measurements section). The following formula is based on prior literature (Ryder et al., 2005) and was used to calculate %WLM:

$$\frac{\text{initial weight loss} - (\text{current weight} - \text{post weight})}{\text{initial weight loss}}$$

Performance-based EF

The Iowa Gambling Task (IGT; Bechara, 2007) was utilized to measure performance-based EF. The IGT measures decision-making using four virtual decks of cards. The participant is instructed to win as much money as possible and that cards will reward or penalize them. Participants are scored based on their use of good decks, which provide smaller rewards more often and have better net outcomes, versus bad decks, which provide larger rewards less often and have poorer net outcomes. A norm-referenced T-score (age-, gender-, race-, ethnicity-matched) is generated based on the total net score, with lower scores indicating more impaired decision making. Mixed results have been noted when comparing IGT performance to performance on other executive functions, decision making, and memory tasks, with impairments in cognitive skills more associated with "cold" decision making a likely cause for the inconsistencies (Buelow & Suhr, 2009). However, there is evidence to demonstrate that IGT shows good construct validity with some measures of executive function and decision-making, like the Wisconsin Sorting Card task (Brand et al., 2007, Buelow & Suhr, 2009)

Self-reported EF

The Behavior Rating Inventory of Executive Functioning (BRIEF-A) is a standardized self-report scale of EF that is well-validated and has demonstrated good internal consistency in adults with obesity (Roth et al., 2005; Rouel et al., 2016). There were moderate to high coefficient alphas for the nine clinical scales (α = 0.65–0.92), and high alphas for the three composite scales (α = 0.93, 0.95, and 0.97, respectively). Three subscales showed internal consistency below the expected value of 0.80 (α = 0.65, α = 0.78, α = 0.79). Participants rate the frequency with which certain behaviors have been a problem in the past month. Scoring of the 75-item questionnaire generates T-scores for the Global Executive Composite (GEC). Higher scores indicate more impaired EF.

Data Analyses

Descriptive statistics characterized key variables. Two candidate covariates (BMI, duration of WLM) were examined via correlations. Potential covariates that significantly correlated with %WLM were retained in the model. Moderation was tested in a hierarchical linear regression model. Step one included BMI as a covariate, step two added mean-centered SES and EF, and step three added the interaction between SES and EF. The hierarchical model was run separately for performance-based and self-reported EF. Significant interactions were followed up with simple slope testing at low and high SES (one standard deviation below and above the mean). All assumptions and analyses were tested via SPSS version 25.

Results

Preliminary Analyses

Descriptive statistics for key variables are reported in Table 1. Participants kept off approximately 13% of the total weight they lost in their lifetime on average. Spearman's correlations between potential covariates (BMI and duration of WLM) and primary variables of interest only revealed a negative correlation between BMI and %WLM ($r = -.41$, $p < .01$) (See Table 2). As expected, SES and Education were moderately associated ($r = .36$, $p < .05$) Thus, BMI was included as a covariate in the main analyses. All relevant assumptions for moderation using hierarchical multiple regression were tested and met.

Moderation Analyses

Performance-based EF (IGT)

The hierarchical regression model testing SES as a moderator of the relationship between IGT and %WLM was significant, $R^2 = 0.24$, $F(4, 39) = 3.11$, $p < .05$; see Table 3. In the first step, higher BMI predicted lower %WLM, $\beta = -0.37$, $p < .05$; $R^2 = 0.14$, $F(1, 42) = 6.72$, $p < .05$. In the second step, IGT and SES did not uniquely predict %WLM, $\Delta R^2 = 0.02$, $\Delta F(2, 40) = 0.40$, $p = .11$. In step three, however, EF significantly interacted with SES in predicting %WLM, $\beta = 0.31$, $p < .05$; $\Delta R^2 = 0.09$, $\Delta F(1, 39) = 4.47$, $p = < .05$, $b = 0.31$, $p < .05$. Simple slope analyses showed a positive effect of EF on WLM at higher levels of SES, a one-point t-score increase in IGT corresponded with a 4.5% increase in %WLM ($\beta = 0.52$, $p < .05$), while at lower levels of SES, there was no relationship between IGT and %WLM ($\beta = -0.12$, $p = .54$); see Figure 1. A post-hoc power analysis for the final model demonstrated that with $\Delta R^2 = 0.09$, $f^2 = 0.10$, $N = 44$, $\alpha = 0.05$, and four predictors, the achieved power to detect the moderation effect was 0.66.

Self-reported EF (BRIEF)

The hierarchical regression model testing SES as a moderator of the relationship between the BRIEF and %WLM was not significant, $R^2 = 0.15$, $F(4, 39) = 1.66$, $p = .18$; see Table 3. In the first step, higher BMI predicted lower %WLM, $\beta = -0.38$, $p < .05$; $R^2 = 0.14$, $F(1, 42) = 6.72$, $p < .05$. In the second step, the BRIEF and SES did not significantly predict %WLM, $\Delta R^2 = 0.01$, $\Delta F(2, 40) = 0.16$, $p = .85$. In step three, the BRIEF did not significantly interact with SES to predict %WLM, $\beta = .03$, $p = .86$; $\Delta R^2 = 0.001$, $\Delta F(1, 39) = .03$, $p = .86$, $b = .026$, $p = .86$. A post-hoc power analysis for the final model demonstrated that with $\Delta R^2 = 0.001$, $f^2 = 0.001$, $N = 44$, $\alpha = 0.05$, and four predictors, the achieved power to detect the moderation effect was 0.08.

Discussion

The goal of the present study was to examine the degree to which SES moderates the relationship between EF and WLM to address gaps in the WLM literature that may inform precision medicine approaches. Given recent studies demonstrating relationships between SES, EF, and weight loss outcomes, we examined whether individuals from different SES backgrounds showed unique relationships between EF and %WLM. EF was measured via a performance-based test and self-reports, as these methods provide unique information about EF and do not correlate highly with each other (Garcia et al., 2013; Toplak et al., 2013). As expected, findings indicated that the relationship between performance-based EF and %WLM was dependent on SES; contrary to our expectation, however, those with high SES experienced a greater benefit of performance-based EF on %WLM than individuals with low SES. Regarding self-reported EF, our hypothesis was not supported, as SES and self-reported EF did not interact to affect an individual's %WLM.

Access to high-cost coping strategies in high-SES individuals may best explain the unique relation between EF and SES in high-SES individuals. It is likely that for high SES individuals, having access to an abundance of weight management resources (e.g., grocery stores, gym memberships/classes, meal preparation services, smartphone applications, and gadgets, etc.) may be more efficiently accessed and utilized for an individual with stronger EF skills. For example, individuals with higher SES may be more likely to own a wearable device to monitor activity, and those with stronger EF skills may be more likely to utilize the tracking features (e.g., weight, food, and exercise tracking) on the device or its associated phone app. Alternatively, EF deficits could also be uniquely hindering those with high SES, perhaps due to increased access to unhealthy foods and mismanagement of extra resources.

In contrast, lower SES individuals often lack basic access to these same resources (Ailshire & House, 2011); thus, EF may manifest differently in each of these scenarios. For higher SES individuals with abundant opportunities, there is a need to organize options, utilize self-control with grocery shopping, and manage memberships efficiently and accurately. Alternatively, for lower SES individuals maintaining weight loss, there are fewer resources through which to apply EF skills of coordinating, organizing, and managing, so EF abilities may have a more limited "range" of impact. In fact, for low SES individuals, the weight-loss intervention program itself may be the primary resource accessible to this group for healthy eating and activity. Once the program ends, these individuals may not have the community structures (e.g., gyms, healthy food markets, etc.) in place to support previous efforts. This interpretation is supported by the recent emphasis on the relationship between social determinants of health and adverse health outcomes (Medvedyuk et al., 2018).

The use of a performance-based EF task is a notable strength of the study design. IGT is specifically designed to detect decision-making deficits and does so in the context of financial gains and losses (Bechara, 2007). One interpretation of these outcomes could imply unique interactions between SES and a financially-oriented EF-dependent task. Although the correlation between IGT and SES was weak and nonsignificant (see Table 2), there are financial patterns across different SES groups that are worthy to note. For example, individuals with low SES experience frequent financial uncertainties which often present as stressors and constraints, rather than solvable complications (Chen & Miller, 2013). In the context of weight management, which can be characterized as a stressor due to the extensive behavior change, resource allotment, and commitment required to maintain success, if low-SES families are attempting to balance weight-related stressors with financial stressors, a "spiral of resource loss" (Hobfoll, 2001) can occur (e.g., a parent misses work to take care of a sick child, loses a job, can't afford gym membership). This financial uncertainty may lead to buying cheaper, unhealthy foods or lower quantities of healthy foods. Thus, real-world decisions about money, food choices, and healthy access to food could be influencing behavior during this performance-based measure and influencing lifestyle choices in the real-world setting, amplifying the significant difference for higher SES individuals compared to lower SES individuals.

Self-reported EF was measured using the BRIEF-A questionnaire and is considered more of a global composite of different behaviors pertaining to EF abilities. Subjective rating scales tend to have more ecological validity than performance-based testing but can be stifled if someone has severe enough impairments that they are not aware of their deficits or of the impact these deficits have on everyday behavior (Barkley, 2012; Chan, 2008). A self-rating scale that requires insight into one's own cognitive abilities may be inherently difficult for someone with impairment in self-awareness as compared to performance-based testing which is rated by a trained observer (Buchanan, 2016), which could explain some of the discrepancies between the performance-based and self-reported EF results.

Limitations

This study has some limitations that should be mentioned. One of the most important limitations is the sample size, which reduced statistical power and did not now allow more complex modeling techniques, such as additional predictors or covariates. The post hoc analyses revealed low power to detect effects, supporting the notion that a larger sample size may improve power and allow for more complex modeling. Given that this study enrolled only those who lost a clinically significant amount of weight, future studies using similar designs may benefit from over-recruitment during a weight loss intervention to allow for a larger recruitment pool of those who lose a clinically significant amount of weight. Alternatively, future research could consider more large-scale designs, such as that of the National Weight Control Registry (Hill et al., 2005). However, with this approach, measurements would need to be adapted for remote data collection, which would introduce another limitation in exchange for an increased sample size. A second limitation was the composition of the sample. The majority of the sample was female, limiting the generalizability of findings to weight loss experiences for males. Despite these limitations, the current study represents an important step toward prioritizing SES and EF in weight management interventions and considering the impacts individual differences and characteristics have on WLM.

For the present study, the best two factors to capture SES included educational history and race, however, it is understood that other variables can be included to strengthen SES as a construct. One recent study acknowledged the complexity of measuring and conceptualizing SES and included a sam ple of additional criteria to be considered in future research (Rodríguez-Hernández et al., 2020). Specifically, they highlight parental education, family income, parental occupation, household resources, and neighborhood resources. Alternatively, SES can also be considered subjective, with perceived SES demonstrating its own separate impact on health outcomes (Nobles et al., 2013) compared to objective components of SES. Therefore, future research should also carefully consider the conceptualization and measurement of SES when studying weight management and could consider the influences of both perceived SES and more objective SES factors related to actual income, occupation, and education status.

Future studies may benefit from expanding upon the present findings. For example, efforts could be made to recruit males and examine sex differences in the studied relationships. Additionally, it may be advantageous to recruit a mix of individuals with varying degrees of success with WLM, including those experiencing weight regain. This allows for more variance in weight maintenance outcomes and allows for an improved investigation of potential barriers to WLM. One final consideration includes isolating the different clinical domains captured in the BRIEF to examine unique associations between individual EF domains, WLM, and SES. Continuation of this line of research could ultimately inform the development of precision medicine strategies that take such relationships into account in treatment selection and delivery.

Conclusion

The present findings suggest that for those with high SES, who already possess basic financial and community resources, higher EF may facilitate the ability to organize, prioritize, and efficiently access available weight management tools and strategies. For those with lw SES who may lack financial and community resources, research should examine the benefit of reducing barriers to such resources via local programs or providing continuous, free, or low-cost access to WLM treatment programs. Overall, if individuals are provided with personalized WLM support aligned with their levels of SES and EF, they may develop the necessary skills to succeed in lifetime WLM.

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Table 1

Descriptive Statistics of Primary Variables (N = 44)

Variable	Mean (*SD*)
%WLM	12.77[a] *(68.41)*
BMI, kg/m^2	32.21[b] *(3.95)*
IGT	49.00 *(7.94)*
BRIEF	54.86 *(8.61)*
Income	5.82[c] *(2.83)*
Education	3.93[d] *(1.30)*
SES	0.00 *(0.81)*
Age, years	57.43 *(11.71)*
Variable	**Mean %**
Sex	
Female	93%
Male	7%
Race	
White	45%
Black/Other	55%

Note. The SES variable was created by combining z-scores for variables of income and education. %WLM= Percent of weight loss maintained, BMI=body mass index, IGT=Iowa Gambling Task, BRIEF= Behavior Rating Inventory of Executive Functioning.
[a]Mean %WLM of 12.77 = participants kept off approximately 13% on average of the total weight they lost in their lifetime.
[b]Mean BMI of 32.21 = classified as obesity on the BMI index.
[c]Mean income of 5.82 = between $50-$70,000/year.
[d]Mean education of 3.93 = greater than high school education.

Table 2

Spearman's Correlations between EF, SES, and Weight Variables (N = 44)

	1	2	3	4	5	6	7	8
1. %WLM	–							
2. Income	.12	–						
3. Education	.05	.36*	–					
4. SES	.08	.83**	.79**	–				
5. BRIEF	-.01	.18	-.22	-.03	–			
6. IGT	.25	.19	.11	.16	-.04	–		
7. BMI	-.41**	-.15	-.12	-.14	-.01	-.34*	–	
9. #Years Maintained	-.24	.01	.16	.06	-.24	.25	-.09	–

Note. * $p < .05$; ** $p < .01$

Table 3

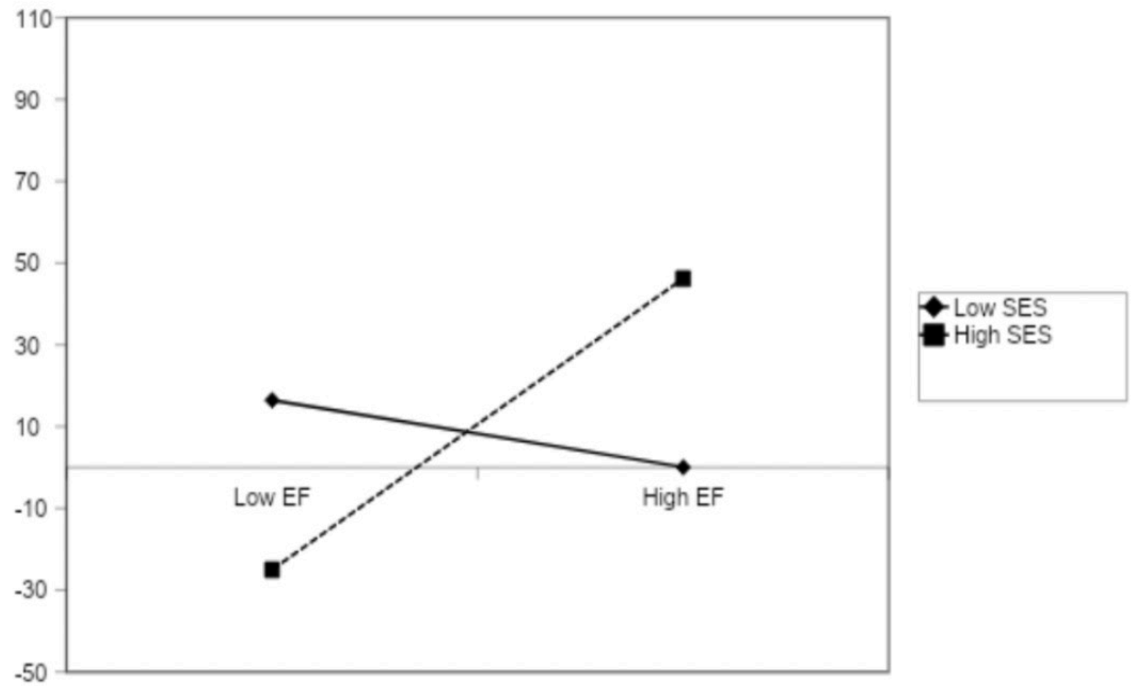
Summary of Hierarchical Multiple Regression Analyses of BMI, EF, and SES as Predictors of %WLM (N = 44)

	IGT (Performance-based)		BRIEF (Self-reported)	
Variable	β	ΔR^2	β	ΔR^2
Step 1		.138*		.38*
BMI	-.37*		-.37*	
Step 2		.017		.007
BMI	-.32*		-.38*	
SES	.02		.04	
EF	.14		.08	
Step 3		.087*		.001
BMI	-.25		-.38*	
SES	.02		.03	
EF	.20		.08	
EFxSES	.31*		.03	

Note. **p* < .05.

Figure 1

Interaction Effect Between Performance-based EF and SES on % Weight Loss Maintenance (N = 44)



Note. Performance-based EF significantly interacted with SES in predicting %WLM.