

The relationship of weight suppression to treatment outcomes during behavioral weight loss

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Abstract Many adults enter behavioral weight loss (BWL) programs at a weight below their highest lifetime weight. The discrepancy between highest lifetime weight and current weight is known as weight suppression (WS). Research has yet to characterize WS during BWL or investigate its relation to weight loss outcomes or treatment acceptability. Adults (N = 272) in a 12-month BWL program were assessed. WS was calculated by subtracting measured baseline weight from self-reported highest lifetime weight. Participants with higher WS lost significantly less weight than those with lower WS during treatment, although they still had clinically meaningful weight losses (e.g., participants with WS above the median: 7.8 kg; participants with WS below the median: 12.0 kg). WS was unrelated to weight losses at 24-month follow-up. Controlling for weight loss, treatment acceptability was unrelated to WS. BWL appears appropriate for those with high WS, but future research should aim to improve outcomes in this group.

Keywords Weight suppression · Behavioral weight loss · Treatment · Obesity · Treatment acceptability

Introduction

Most adults with overweight or obese body mass indexes (BMIs) who initiate a weight loss attempt rely on behavioral approaches, including self-directed lifestyle modification (i.e., changes to diet and exercise) or formal behavioral weight loss (BWL) programs (Ciao et al., 2012; Santos et al., 2017). Behavioral approaches typically yield clinically significant but modest weight losses (Christian et al., 2010; Tang et al., 2016), and the majority of individuals remain in the overweight or obese range following these attempts (Wadden et al., 2004). Because adults with overweight or obese BMIs tend to have ambitious weight loss goals (Foster et al., 1997; O’Neil et al., 2000), and because some amount of weight regain is common following a loss (Dombrowski et al., 2014), many may initiate subsequent weight loss attempts even if they are maintaining a weight loss. Indeed, research suggests that adults with overweight or obese BMIs engage in several weight loss attempts during their lifetime (Marchesini et al., 2004). Thus, it is possible that a meaningful proportion of individuals enter a BWL program at a weight that is lower than their highest lifetime weight. The discrepancy between one’s highest lifetime weight and current weight is referred to as weight suppression (WS). Research has yet to characterize WS in a BWL sample or to examine its relation to key treatment outcomes, like weight change, treatment acceptability, or engagement. However, in non-BWL samples, including in healthy individuals and those with eating disorders, WS has been shown to be a robust predictor of weight gain (Berner et al., 2013; Carter et al., 2015; Lowe et al., 2006).

Although approximately 20% of adults who have lost weight behaviorally successfully maintain a significant weight loss (Wing & Phelan, 2005), previous studies sug-

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gest that there is a strong propensity towards weight regain (Dombrowski et al., 2014). Prior research suggests that this propensity may depend on the amount of weight that an individual has lost during a discrete attempt. That is, individuals who lose a greater amount of weight during a BWL attempt may regain a greater amount of weight afterwards (McGuire et al., 1999), although their net weight loss may still be greater than those who lost less weight initially (Barte et al., 2010). These findings support the concept that there is a tendency to regain towards previously achieved weights. Further supporting this concept, one study found a .96 correlation between initial BMI and BMI 3 years later in adults who had lost a modest amount of weight through dietary changes, indicating that weight change was strongly associated with initial weight (Ferrannini et al., 2014). While prior studies have focused on acute weight loss or proximal BMI as predictors of weight regain, it seems possible that the discrepancy between highest historical weight and current weight (i.e., WS) may similarly predict weight loss maintenance. That is, just as individuals with a higher acute weight loss may experience greater amounts of weight regain, those with higher WS may be at greater risk for weight regain. In the context of a BWL program, higher levels of WS may make additional weight loss increasingly difficult, and weight regain increasingly likely, but research has yet to examine these questions.

While the mechanisms contributing to weight regain are not fully understood, individual biological, psychological, and behavioral factors appear to make maintaining a weight loss challenging. Recent research has demonstrated that biological processes, including thermogenic adaptation to lost weight, may heighten the risk for weight regain (Ochner et al., 2013). Adaptive thermogenesis promotes conservation of energy and subsequently may contribute to return to previous weights through a decrease in resting metabolic rate, which occurs in response to weight loss (Müller et al., 2016). Additional biological adaptations such as changes to appetitive hormones (e.g., decreases in leptin and increases in ghrelin) simultaneously promote weight regain following a loss (Evert & Franz, 2017). Prior studies have also documented psychological changes following a weight loss that may increase the risk of weight regain, including increased cravings for highly palatable, energy-dense foods (Gilhooly et al., 2007). Finally, as individuals attempt to maintain the eating and physical activity behaviors that help prevent weight regain, they may experience behavioral fatigue, which could contribute to weight regain (Smith & Wing, 1991). Thus, individuals with high levels of WS, who are presumably experiencing counter-regulatory processes that make weight loss maintenance challenging, may have particular difficulty losing additional weight during a BWL program. Moreover, on

average, adults lose 10% of their pre-treatment body weight in BWL programs; while some lose more, many individuals experience a weight loss plateau after this point (Franz et al., 2007). It is unclear whether the ability to achieve a 10% weight loss resets each time an individual initiates a BWL attempt, or if amount of weight already lost (i.e., WS) influences the point at which a weight loss plateau begins to occur. If so, individuals with higher levels of WS, who are by definition closer to a lifetime 10% weight loss, may lose less weight than those entering a BWL program with lower levels of WS.

Although it seems probable that those with higher levels of WS will experience a smaller acute weight loss during BWL, it is unclear if their WS at end of treatment (the discrepancy between highest lifetime weight and end of treatment weight) will remain larger than that of individuals who enter treatment with lower WS. On one hand, individuals with high baseline WS enter treatment with a greater weight discrepancy, which may make maintaining a larger discrepancy post-treatment more likely; on the other hand, if they lose less weight in the intervention, those with low baseline WS could “catch up” and conclude treatment with a similar lifetime discrepancy. Understanding how WS relates to both acute weight loss during a BWL attempt and overall discrepancy between highest lifetime weight and end of treatment weight will help elucidate the clinical implications associated with pre-treatment WS.

In addition to weight change, other treatment outcomes, like acceptability and engagement, may vary by level of WS. Individuals who enter BWL with higher levels of WS have presumably learned and been utilizing behavioral skills that allowed them to successfully lose weight and maintain a loss for some period of time (Wing & Hill, 2001). It is possible that their ability to lose weight and maintain some amount of weight loss indicates that they are well-suited for BWL treatment and that they may find it highly acceptable and remain engaged. On the other hand, if these individuals have already developed many of the skills that are taught during BWL programs, they may experience less novelty than those for whom behavioral strategies are newer. In turn, they may feel less satisfied with treatment, and may disengage. Additionally, although some research suggests that individuals who have previously lost weight have more realistic expectations for a secondary weight loss attempt (Fabricatore et al., 2008), data has typically shown significant disparities between expectations and realities regarding weight losses (Foster et al., 2001, 1997). Having unrealistic expectations may lead to dissatisfaction within a BWL program, and has been shown to predict treatment dropout (Sasdeh et al., 2018). If those with higher levels of WS indeed lose less weight, as hypothesized, they may be at greater risk for dissatisfaction and diminishing engagement.

This study, which is the first to our knowledge to examine WS and its relation to outcomes during a BWL program, fills an important gap in the literature because research on potential predictors of BWL outcomes are needed to improve treatment efficacy (Jensen et al., 2014). A preliminary aim of the current study is to characterize the distribution of WS in a BWL sample, with the hypothesis that WS will be relatively common. The primary aim of this study is to examine the relationship between WS and weight loss outcomes in a BWL sample; we hypothesize that those with higher baseline WS will lose less weight over the course of the intervention and follow-up period. A secondary aim is to examine the relationship between WS and treatment acceptability and engagement, with the hypothesis that greater WS will predict poorer treatment acceptability and engagement. Finally, although we are primarily interested in pre-treatment WS, it is important to acknowledge that an individual's WS is a dynamic value that will change over the course of BWL if the individual loses weight. Thus, we also seek to explore the relationship between baseline WS and WS at end of treatment and follow-up (i.e., the discrepancies between highest lifetime weight and weight at end of treatment and follow-up). The purpose of these exploratory analyses is to investigate whether individuals who enter treatment with a high level of WS conclude treatment with a larger discrepancy between highest lifetime weight and post-treatment weight compared to those with low baseline WS. An additional exploratory aim is to investigate the effect of end of treatment WS on maintenance of weight loss achieved during treatment, as it is possible that, given the dynamic nature of WS, end of treatment WS (a more proximal measure than baseline WS) may be a better predictor of weight loss maintenance.

Method

Participants

The current study was a secondary analysis from a large BWL study (Butryn et al., 2017). For the parent study, 283 participants were recruited from the community using print, online, and radio advertisements. To meet eligibility criteria for the parent study, participants were required to be between 18 and 70 years of age, have a BMI of 27–45 kg/m², and be able to engage in physical activity. Individuals were ineligible if they had lost more than 5% of their body weight within the last 6 months, recently changed medications that could impact appetite or body weight, had a medical (e.g., cancer) or psychiatric condition (e.g., schizophrenia) that could pose risk for participation or interfere with adherence to treatment recommendations, or were pregnant or planning to become pregnant during the study timeframe. All partic-

ipants provided written informed consent. The study was approved by Drexel University's Institutional Review Board.

Procedure

Participants in the parent study were randomized to one of three group-based BWL conditions. Conditions were identical in terms of treatment contact (i.e., 26, 75-min sessions in groups of 10–15 participants) but varied in terms of the skills emphasized. One condition was a standard behavioral treatment condition, one condition emphasized making changes to the home food and exercise environment, and the third condition emphasized changing the home food and exercise environment using an acceptance-based framework (see Butryn et al., 2017 for additional details). The interventions consisted of 6 months of BWL treatment (4 months of weekly and 2 months of bi-weekly groups) immediately followed by 6 months of weight loss maintenance treatment (monthly groups). All conditions included core behavioral skills adapted from the Look AHEAD manual (2006) and the Diabetes Prevention Program (1999) including self-monitoring, regular weighing, reducing calorie intake based on standard calorie deficit guidelines, and adhering to an exercise prescription.

Participants completed in-person research assessments at baseline (0 months), 6-months, 12-months (end of treatment), and 24-months (follow-up).

Measures

Demographics

Participants completed a self-report demographics questionnaire including age, sex, and race at baseline.

Height and weight

Height and weight were measured with a Seca[®] scale (sensitive to .1 kg) and built-in stadiometer (rounded to the nearest quarter inch) in duplicate by study staff with participants in light street clothing. Weight was measured at baseline, end of treatment, and follow-up. Height was taken at baseline to calculate BMI.

Highest lifetime weight

Participants reported their highest adult weight (excluding pregnancy) since age 21 on the Weight and Lifestyle Inventory (WALI; Wadden & Foster, 2006). Weight was reported in pounds and converted to kilograms for data analysis. Previous research suggests recall of historical weights is generally accurate and independent of the pas-

sage of time (Casey et al., 1991; de Fine Olivarius et al., 1997).

Weight suppression (WS)

Per a commonly accepted definition of WS (Lowe, 1993), baseline WS was calculated by subtracting objectively measured baseline weight from self-reported highest adult weight. As originally conceptualized in the literature by Lowe (1993), WS cannot have a negative value; it must be a positive number (indicating that an individual is currently below his/her highest weight) or 0 (indicating that an individual is currently at his/her highest weight). For 77 of the 283 participants in the parent study, this calculation produced a negative baseline WS value, indicating that participants reported their highest adult weight as lower than their current measured weight. Consistent with prior studies of WS, negative values were recoded to zero (i.e., baseline weight was assumed to be highest adult weight) (Herzog et al., 2010; Stice et al., 2011). This method accounts for negative weight suppression values that are due to normal weight fluctuation, scale discrepancies, and those that are due to individuals misinterpreting the question and reporting on their highest lifetime weight *besides* their current weight. Additionally, because we compared self-reported highest weight with measured current weight, those who were near their highest ever weight sometimes had negative weight suppression values. Notably, 54.55% ($n = 42$ of 77) of negative WS values fell within 2 kg from 0, a range that is consistent with normal diurnal weight fluctuation (Lohman et al., 1988). As previously mentioned, individuals were excluded from the parent study if they had lost more than 5% of their body weight in the 6 months before treatment. Thus, baseline WS levels had been relatively stable for a minimum of 6 month at the time of assessment.

End of treatment WS was calculated for exploratory analyses by summing baseline WS and treatment weight loss at end of treatment. Negative values (which indicated that participants gained weight during treatment, such that their end of treatment weight exceeded their previous highest adult weight) occurred for 9 participants, and were recoded to zero to indicate no WS at end of treatment.

Treatment acceptability and engagement

Perceived treatment effectiveness and treatment satisfaction were each assessed at end of treatment using two single-item self-report questions (“How effective was this program in helping you lose weight?” and “How satisfied were you with the approach we used to help you lose weight?”) on 5-pt Likert scales (e.g., 1 = not at all effective, 5 = very effective) with higher scores indicating

greater treatment acceptability. Session attendance, a proxy for treatment engagement, was collected by clinicians at each session and summed at the end of treatment to determine total number of sessions attended.

Statistical analysis plan

Analyses were conducted using SPSS v. 24 (IBM Corp., 2016) and in RStudio (RStudio Team, 2015). Alpha levels were set at the .05 level. For some analyses, to aid in interpretation of findings and further illustrate the relationship between WS and outcome, baseline WS (originally a continuous variable) was recoded to a categorical variable with two levels, such that those falling above the median WS value (i.e., 2.04 kg or 4.50 lbs) were considered to have “high WS” and those falling at or below the median value were considered to have “low WS.” Of note, these categorical analyses were intended to supplement the primary continuous analyses. Preliminary analyses (Pearson bivariate correlations and independent samples t-tests) assessed for differences in baseline WS (as a continuous variable) by demographic characteristics (age, race, and sex) and treatment condition so that subsequent analyses could control for possible confounding variables; these continuous analyses were also run with categorical WS for illustrative purposes.

Primary outcomes were: (1) weight loss from baseline to end of treatment and follow-up, and (2) treatment acceptability and engagement. Outcomes for exploratory analyses were: (1) discrepancy between highest lifetime weight and weight at end of treatment and follow-up (i.e., end of treatment and follow-up WS), and (2) weight loss maintenance from end of treatment to follow up. Relationships between baseline or end of treatment WS and outcome variables were examined using OLS regressions or Pearson bivariate correlations. Supplemental analyses meant to illustrate our continuous findings investigated differences between participants with high versus low baseline WS utilizing ANCOVAs.

Because baseline BMI is a reliable predictor of weight loss (Teixeira et al., 2005), we tested this relationship in our sample and observed a significant relationship, $r(270) = -.24$, $p < .001$; thus, baseline BMI was controlled for in both continuous and categorical analyses predicting weight loss at end of treatment and follow-up. In the exploratory analysis predicting weight loss at follow-up from end of treatment WS, BMI at end of treatment was included as a covariate given that it was significantly related to weight loss during this time frame, $r(270) = -.35$, $p < .001$. In analyses examining treatment acceptability as the outcome variable, weight loss at end of treatment was controlled for, as weight loss outcome was related to perceived treatment effectiveness, $r(195) = -.46$, $p < .001$,

and treatment satisfaction, $r(194) = -.75, p < .001$, in our sample, consistent with prior research (Foster et al., 1997; Gorin et al., 2007).

Only individuals with available, valid WS data were included in analyses; of the 283 individuals in the parent study, 11 did not report on highest lifetime weight. Thus, 272 individuals had valid WS data and were included in data analyses for this study. At end of treatment (12-months) 17.65% of participants with valid WS data ($n = 48$) had missing research assessment weights; at follow-up (24-months), 24.63% ($n = 67$) had missing research assessment weights. Consistent with prior research and recent recommendations for handling missing weight data in obesity studies (Batterham et al., 2013; Elobeid et al., 2009; Gadbury et al., 2003), multiple imputation, which has been found to reduce bias and provide conservative estimates of weight outcomes (Li et al., 2015), was utilized. Multiple imputation was performed in SPSS using MCMC algorithms known as chained equations imputation (Yuan, 2010). Rubin's rules were used to combine results from multiply imputed data. Pooled test statistics for ANCOVAs were calculated in R Studio using the miceadds package (Robitzsch et al., 2018), which uses a combination of Chi Square statistics for multiply imputed datasets. Analyses were also run without multiple imputation and patterns remained largely similar; thus, consistent with recommendations, we present results from multiply imputed data. Acceptability ratings were available for 197 participants; due to the nature of the measure, missing data were not imputed and analyses included only those with available data. There were no missing attendance data. Data were inspected for assumptions of normality. One outlier was identified on the WS variable ($WS = 55.34$ kg), and analyses were conducted with and without this individual's data. As the pattern of results did not differ, the analyses presented here include the outlier so as not to exclude any clinically relevant values. Baseline and end of treatment WS were square-root transformed to correct for positive skewness.

Results

Participant characteristics and baseline WS

Participants had an average baseline BMI of 35.16 ($SD = 4.94$) and an average WS of 4.26 kg ($SD = 6.42$, range 0–55.34 kg). The distribution of WS values was positively skewed due to zero-inflation, as 79 participants (29.0%) entered the study at their highest lifetime weight. The sample was split based on the WS median (2.04 kg): 49.6% ($n = 135$) of the sample had a WS above the median (defined as the “high WS group”), and 50.4% ($n = 137$) fell below the median (“low WS group”). Baseline WS was

unrelated to age, $r(268) = .03, p = .65$, baseline BMI $r(270) = -.01, p = .85$, sex, $t(270) = -1.23, p = .22$, or race, $t(270) = -1.12, p = .26$. Demographic data are presented in Table 1 by categorical WS (high vs. low) for illustrative purposes. There were no significant differences in baseline WS by treatment condition ($F(2, 269) = 2.25, p = .11$) and, as reported elsewhere (Butryn et al., 2017), weight losses did not differ by condition; as such, the three treatment conditions were combined for all analyses.

Weight loss outcomes

OLS regressions were conducted to determine the effect of baseline WS on weight loss at end of treatment and at follow up. Controlling for baseline BMI, WS was a significant predictor of end of treatment weight loss, $F(2, 269) = 12.923, p < .001, b = 1.24, SE = .41, t(269) = 3.04, p = .002, sr^2 = .03$, such that greater WS predicted less weight loss in treatment. This pattern did not hold for follow-up weight loss: when controlling for baseline BMI, WS did not significantly predict follow-up weight loss, $F(2, 269) = 16.195, p < .001, b = .46, SE = .46, t(269) = 1.00, p = .31, sr^2 = .003$. One-way ANCOVAs comparing end of treatment and follow-up weight change by high and low WS categories, controlling for baseline BMI, were conducted to illustrate the observed relationships and corroborated these findings (see Table 2, Fig. 1).

Treatment acceptability and engagement

OLS regressions were conducted to determine whether baseline WS predicted treatment satisfaction and perceived treatment effectiveness. When WS was the only predictor entered into the model, higher baseline WS predicted lower perceived treatment effectiveness, $F(1, 195) = 3.87, p = .05, b = -.10, SE = .05, t(195) = -1.97, p = .049, sr^2 = .02$, but not poorer treatment satisfaction, $F(1, 194) = 1.76, p = .19, b = -.06, SE = .05, t(195) = -1.33, p = .12, sr^2 = .01$. When end of treatment weight loss was entered into the model as a control variable, end of treatment weight loss, but not WS, was a significant predictor of perceived treatment effectiveness ($F(2, 194) = 49.60, p < .001$; end of treatment weight loss: $b = -.07, SE = .01, t(194) = -9.65, p < .001, sr^2 = .32$; WS: $b = -.03, SE = .04, t(195) = -.65, p = .52, sr^2 = .001$) and treatment satisfaction ($F(2, 193) = 25.90, p < .001$; end of treatment weight loss: $b = -.05, SE = .01, t(193) = -7.03, p < .001, sr^2 = .20$; WS: $b = -.01, SE = .01, t(193) = -.23, p = .82, sr^2 = .0002$). Table 2 presents the findings controlling for end of treatment weight loss categorically, using ANCOVAs to supplement continuous analyses.

Table 1 Sample baseline characteristics

	Descriptive statistics: <i>M</i> (SD)			Significance test of low versus high WS	<i>p</i> value
	Total (<i>N</i> = 272)	Low WS (\leq 2.04 kg) (<i>n</i> = 137)	High WS ($>$ 2.04 kg) (<i>n</i> = 135)		
BMI (kg/m ²)	35.15 (4.94)	35.20 (4.87)	35.12 (5.03)	<i>t</i> (270) = .14	.89
Age (years)	53.15 (9.69)	52.32 (9.43)	54.00 (9.90)	<i>t</i> (268) = 1.43	.16
% Female	79.0%	76.6%	81.5%	χ^2 (1, <i>N</i> = 270) = .96	.37
% White	67.5%	70.8%	63.7%	χ^2 (1, <i>N</i> = 270) = 1.56	.25

WS weight suppression; the high and low WS groups did not significantly differ on BMI, age, sex, or race

Table 2 Differences in outcome variables by baseline weight suppression (WS)

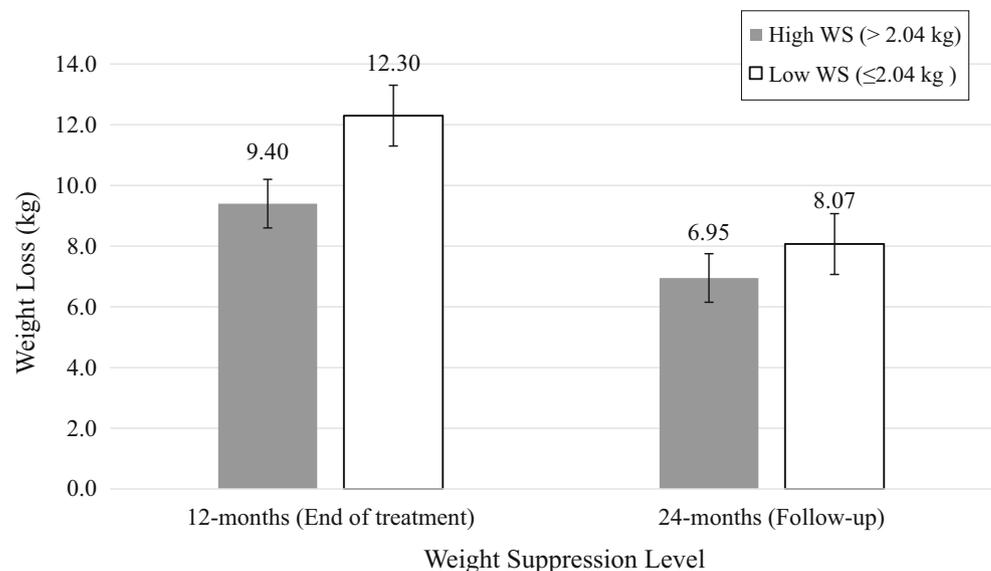
Weight outcomes (kg)	Low WS (\leq 2.04 kg) (<i>n</i> = 137) <i>M</i> (SE)	High WS ($>$ 2.04 kg) (<i>n</i> = 135) <i>M</i> (SE)	ANOVA statistics		
			<i>df</i>	<i>F</i>	<i>p</i> value
End of treatment weight loss ^a	12.30 (.81)	9.40 (.81)	1269	6.45	.01
Follow-up weight loss ^a	8.07 (.90)	6.95 (.91)	1269	.72	.40
Difference between highest lifetime weight and end of treatment weight	12.75 (.83)	17.53 (.99)	1270	13.61	<.001
Difference between highest lifetime weight and follow-up weight	8.10 (.97)	15.08 (1.11)	1270	19.27	<.001
Treatment acceptability					
Treatment satisfaction ^b	4.38 (.08)	4.40 (.08)	1193	.03	.86
Treatment effectiveness ^b	4.37 (.08)	4.30 (.09)	1194	.40	.53

WS weight suppression

^aANCOVAs comparing end of treatment weight loss and follow-up weight loss in individuals with low versus high WS controlled for baseline body mass index. Means and standard errors are adjusted for baseline body mass index

^bANCOVAs comparing treatment satisfaction and effectiveness in individuals with low versus high WS controlled for end of treatment weight loss. Means and standard errors are adjusted for end of treatment weight loss

Fig. 1 Means and standard errors for weight loss at end of treatment (12-months) and follow-up (24-months), adjusted for body mass index at baseline, for those with high versus low baseline weight suppression based on median-split



A Pearson bivariate correlation was also conducted to determine whether baseline WS was related to attendance at group sessions, a proxy for treatment engagement. There

was no correlation between baseline WS and session attendance, $r(271) = -.07$, $p = .24$.

Discrepancy between highest lifetime weight and post-treatment weights

OLS bivariate regressions were conducted to determine how well baseline WS predicted (1) the discrepancy between highest lifetime weight and end of treatment weight (i.e., WS at end of treatment), and (2) the discrepancy between highest lifetime weight and follow-up weight (i.e., WS at follow-up). Both regressions were significant and indicated that for those with higher baseline WS, there was a greater difference between highest lifetime weight and weights at end of treatment, $F(1, 270) = 43.91$, $p < .001$, $b = 2.94$, $SE = .44$, $t(270) = 6.69$, $p < .001$, $sr^2 = .14$, and follow-up, $F(1, 270) = 53.31$, $p < .001$, $b = 3.70$, $SE = .50$, $t(270) = 7.37$, $p < .001$, $sr^2 = .17$. Table 2 presents these findings categorically for illustrative purposes, using ANOVAs.

Weight maintenance outcomes

As an exploratory aim, an OLS regression was also conducted to determine the relation of end of treatment WS to weight regain from end of treatment to follow-up. Controlling for end of treatment BMI, end of treatment WS was a significant predictor of weight regain, $F(2, 269) = 20.127$, $p < .001$, $b = .77$, $SE = .38$, $t(269) = 2.02$, $p = .04$, $sr^2 = .02$, such that greater end of treatment WS predicted greater weight regain between end of treatment and follow-up.

Discussion

This study aimed to characterize WS in a sample of adults entering a BWL program and to examine the relation of baseline WS to: (1) end of treatment weight loss, and (2) treatment acceptability and engagement. Exploratory aims included examination of: (1) the relation of baseline WS to WS at end of treatment and follow-up to determine whether individuals who enter treatment with a high discrepancy between highest lifetime weight and current weight continue to maintain a higher discrepancy at post-treatment than those with low WS, and (2) the relation of WS at end of treatment to maintenance of weight loss at follow-up. To our knowledge, this is the first study to examine the relationship of WS to outcomes in the context of BWL. Given the need to identify predictors of suboptimal outcome in BWL programs to inform future intervention development research, this study fills an important gap in the literature.

The majority of individuals in this sample entered treatment with a low level of WS (i.e., less than 3 kg), and approximately 30% reported that they were at their highest

lifetime weight at treatment start. However, over one-third of participants entered treatment with WS of greater than 5 kg, and the highest WS was over 50 kg, demonstrating the wide variability in the sample. On average, individuals with high baseline WS in this BWL sample achieved a clinically meaningful weight loss during treatment (i.e., approximately 9 kg), although it was smaller than the average weight loss of those with low baseline WS (approximately 12 kg). Thus, BWL may be beneficial for individuals with higher levels of WS, both for additional weight loss and to prevent the regain of weight lost prior to treatment start. The fact that these individuals enter treatment already maintaining a weight loss may be evidence that they are well positioned to continue to maintain a weight loss and even lose more weight, as they have already had to manage counter-regulatory drives that push them towards weight regain. Nonetheless, higher WS was associated with smaller weight losses at end of treatment, even after controlling for baseline BMI, as hypothesized. Specifically, by end of treatment, participants with low WS had lost approximately 3 kg more than participants with high WS, an amount that is both clinically and statistically significant. This finding is consistent with the growing body of literature demonstrating the propensity to regain towards previously achieved higher weights (Dombrowski et al., 2014), and suggests that individuals entering a BWL program with high WS may achieve less weight loss than is typically expected during BWL.

One possible explanation for this tendency towards weight regain is the biological changes that occur in the body after a weight loss. These include a slowed metabolic rate, changes in appetitive hormones such as leptin, and increased food cravings; together, these change work to promote weight regain (Gilhooly et al., 2007; Müller et al., 2016; Ochner et al., 2013). Striking evidence in support of the metabolic hypothesis came from a study of 16 individuals who were studied while participating in a televised weight loss competition: after 30 weeks, participants had lost an average of 57.6 kg and exhibited an average resting metabolic rate decrease of 789 kcal/day from their baseline measurement (Johannsen et al., 2012). Although a reduction in metabolic rate was certainly intuitive and expected given the rapid and extreme decrease in body mass, the unexpected result was that this slowing in metabolism was significantly greater than the metabolic values predicted based on participants' weight losses and body compositions. The 30-week resting metabolic rate was predicted to be only 286 kcal per day lower compared to baseline; the striking difference between the observed and expected values shows that participants experienced a significant metabolic adaptation in response to their weight loss. Notably, a follow-up study of these individuals indicated that 6 years later, participants had regained the majority of

their lost weight and yet maintained an extreme metabolic adaptation of -499 kcal/day from their starting metabolic rate (Fothergill et al., 2016). Taken together, these two studies suggest that the slowed metabolism and persistent metabolic adaptation that individuals with high WS experience compared to individuals of similar body weights and body compositions with low WS may help explain the smaller weight losses the WS group in our study experienced.

Despite the reduced weight losses in participants with high WS, the exploratory analyses examining the relation of baseline WS to WS at end of treatment and follow-up further support the notion that BWL may still be of clinical utility to those with high baseline WS. Specifically, baseline WS was positively related to WS at end of treatment and follow-up such that participants who began treatment with higher WS also had a higher overall WS at end of treatment and follow-up compared to those with lower baseline WS. In other words, these participants maintained greater discrepancies between their highest lifetime weight and post-treatment weights than those with lower baseline WS by approximately 5 kg at end of treatment and 7 kg at follow-up. Thus, while individuals who enter BWL with higher WS lose less weight over the course of the acute treatment period, they appear to continue to successfully maintain a large overall weight discrepancy from their highest weight to post-treatment weights.

Baseline WS did not significantly predict weight loss at follow-up, possibly because WS values changed as a result of weight losses during treatment. That is, baseline WS may have become less predictive as participants lost varying amounts of weight during treatment, thus shifting their WS value. This possibility is supported by the exploratory aim that found that WS at end of treatment (i.e., the discrepancy between highest lifetime weight and weight at end of treatment) was a significant predictor of weight regain between end of treatment and follow-up. Thus, the relation of WS to weight outcome appears to shift as weight changes during treatment. Additionally, the observed relationship between WS and weight change is consistent with a substantial body of literature in other populations, including in patients with eating disorders and healthy college students, showing that WS is a robust predictor of weight gain (Herzog et al., 2010; Lowe et al., 2006; Witt et al., 2014). Our results highlight the importance of thoughtful calculation and timing of the measurement of WS to account for the dynamic nature of this variable. Additionally, while this study suggests that WS is a meaningful predictor of outcome during BWL, clinicians and researchers should certainly still attend to other well-established predictors of weight loss outcome, particularly those that can be measured objectively (e.g., baseline

BMI), during case conceptualization and treatment development and planning.

This study also found that higher levels of WS were associated with poorer perceived treatment efficacy, although this relationship was no longer significant when controlling for weight loss during treatment (which was a significant predictor of perceived treatment efficacy). WS was unrelated to treatment satisfaction. These findings suggest that, while WS itself may not predict poorer treatment acceptability, individuals with high levels of WS tend to lose less weight in treatment, which in turn may result in a sense that treatment is not effective. Additionally, it is possible that individuals with high baseline WS, who have successfully lost and kept off a substantial amount of weight prior to treatment, have previously learned and are regularly practicing the effective weight control strategies taught within the group intervention. Indeed, previous studies find that individuals who are successfully maintaining a weight loss tend to practice many of the behaviors recommended during BWL treatment, including engaging in a high level of physical activity, eating a low-calorie diet, and self-monitoring weight (Wing & Phelan, 2005). Thus, participants with high baseline WS may experience less novelty and benefit from the skills taught during a standard BWL program, and may, therefore, report lower levels of treatment acceptability. However, it is crucial to note that although high WS resulted in lower perceived treatment effectiveness, the mean rating was still in the acceptable range, and there was no relation between WS and treatment satisfaction. Thus, individuals with high WS still appear to experience clinically significant benefits and enjoyment from treatment.

To further improve acceptability ratings, bolster treatment engagement, and improve weight loss outcomes, future research could test the efficacy of tailoring treatment based on an individual's baseline WS. Baseline WS varied considerably within this study's sample, ranging from 0 kg to greater than 50 kg. Individuals entering treatment with high levels of WS may need to adopt different expectations for their weight loss trajectory than those entering with low levels of WS. Setting realistic expectations may be particularly important given our finding that individuals with high WS report lower perceived treatment effectiveness, seemingly because of their reduced weight losses. Additionally, prior research suggests that individuals who end BWL treatment at a weight that they had previously categorized as "disappointing" or higher than their "acceptable" end-weight are at greater risk of attrition (Dalle Grave et al., 2015), demonstrating the potential importance of cultivating reasonable weight loss expectations in participants with high WS. While WS was not related to session attendance (a proxy for engagement) in our sample, future research should continue to explore this possibility

using other markers of engagement, for example completion of food records, which have been found to predict outcome (Rosenbaum et al., 2018).

Future research also could determine if individuals entering a program with high levels of WS may benefit from specialized skills and training that specifically address their biobehavioral drive towards weight regain, which may improve both weight loss outcomes and treatment satisfaction. For example, we recommend that treatment providers complete a thorough weight history assessment that includes assessment of an individual's current level of WS. Participants with high WS may need additional psychoeducation about their propensity towards weight regain, discussion with their treatment provider to set realistic, personalized weight loss goals that take into account their WS, and creative adaptation of their existing weight loss skills to fight this biobehavioral drive. These adaptations could include an emphasis on acceptance-based strategies to promote willingness to utilize behavioral weight control skills even in if their drive towards weight gain produces physiological sensations (e.g., increased hunger or cravings) that make adherence challenging. Research has shown that acceptance-based strategies show promise in facilitating weight loss (Forman et al., 2013) and weight loss maintenance (Lillis et al., 2016), and these additional skills may be particularly well-suited to weight suppressed individuals.

In addition to the clinical implications provided by study results, the findings also have methodological implications for future BWL trials, and suggest areas for future research. Specifically, given the variability in baseline WS and its relation to treatment outcome, investigators may want to assess for baseline WS at the start of BWL trials and consider stratifying by or retroactively controlling for this variable in outcome analyses. Future research might investigate whether there is a cut-point at which high WS prevents an individual from losing a meaningful amount of weight during BWL, and, if so, whether these individuals may benefit from interventions specifically designed to help them continue to maintain their weight losses rather than lose additional weight. Future research should also consider whether additional factors, like amount of time spent at previously achieved highest lifetime weight, time since reaching highest lifetime, or experiencing large weight losses in the past but then regaining that weight, influence the relation of WS to BWL outcomes.

This study had several strengths, including use of a relatively large sample of adults receiving BWL treatment, measurement of outcomes at several time points, and examination of multiple outcome variables. Limitations included the use of self-reported highest lifetime weight

and the skewness of our sample due to many individuals entering the trial at their highest lifetime weight, issues with which prior studies of WS have also had to contend (Herzog et al., 2010; Stice et al., 2011). Although prior research suggests that recall of previous weights is generally accurate and uninfluenced by the passage of time (Casey et al., 1991), this particular sample's accuracy at reporting highest lifetime is unknown; the fact that 28.30% of the sample reported a highest lifetime weight below their current weight may suggest inaccuracy in reporting, and indicates that future research should utilize verified weights (e.g., from doctor's visits) to examine WS during BWL. The current results should be interpreted cautiously given the limits of self-report data, and the fact that a large percentage of individuals reported a highest lifetime weight below their current measured weight, which necessitated data recoding and data transformations due to a zero-inflated distribution. Nonetheless, it is notable that over half of the negative WS values fell within 2 kg from 0, and may not indicate inaccuracy in reporting, particularly given that daily weight fluctuation tends to be greater in individuals with higher BMIs (Truesdale et al., 2006). The sample was also largely white and female, which indicates that future research in diverse samples should be conducted. Additionally, individuals who had lost more than 5% of their weight in the six months prior to treatment start were excluded and, while this allowed us to examine individuals whose level of WS (or lack thereof) had been relatively stable for meaningful amount of time, it also leaves open questions about individuals who are on a weight loss trajectory upon entering a BWL program. Ultimately, despite limitations, the findings presented here warrant further research regarding the relation of WS to outcome in adults with overweight or obese BMIs undergoing BWL treatment in order to identify ways that current programs can be improved to better meet the needs of participants.

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Compliance with ethical standards

Conflict of interest Christine C. Call, Amani D. Piers, Emily P. Wyckoff, Michael R. Lowe, Evan M. Forman, and Meghan L. Butryn declare that they have no conflict of interest.

Human and animal rights and Informed consent 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 was obtained from all individual participants included in the study.

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