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REGULAR ARTICLE

Mediators of Weight Loss Maintenance in the Keep It Off Trial

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Abstract

Background An important step toward enhancing the efficacy of weight loss maintenance interventions is identifying the pathways through which successful interventions such as the Keep It Off trial have worked.

Purpose This study aimed to assess the viability of mediated relationships between the Keep It Off Guided intervention, conceptually and empirically grounded potential mediators, and weight. Repeated measurement of mediators and weight enabled documentation of the temporal ordering of intervention delivery and changes in mediators and in weight among participants randomized to the Guided intervention or Self-Directed comparison group.

Methods Total, direct, and indirect effects of the Guided intervention on weight change were calculated and tested for significance. Indirect effects were comprised of the influence of the intervention on three change scores for each mediator and the relationship between mediator changes and weight changes 6 months later.

Results Guided intervention participants regained about 2% less weight over 24 months than Self-Directed participants. Starting daily self-weighing accounted for the largest share of this difference, followed by not stopping self-weighing.

Conclusions Daily self-weighing mediated 24-month weight loss maintenance.

Trial Registration Number The trial is registered with ClinicalTrials.gov (Identifier: NCT00702455 www.clinicaltrials.gov/ct2/show/NCT00702455).

Keywords Weight loss maintenance · Behavioral intervention · Maintenance · Physical activity · Self-monitoring

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Introduction

Long-term weight loss maintenance remains a challenge for obesity treatment [1, 2]. Strategies to improve outcomes have included increasing treatment duration [3–5] and incorporating lessons learned (e.g., high physical activity levels) from the National Weight Control Registry [1, 6, 7]. Additionally, recent studies have focused on the optimal ways to engage people during the weight loss maintenance phase [8], including the development and evaluation of behavioral interventions exclusively for the maintenance phase [9–11].

Three randomized controlled trials evaluating maintenance-specific interventions showed a similar pattern of results. The Weight Loss Maintenance multi-site trial [8] randomized overweight or obese adults who had lost at least 4 kg during a 6-month weight loss program to one of three 30-month weight loss maintenance conditions: monthly personal contact, unlimited access to an interactive technology-based intervention, or a self-directed control condition. Participants in the personal contact group regained less weight than those in the self-directed group, but weight regain did not differ between the interactive technology-based and self-directed groups [8]. The STOP Regain trial tested the efficacy of a face-to-face program and an Internet-based program, compared with a newsletter control group, in preventing 18-month weight regain among participants who had lost a

minimum of 10% of their body weight and showed that the face-to-face group was the most promising [9]. The Keep It Off randomized trial also recruited participants after they had lost at least 10% of their body weight and showed that participants in the Guided phone- and mail-based intervention regained significantly less weight over 24 months compared to a brief, Self-Directed maintenance intervention [11]. Results of these trials were strikingly similar and suggest clinically meaningful but modest effects for maintenance interventions that include sustained intervention support.

Weight Loss Maintenance Mediators

An important step toward enhancing the efficacy of weight loss maintenance interventions is identifying the pathways through which successful interventions have worked. Although many studies have examined factors that are associated with weight change, such as intervention adherence [12, 13], and secondary outcomes of interventions including psychological factors such as depression, body image, and disinhibition [14, 15], few have conducted formal mediation analyses. Mediation analyses can inform intervention development and refinement in several ways including confirming that an intervention is having the intended effect on hypothesized mediators of change and in turn the outcome of interest. Mediation analyses can also elucidate areas of improvement for interventions [16].

Mediation analyses have been conducted to better understand behavior change mechanisms in the context of multiple types of health behavior change interventions, including physical activity [17–21], dietary intake [22, 23], and weight loss [24], with some research focused on mediators of weight loss maintenance [24]. For example, Teixeira and colleagues [24] evaluated whether self-regulation constructs were mediators of weight loss and 2-year weight loss maintenance in a large sample of overweight women. Results showed that lowering emotional eating and adopting a flexible dietary restraint pattern were critical for sustained weight loss. They also reported that exercise, intrinsic motivation, and self-efficacy were important mediators of long-term weight loss maintenance.

Keep It Off Mediators

The Keep It Off behavioral intervention was designed to help people who had recently lost at least 10% of their body weight maintain their weight loss over a 2-year period. The conceptual framework for the intervention was informed by several theoretical models including Rothman's Decision Criteria Maintenance Model [25], the Relapse Prevention Model [26], and state-of-the art weight-related behavioral interventions which promote self-regulation behaviors, such as self-monitoring, stimulus control, and problem solving. The following key strategies were promoted during the Keep It Off study: (1) taking part in 60 to 90 min of moderate-intensity physical activity each day; (2) regularly writing down weight, physical activity, and eating, preferably daily; (3) eating a diet moderate in calories; (4) eating breakfast every day; (5) enlisting social support; (6) not letting "lapses" turn into full "relapses"; and (7) appreciating progress made.

The goal of this manuscript is to identify factors that explain why Keep It Off Guided participants were more successful in maintaining their weight loss over the 2-year study period relative to Self-Directed participants. The conceptual framework of the intervention [27–29] and empirical literature on weight loss and maintenance guided the selection of mediators. The Keep It Off measurement protocol enabled a robust examination of mediators of weight loss maintenance. Potential mediators and weight were measured every 6 months for the 24-month post-randomization period so that short- or long-term changes, or relationships between them, would more likely be observed. Due to random assignment and repeated measurement of mediators and outcomes, it was possible to assert causality in the relationships between treatment group and change in mediators and identify patterns of results consistent with causal meditation among mediators that were related to weight. This mediation analysis has the potential to both identify behavioral targets that are most strongly related to weight and to shed light on areas where the intervention could be enhanced by focusing on behaviors that were related to weight change but not influenced by the intervention.

Method

Recruitment

We used multiple strategies to recruit eligible participants who intentionally lost at least 10% of their body weight during the past year. Adopting National Weight Control Registry [30] procedures, participants were asked to provide documentation to ensure the veracity of their self-reported weight loss. Additional eligibility criteria were as follows: 19 to 70 years old, previous year enrollment in the HealthPartners health plan, and BMI $\geq$20.5 kg/m^2. Exclusion criteria included anorexia nervosa history, bariatric surgery, modified Charlson [31] score $\geq$3, non-skin cancer, congestive heart failure, use of a phone-based weight loss program to achieve their recent weight loss, or current participation in another weight management study. Participants consented to study participation and provided baseline weight and questionnaire data at an in-person baseline visit prior to being randomized equally to the Keep It Off Guided or Self-Directed Intervention. The recruitment and enrollment processes are described in greater detail elsewhere [10, 11].

Intervention

The Self-Directed study arm included two phone coaching sessions that took place in the first month after randomization. Self-Directed participants received a 10-chapter Keep It Off course book with topics such as key weight loss maintenance behaviors, weight loss history, physical activity, menu planning, stimulus control, problem solving, overcoming barriers to physical activity and healthy eating, relapse prevention, and body image and weight goals. Participants also received a Keep It Off logbook to record their eating, physical activity, and weight for a month. During the two calls, participants reviewed the instructions for self-monitoring and the course book. Participants had no further contact with their phone coach.

The Guided study arm included 10 biweekly phone coaching sessions followed by eight monthly and six bimonthly calls and bimonthly weight graphs and letters beginning at month 8. Guided participants worked through the Keep It Off course book [10, 11] during the biweekly calls and then transitioned to the monthly and bimonthly call phase. Guided participants received Keep It Off logbooks and reported their weight weekly for the study duration either during scheduled calls, by email, or on the study website. Participants were not given specific calorie and fat goals but were encouraged to self-monitor dietary intake, calories, fat grams, and body weight to establish their optimal calorie range for weight maintenance. Participants were encouraged to work toward the goal of engaging in 60 to 90 min of moderate-to-vigorous physical activity, most days a week. Participants also received bimonthly feedback weight graphs and reports based on their weight loss maintenance progress. Accompanying each mailing was a small incentive for continuing participation. Finally, if participants showed a weight gain trend (i.e., 2 lb or greater) and did not have a call scheduled in the next 2 weeks, phone coaches emailed or called them to provide extra support to help reverse the weight gain. Participant reports of diet and activity were used to target which components of their weight maintenance plan appeared to be contributing to weight gain. An action plan was developed, and follow-up phone calls were scheduled as needed to help the participant stabilize their weight.

Keep It Off study protocols were reviewed and approved by the HealthPartners Institutional Review Board, and informed consent was obtained from all individual participants in the study. The trial is registered with ClinicalTrials.gov (Identifier: NCT00702455 http://www.clinicaltrials.gov/ct2/show/NCT00702455?term=Keep+It+Off&rank=1).

Measures

Data collection points were at baseline (0 months) and at 6, 12, 18, and 24-month follow-ups. The baseline, 12-month, and 24-month measurements were conducted in person; 6- and 18-month measurements were conducted via telephone by evaluation staff blind to study condition. The exceptions to this schedule were dietary intake and body image, which were only measured annually.

Weight Change Outcome The outcome in all reported analyses is percent weight change relative to baseline. Three measures were calculated for each randomized participant as 12-, 18-, or 24-month weight minus baseline weight divided by baseline weight. At baseline and 12 and 24 months, weight and height were measured in person with participants in light clothing without shoes (Seca 770 Medical Scale; Seca 214 Portable Height Rod). The 6- and 18-month observations were self-reported and adjusted for potential underreporting [32].

Hypothesized Mediators of Weight Loss Maintenance For each hypothesized mediator, three mediator change measures per person were calculated as 6, 12, or 18 months minus baseline.

Moderate to Vigorous Physical Activity Physical activity was assessed using the Paffenbarger Physical Activity Questionnaire [33]. This instrument asks individuals to indicate the number of city blocks walked, flights of stairs climbed, and light, medium, and heavy leisure time activities in the past week. It has been shown to have satisfactory reliability [34] and predictive validity [35] and to be sensitive to physical activity change in intervention studies [7, 36]. The caloric expenditures from self-reported moderate and heavy activities were summed to estimate weekly kilocalorie of energy expenditure from moderate to vigorous physical activity (MVPA).

Dietary Intake Dietary intake was assessed using the National Cancer Institute's web-based Diet History Questionnaire (DHQ). Although no formal, large validation study of the web-based DHQ has been conducted, several studies document acceptable reliability and validity of the paper-and-pencil version [37, 38]. DHQ-derived total daily energy intake (kcals) was calculated from baseline and 12- and 24-month reports.

Lifestyle Behaviors Participants reported on lifestyle behaviors potentially related to weight regain. Meal regularity was calculated as the mean of the number of times in the past week participants reported they ate (a) breakfast, (b) lunch, and (c) dinner. TV-related eating was calculated as the mean of five items that assessed the number of times in the past week participants reported (a) eating after 7 PM, (b) eating a snack while watching TV, (c) eating meal while watching TV, and the number of hours spent watching TV on an average (d) weekday and (e) weekend day. Eating away from home was

calculated as the mean number of times in the past week participants reported eating (a) fast food and (b) food purchased from a convenience store. For each composite, item responses were averaged so that higher scores indicated more meal regularity, more TV-related eating, and more eating away from home.

Self-Monitoring Behaviors The frequency with which participants implemented intentional weight control strategies was calculated as the mean of how often participants wrote down (a) the calorie content of foods they ate and (b) the amount and type of exercise they had done and (c) used meal replacements, (d) planned meals, and (e) planned exercise to manage their weight.

Participants also responded to "How often do you weigh yourself?" [39] with options ranging from "never" through "every day" and "more than once a day." Responses were dichotomized as less than daily self-weighing and at least daily self-weighing. Change in daily self-weighing (stopped daily self-weighing, no change, started daily self-weighing at 6, 12. or 18 months relative to baseline) was represented by two binary indicators: starting daily self-weighing and stopping daily self-weighing relative to baseline.

Body Shape Satisfaction A 16-item version of the Body Shape Questionnaire shown to have acceptable reliability and validity [40] measured body shape satisfaction. Participants rated the frequency with which they experience body shape concerns on items such as "Have you been so worried about your shape that you have been feeling you ought to diet?" Responses to all items were averaged so that higher scores indicated greater body shape satisfaction.

Analysis Plan

The analytic dataset was constructed to support the primary hypothesis test of whether experimentally induced changes in mediators from baseline to the 6-, 12-, and 18-month follow-ups could mediate changes in weight from baseline to 12, 18, and 24 months. Each randomized participant had three observations that represented 6-month lags between changes in mediators and in weight. The first observation consisted of the baseline to 6-month mediator change scores and baseline to 12-month percent weight change. The second and third observations consisted of the baseline to 12- and 18-month mediator change scores, respectively, and baseline to 18 and 24 month weight changes.

The primary efficacy analyses demonstrated that Guided participants regained significantly less weight than Self-Directed participants at 12 and 24 months [11]. For the mediation analyses, one multilevel regression model predicted each participant's three weight change measures from randomized treatment group to estimate the average percent weight change across all follow-ups among Guided relative to Self-Directed participants. This model quantified the total treatment effect that could then be partitioned into direct and indirect effects of the Guided intervention. A general linear model predicted percent weight change at 18 months from treatment group to quantify the total treatment effect for which only one baseline to 12-month mediator change score was available (i.e., dietary intake, body image).

Seven multilevel path models each simultaneously estimated the direct, non-mediated effect of the Guided vs. Self-Directed treatment group on percent weight change (c′ path) as well as the parameters necessary for calculating strength of the indirect, mediated effect of the Guided vs. Self-Directed treatment group on change in one selected mediator (a path) and its association with subsequent percent weight change (b path). As a result of the 6-month lags built into the structure of the dataset, the a path estimated the effects of randomization to the Guided vs. Self-Directed treatment group on changes in mediators at 6, 12, and 18 months, and the c′ path estimated the treatment group effect on changes in weight at 12, 18, and 24 months. The b path estimated the association between change in a mediator and percent weight change 6 months later.

In these seven multilevel path models, treatment group was a binary classification variable, mediator and percent weight change scores were specified as normally distributed, and path coefficients were estimated as fixed parameters. The mediators representing starting and stopping daily self-weighing were specified as binomial. The multilevel path models nested three mediator-percent weight change observations within each participant, specified participant-specific random intercepts, and implemented restricted maximum likelihood (for normal mediators) or weighted least squares (for binary mediators) estimation. Two additional path models assessed mediation through dietary intake and body image from a single observation per person (percent weight change at 18 months, mediator change at 12 months).

Indirect effects were calculated using a distribution of the product approach for models in which the a or b path was significant ($p < .05$), and the other was significant ($p < .05$) or approached significance ($p < .10$). The strength of the indirect effects was estimated as the multiplicative product of the a and b coefficients, and their significance was assessed by means of asymptotic 95% confidence limits around the ab estimates [41].

Interpretation of these path models follows the approach described by Kraemer and colleagues [42, 43]. This approach advocates assessing whether a post-intervention measure is predicted by the intervention (i.e., is the a path $p < .10$?) and whether it is related to the outcome (i.e., is the b path $p < .10$?). The intersection of answers to these two questions is then used to characterize the relationship of each measure with respect to the significant treatment-outcome relationship. Measures for which both answers are 'yes' and the indirect effect is

significant at $p < .05$ will be considered significant mediators of the Guided intervention effect on percent weight change.

The percent weight change outcome was calculated from weight values used in the primary efficacy analyses [11]. For sporadically missing values, participants' previously and subsequently observed weights were used for imputation via linear interpolation. For monotonically missing values, 3.96 lb per missed follow-up was added to the last observed weight [9]. Missing mediator change scores resulted from monotonic and non-monotonic survey non-response at the 6-, 12-, or 18-month follow-up. The models with normally distributed mediators were estimated via maximum likelihood estimation with standard errors calculated using robust sandwich estimators. Models with binary mediators were estimated via weighted least square parameter estimation using a diagonal weight matrix with standard errors calculated using a full weight matrix.

Results

Study participants (N = 419) were primarily non-Hispanic White (86.9%) women (81.6%) who were on average 46.4 (SD = 10.7) years old, overweight (BMI M = 28.5, SD = 4.9; weight M = 175.9, SD = 35.5), and had lost 16.2% (SD = 5.3) of their body weight prior to enrolling in Keep It Off (Table 1). There were no baseline differences by treatment group in these or other key demographic characteristics [11].

Most participants (n = 334, 79.7%) were retained at all follow-ups. Forty-one (9.8%) missed follow-ups sporadically, representing 58 missed observations; and 44 (10.5%) dropped out at 6 (n = 21), 12 (n = 10), 18 (n = 2), or 24 months (n = 11), representing 129 missed observations. Participants with complete data were more likely to be non-Hispanic white (89.8%) than those who dropped out (75.0%) or sporadically missed follow-ups (75.6%). They also had lower baseline weight (M = 173.6) and BMI (M = 28.1) than those with sporadically missing data (M = 194.6, M = 30.9).

Presented in Table 2 are the percent changes in weight from baseline to 12, 18, and 24 months and changes in potential mediators from baseline to 6, 12 and 18 months, that formed the basis of the mediational analyses. While participants in both treatment groups regained weight over time, by 12 months, the Self-Directed participants had regained 2% more weight relative to baseline (M = 3.12%) than Guided participants (M = 1.04%), a difference that remained at 18 and 24 months. Other notable patterns were observed for MVPA and self-weighing. Self-Directed participants reported engaging in about 225–270 fewer kcal of MVPA at the three follow-ups than at baseline in contrast to Guided participants whose activity fluctuated by fewer than 100 kcal relative to baseline. Even though fewer Guided than Self-Directed participants reported daily self-weighing at baseline (42.6 vs. 52.4%, $p < .05$), the Guided participants tended to report more starting (34, 32, 25%) than stopping (9, 8, 12%) of self-weighing, whereas the Self-Directed participants appeared almost as likely to report starting (13, 10, 8%) as stopping (13, 15, 20%).

Efficacy of Guided Intervention

The first objective of these analyses was to quantify the direct relationship between the Guided vs. Self-Directed treatment groups and percent weight change. Averaged across three time lags (Baseline to 12, 18. and 24 months), Guided participants gained 2.18% less of their baseline weight (LS Mean = 2.53%) than Self-Directed participants (LS Mean = 4.71%, $p < .006$). This direct intervention–outcome effect is the benchmark that will be decomposed into direct and indirect components to identify significant mediators of weight loss maintenance.

Does Guided Intervention Predict Mediator Change?

If a mediated relationship is to be viable, randomization into the Guided rather than Self-Directed group must be predictive of subsequent change in the mediator (a path). Of the nine relationships assessed, four resulted in a marginal or significant change in the mediator as a function of the Guided intervention (Table 3, first column). Guided participants were more likely than Self-Directed participants to have started

Table 1 Baseline characteristics of Keep It Off participants

	Guided	Self-Directed	All
N	209	210	419
Age, M (SD)	46.6 (10.9)	46.3 (10.3)	46.4 (10.7)
Female (%)	80.9	82.4	81.6
BMI, M (SD)	28.6 (4.5)	28.4 (5.2)	28.5 (4.9)
Non-Hispanic White (%)	87.1	86.7	86.9
College degree (%)	67.0	61.9	64.4
Employed part-time or full-time (%)	86.6	87.6	87.1
% weight loss prior to study, M (SD)	16.6 (5.6)	15.7 (5.0)	16.2 (5.3)

Table 2 Mean and (SD) or percent for primary weight outcome and potential mediators and change relative to baseline (Δ vs. 0 months), by treatment group and measurement point

	Guided					Self-Directed				
	0 months	6 months	12 months	18 months	24 months	0 months	6 months	12 months	18 months	24 months
N	209	209	209	209	209	210	210	210	210	210
Weight, pounds	176.71(34.73)	176.67 (35.56)	178.40 (36.78)	181.31 (38.73)	183.55 (39.27)	175.12 (36.29)	176.22 (37.22)	180.47 (39.41)	183.45 (39.92)	185.65 (40.68)
% Δ vs. 0 months			1.04 (7.15)	2.60 (8.46)	3.96 (9.52)			3.12 (7.61)	4.87 (8.83)	6.14 (9.56)
N	209	194	178	184	179	210	199	194	198	191
MVPA, kcal/100	7.99 (11.56)	8.53 (13.23)	7.10 (10.22)	7.87 (12.03)	7.63 (13.18)	9.99 (13.95)	7.62 (11.75)	7.64 (11.35)	7.38 (12.35)	7.42 (12.72)
Δ vs. 0 months		.55 (10.42)	−.87 (9.21)	−.15 (12.34)			−2.25 (11.30)	−2.26 (10.91)	−2.69 (13.24)	
Daily self-weighing (%)	42.6*	67.5	68.0	57.7	60.3	52.4	53.3	48.5	41.8	43.5
Start vs. 0 months		33.5	32.0	25.3			13.1	10.3	8.2	
Stop vs. 0 months		9.3	7.9	11.5			12.6	14.9	19.9	
Weight control[a]	2.67 (.68)	2.94 (.79)	2.87 (.72)	2.62 (.75)	2.66 (.70)	2.68 (.76)	2.77 (.78)	2.73 (.75)	2.56 (.74)	2.51 (.80)
Δ vs. 0 months		.23 (.80)	.19 (.68)	−.07 (.81)			.08 (.68)	.04 (.66)	−.12 (.73)	
Dietary intake, kcal/100	15.56 (6.47)		14.66 (5.85)		14.29 (5.72)	16.11 (6.41)		15.05 (6.08)		15.87 (6.33)
Δ vs. 0 months			−.74 (5.46)					−1.17 (5.20)		
Meal regularity[a]	4.50 (.61)	4.71 (.46)	4.54 (.57)	4.66 (.46)	4.47 (.60)	4.53 (.65)	4.71 (.50)	4.56 (.57)	4.62 (.50)	4.52 (.60)
Δ vs. 0 months		.20 (.48)	.03 (.52)	.15 (.51)			.18 (.51)	.04 (.48)	.08 (.53)	
TV-related eating[a]	2.42 (.81)	2.20 (.80)	2.34 (.84)	2.20 (.78)	2.35 (.82)	2.38 (.79)	2.21 (.77)	2.34 (.77)	2.29 (.78)	2.35 (.76)
Δ vs. 0 months		−.19 (.58)	−.06 (.55)	−.21 (.59)			−.17 (.67)	−.06 (.60)	−.08 (.72)	
Eating away from home[a]	1.42 (.52)	1.39 (.51)	1.44 (.52)	1.40 (.54)	1.42 (.49)	1.38 (.50)	1.37 (.47)	1.37 (.48)	1.44 (.53)	1.45 (.50)
Δ vs. 0 months		−.03 (.51)	.03 (.56)	.01 (.63)			.01 (.45)	−.01 (.51)	.09 (.62)	
Body shape satisfaction[a]	4.62 (.86)		4.71 (.99)		4.71 (.93)	4.65 (.86)		4.60 (.97)		4.47 (1.03)
Δ vs. 0 months			.05 (.71)					−.07 (.66)		

[a] Range = 1–5

* $p < .05$, baseline Guided vs. Self-Directed comparison

($p < .001$), and less likely to have stopped ($p < .05$), daily self-weighing. They also reported engaging in about 225 more kcal of MVPA per week ($p < .05$) and more frequently implemented weight control strategies ($p < .10$) at 6, 12, or 18 months.

Does Mediator Change Predict Percent Weight Change?

For eight of the nine potential mediators, change from baseline was marginally or significantly related in the expected direction to percent weight change relative to baseline measured 6 months later (Table 3, second column; b path). For example, each 100 kcal expended on MVPA per week was associated with .09% weight loss 6 months later ($p < .001$). Similarly, each increase of 100 cal consumed per day was associated with a weight increase of .22% 6 months later ($p < .05$). More frequently employing weight control strategies ($p < .001$), starting daily self-weighing ($p < .001$), and improved body image ($p < .001$) were each associated with weight decreases; eating more meals at fast food venues ($p < .001$) and stopping self-weighing ($p < .001$) were associated with weight increase.

Significant Mediators of Weight Change

Critical for the task of identifying significant mediators of percent weight change, all four mediator changes that differed by treatment group were also significantly related to percent weight change. The higher proportion of Guided participants who started to weigh themselves daily predicted 1.70% (95% CI −2.72, −.67) less weight regain. The fewer Guided participants who stopped daily self-weighing predicted .75% (95% CI −1.47, −.04) less weight regain. Starting and stopping self-weighing were the only post-intervention measures that met all three criteria (caused by the intervention, predictive of percent weight change, significant indirect effect) to be considered significant mediators of the Guided intervention on percent weight change. Because each mediated relationship was estimated separately, it is possible that simultaneously estimating other mediators would reduce the magnitude of these estimated indirect effects.

MVPA and the use of weight control strategies were both sufficiently related to the intervention and weight change for the mediated relationships to be considered potential mediators of percent weight change. The indirect effects of MVPA (−.19%, 95% CI −.38, .00) and weight control strategies (−.32%, 95% CI −.67, .04) predicted lower percent weight regains among Guided participants but neither was statistically significant.

Three of the potential mediators—eating away from home, body shape satisfaction, and dietary intake—were nonspecific predictors of percent weight change. Each was predictably related to changes in weight but was not affected by exposure to the Guided intervention. These constructs represent opportunities for future interventions.

Table 3 Path coefficients (standard errors) from models decomposing the total relationship between treatment group and percent weight change into the relationships between the Guided vs. Self-Directed intervention and mediator change (a path), mediator change and percent weight change (b path), and residual direct effect of the Guided vs. Self-Directed intervention on percent weight change (c′ path) and the resulting indirect effect

	a path (se): Guided vs. Self-Directed to mediator change	b path (se): mediator change to percent weight change	c′ path (se): Guided vs. Self-Directed to percent weight change	Indirect effect (95% CL)
Significant mediators of weight change				
Start daily self-weighing	.74 (.13)***	−2.30 (.58)***	−.48 (.90)	−1.70 (−2.72, −.67)
Stop daily self-weighing	−.30 (.14)*	2.48 (.43)***	−1.42 (.79)$^{+}$	−.75 (−1.47, −.04)
Potential mediators of weight change				
MVPA, kcal/100	2.24 (.94)*	−.09 (.03)***	−1.99 (.77)**	−.19 (−.38, .00)
Weight control	.11 (.06)$^{+}$	−2.81 (.50)***	−1.86 (.75)*	−.32 (−.67, .04)
Nonspecific predictor of weight change				
Eating away from home	−.02 (.05)	2.29 (.60)***	−2.12 (.77)**	
Body shape satisfaction	.11 (.07)	−4.76 (.67)***	−1.74 (.79)*	
Dietary intake, kcal/100	.44 (.57)	.22 (.10)*	−2.27 (.77)**	
Irrelevant to weight change				
Meal regularity	.03 (.04)	−1.21 (.88)	−2.15 (.78)**	
TV-related eating	−.05 (.05)	.95 (.65)	−2.13 (.77)**	

$^{+}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Finally, meal regularity and TV-related eating were not related to either the Guided intervention or weight change.

Discussion

The goal of the present work is to assess the potential for each of nine factors to mediate a successful weight loss maintenance intervention, the Keep It Off Guided intervention. The results reported here have added to our understanding of the behavioral mediators of weight loss maintenance by documenting the temporal ordering of intervention delivery, changes in mediators, and percent changes in weight and by comparing the proportional contribution of each potential weight change mediator. We assert that self-weighing behaviors are significant mediators of weight change that could have been caused by the Guided intervention. There was more change in these behaviors among participants randomized to the Guided than the Self-Directed intervention, and changes in mediators lagged changes in outcomes by 6 months making the pattern of effects consistent with causal mediation.

Specifically, results indicated that uptake and maintenance of daily self-weighing were significant mediators of the Keep It Off Guided intervention. Guided intervention participants regained about 2% less weight over the 24 months post-randomization than Self-Directed participants. Starting daily self-weighing explained a greater share of this relative difference than any other potential mediator that was assessed. Continuing with (i.e., not stopping) self-weighing explained a smaller but significant share. Although not reported in detail, this same pattern of results obtained when BMI was treated as the outcome and when the analysis was limited to women.

The benefits of regular self-weighing on weight change have been systematically documented [44], with concurring evidence from the direct manipulation of self-weighing in efficacy trials [45] and from the associations between self-weighing and weight change in trials [46, 47] and observational studies. [48, 49].

Associations between moderate-to-vigorous physical activity and long-term weight loss maintenance have been reported [50–54] but a possible causal role of MVPA remains undocumented. Surprisingly, self-monitoring behaviors such as writing down calorie content of foods and the amount and type of exercise were predictive of percent weight change but were not determined to be significant mediators of the intervention effect. Increases in caloric intake and in the frequency with which participants reported eating away from home were associated with increases in weight. Increases in body shape satisfaction were related to decreases in body weight over time.

The question of why self-weighing was the strongest mediator of the intervention effect on weight change remains open. Reductions in dietary intake and increases in physical activity were both predictably associated with weight change but neither proved to be as markedly strong a mediator as self-weighing. Recommending a behavior as simple to adhere to as self-weighing may have prompted participants to notice and respond to weight increases via changes in diet or activity while they were still small enough to reverse and prevent more substantial regain (i.e., moderated mediation) [46]. However, these energy balance factors are complex intermediaries in the self-weighing–weight change relationship that were likely not assessed with sufficiently precise timing or specificity to capture such complex relationships. Another possibility is that self-weighing is a behavioral manifestation of intervention-induced changes in affect, cognition, or motivation that were not anticipated or measured. Given the magnitude of the self-weighing indirect effect, and the promise it may hold for successful weight loss, efforts directed toward identifying modifiable factors that promote self-weighing and effectively managing the resulting behavioral cascade are warranted. The lack of intervention effect on changes in several factors predictive of weight change could be due to issues such as a lack of emphasis on these behaviors in the intervention, poor measurement sensitivity (e.g., dietary intake), or not being very amenable to direct intervention (e.g., body shape satisfaction).

As is often true for randomized trials, it would be inappropriate to generalize these results beyond the population from which the participants were recruited—educated, employed middle age non-Hispanic White women who were successful at achieving a significant weight loss in the previous year. The annual rather than biannual measurement of dietary intake made it infeasible to more fully explore the intriguing and potentially complex relationships among self-weighing, MVPA, and dietary intake in mediating weight loss maintenance.

Daily self-weighing emerged as a clear mediator of weight loss maintenance and there appeared to be opportunities for improving weight loss maintenance to be realized in future work. As one example, eating away from home and dietary intake were associated with weight increases but not affected by the intervention. This and other interventions might be strengthened by devising strategies to promote changes in behaviors such as eating away from home, body shape satisfaction, and dietary intake that in this study were nonspecific predictors of weight loss maintenance.

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Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors AL Crain, NE Sherwood, BC Martinson, and RW Jeffery declare that they have no conflict of interest. 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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