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Evaluating the Effectiveness of Daily Self-Weighing to Prevent Age-Related Weight Gain

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Abstract

Objective: Age-related weight gain refers to the gain in adult body weight with age. What makes age-related weight gain a serious public health problem is that the higher the rate of age-related weight gain, the greater the incidence of many weight related diseases such as diabetes, hypertension and heart disease. We examined the efficacy of daily self-weighing to reduce age-related weight gain among university employees.

Design: Participants were randomized into two groups. One group (experimental) were given internet-based scales and asked to weigh themselves daily. They received an email reminder if more than three days elapsed between weighings. The other group (control), like the experimental group, was weighed at the beginning and the end of the two-year experimental period.

Settings: The initial and final weighing occurred in the metabolic unit of the division of nutritional sciences, Cornell University, Ithaca, NY.

Participants: The participants were 286 adult employees of a Cornell University

Results: Using the conventional intent-to-treat analysis neither the within subject weight change over time (-0.38 kg [-1.27 kg, 0.50 kg], control: 0.19 kg [-0.56 kg, 0.93 kg]) nor the between groups (0.40 kg, p=0.183) reached statistical significance. However, when the non-compliers from both the experimental and control group were removed, the self-weighers gained significantly less weight than the controls (0.59 kg (p=0.048)). Analyses controlled for baseline weight, gender, ethnicity, age, education, marital status, weight change the year before the study, and baseline weighing frequency.

Conclusion: Compliers to daily self-weighing gained significantly less weight over two years than a matched group who did not self-weigh.

Introduction

Figure 1 display a phenomenon called age-related weight gain and refers to the observation that as we get older we gain weight [1]. The phenomenon is ubiquitous being observed in almost every industrialized country in the world. It occurs in both males and females though at slightly different rates. The rate of age-related weight gain is slow, but incessant. It is highest in young adulthood decreasing steadily until the end of life. On average, individuals gain about one pound per year between the ages of 20-40, resulting in a 20-pound (9.1 kg) weight gain [2] by midlife. Independent of weight in early adulthood, the rate of age-related weight gain increases the risk for obesity [3], mortality [4], and many diseases [5], including cardiovascular diseases, metabolic syndrome [6], and type ii diabetes mellitus [7]. Additionally, weight gain increases susceptibility to functional impairment [8], pulmonary dysfunction [9], and negatively impacts psychological health [10]. Because all these pathologies result from increased weight gain, it is reasonable to suggest reducing the rate of age-related weight gain should decrease the prevalence of those diseases that are related to the weight gain. Unfortunately, the outcomes of weight gain prevention studies are mixed. Some studies have showed successful intervention outcomes [11,12] while others have failed to observe significant differences in weight change between intervention and control groups [13,14]. Most weight gain prevention studies use interventions with multiple components, such as diet modification [11,15,16], physical activity [16] regular meetings [17], incentives [17,18], and behavioral strategies such as regular self-weighing [16,19,20,21]. Although these multi-component interventions were shown to provide better results

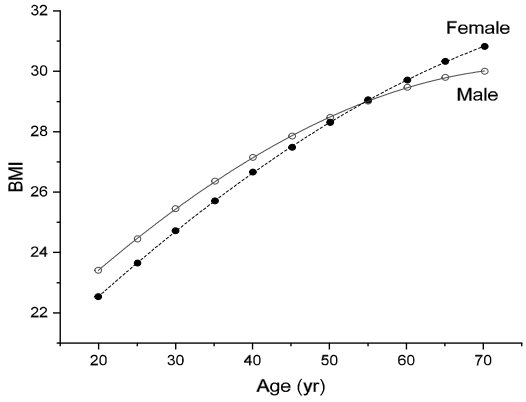

Figure 1: BMI as a function of age Replotted from [1].

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for weight management than either alone, it is difficult to identify the "active ingredient(s)" of an effective intervention. To determine the effective component of a successful weight gain prevention program the intervention components need to be tested separately. One simple and cost-efficient component that could serve as a weight gain prevention intervention is frequent self-weighing [22]. Frequent self-weighing is an effective weight control strategy [23,24]. Self-weighing may increase an individual's awareness of weight change, facilitate selection of appropriate weight maintenance strategies, and encourage continual self-adjustive behaviors based on the feedback from the scale to aid in weight control [25]. In multi-component weight gain prevention studies, frequent self-weighing (weekly and daily) is associated with better weight maintenance outcomes [16,20,22,26]. Studies where daily self-weighing with daily feedback on weight as the only intervention component have been published [12,27,28]. While two studies [12,27] showed a beneficial effect of daily self-weighing on weight gain prevention, one study did not find a significant effect [28]. All three studies were conducted among first-year college students which drastically reduce the generalizability of the findings. Compared to college freshmen, workplace employees make up a more significant share of the U.S. Population [29]. Preventing age-related weight gain among this population is essential considering the obesity-related morbidities, absenteeism, reduced productivity, and health care costs [30]. Therefore, finding a strategy to prevent age-related weight gain among the employee population will generate enormous health and economic benefits. The purpose of this randomized controlled trial was to examine the efficacy of daily self-weighing alone to prevent age-related weight gain among university employees.

Methods

Study population

The employees of a university on the east coast were recruited via on-campus advertisement between June and august 2017. Eligible participants were 18 years or older, a current employee, planning to stay in the local area for two years, and owners of a bluetooth-enabled device. Individuals were excluded if they were undergraduate or graduate students, pregnant or planning to get pregnant, currently in a weight loss program or under evaluation for bariatric surgery, and/or had a history of eating disorders. All protocols and procedures in this study were approved by the institutional review board for human subject's research of Cornell University. Written informed consent was obtained from all participants before the study started. The study is retrospectively registered on clinicaltrails.gov [nct03717428] due to technical difficulties we experienced with the clinicaltrials.gov website and communication issues. The authors confirmed that all ongoing and related trials for this intervention are registered.

Study design: overview

The study was a two-year, prospective, randomized control trial of daily self-weighing. The primary outcome was the change in body weight over two years. Eligible participants consented to participate, completed the baseline survey online, and attended an enrollment session. At the enrollment session, participants' heights and weights were measured by trained research assistants, and they were randomized to either the intervention or control group using a random number generated by excel. Due to the nature of the study, researchers were not blinded to the group assignment, and participants were not blinded to their own conditions while control group participants were blinded to the intervention strategy to prevent them from being influenced by knowing the intervention strategy. Two years after the enrollment session, participants in both groups completed the end-of-study survey online, and attended the follow-up session, where the trained research assistants measured their heights and weights again. Participants were also invited to participate in an individual semi-structured interview about their experiences in the study. Details of the interview will be elaborated in a subsequent publication. All study participants received $25 cash compensation at the enrollment session and $50 cash compensation at the two-year follow-up session.

Intervention

At the enrollment session, each intervention group participant received a smart scale (body+; withings, issy-les-moulineaux, france) and a research assistant (trained graduate student) helped them install the withings health mate app on their personal device for scale connection and data transmission. After each weighing, a display is made visible to the participant depicting the weight at last seven weighing's. Each time a participant weighed themselves, the data was transmitted automatically to a university server accessible to the researchers. Participants could access their weight data on the app and associated website but were not required to review it. Participants were instructed to maintain their weight, and the goal weight in the app was set to their baseline weight. Intervention group participants were instructed to place the scale close to their bed and weigh themselves as soon as they rose from bed. Participants informed the research team if they were unable to weigh for more than three consecutive days due to travel or health conditions. Automatic email reminders, which encouraged participants to continue self-weighing the next day and suggested potential termination due to noncompliance, were sent to the participants who did not weigh for 3, 7, or 14 consecutive days without informing the researchers in advance. Participants were terminated from the study if they did not weigh for 14 consecutive days and did not respond to the emails from the research team in the next seven days.

Control group

At the enrollment session, the control group participants were instructed to maintain their habitual behaviors. They were also provided with a brief handout with the center for disease control (cdc) website links on lifestyle recommendations to resist weight gain. At approximately one year after baseline, all control group participants received a brief one-year follow-up online survey requesting information on changes in contact information and/or health conditions.

Measures

Height and weight: at both enrollment and two-year follow-up sessions, registered dietitians or trained research assistants measured each participant's height and weight to the nearest 0.1 cm and 0.01 kg using the same calibrated digital measuring station (seca284; seca gmbh & co. K., hamburg, germany). All participants were weighed in their undergarments and a paper gown. At the two-year follow-up session, participants were weighed at about the same time of the day (morning, afternoon, evening) as in the enrollment session. Only 4 participants (1.6%) failed to return at the same time of the day.

Weighing frequency: the weighing frequency of the intervention group participants was calculated from the recorded weights as a percentage of the days the participant weighed per total number of days in the study. The self-weighing frequency of the control group participants was obtained through the end-of-study survey. The item asked, "Over the past two years in the study, how often did you weigh yourself on average?".

Response options were: never, less than once per month, once a month, several times per month, once a week, several times per week, once a day, several times a day, and i choose not to answer. The responses were then collapsed into four categories: less than monthly, at least monthly, at least weekly, and at least daily.

Weight history: information on weight history was collected from the baseline survey. Participants were asked about their maximal lifetime weight (except for pregnancy) and weight change during the year before the study (gained weight, lost weight, remained the same as last year).

Variables that could contribute to the weight change: In the baseline and end-of-study surveys, information was collected on other potential causes of individual weight change during the study. Variables included the use of medications that could cause weight gain or loss, occupational and recreational physical activity, and weight loss surgery. The end-of-study survey included questions about dietary change, participation in weight loss programs, and significant changes in health during the study (e.g., surgery, cancer diagnosis).

Psychological variables: to assess the psychological aspects of the participants, in both baseline and end-of-study surveys, depressive symptoms were measured with the patient health questionnaire-9 (phq-9) scale [31], disordered eating symptoms with the eating disorder examination questionnaire short (ede-qs) [32], and eating behaviors (cognitive restraint, uncontrolled eating, emotional eating) with the three factor eating questionnaire revised, 18-item (tfeq-r18) [33].

Demographic information: demographic information (e.g., age, gender, ethnicity, marital status, household size, household income, education level) was collected from the baseline survey. In the end-of-study survey, any changes in the demographic information provided at baseline were collected. Intervention group participants were asked about their willingness to continue self-weighing after the study.

Statistical analysis

The sample size was calculated based on an 80% statistical power to detect a 2-kg difference in weight change between the intervention and control groups with the estimated standard deviation as 5.9 and the estimated attrition rate as 20%, which was estimated based on a similar study of daily self-weighing [34]. For the baseline characteristics, continuous variables were summarized as means with standard deviations, while categorical variables were summarized as percentages. Between-subject t-tests and chi-square tests were conducted to detect significant baseline differences between groups.

Complete-case analysis

A complete-case analysis was performed first, with all participants who completed the study included in the analysis. Since this study intended to examine the efficacy of the daily self-weighing intervention, no imputations were made for missing data and participants. Within-subject paired t-tests were conducted to examine weight change over time in each group and a test of equivalence, which used the 3% weight change as thresholds, was conducted among the intervention group participants. Participants' weight changes over time were calculated with the weight measurements obtained in the enrollment and two-year follow-up sessions, where the same standard scale at the research site was used to ensure a fair comparison. The difference in weight change between groups was analyzed using generalized linear regression, adjusting for gender, age, baseline weight, ethnicity, and baseline weighing frequency, baseline marital status, education, and participants' weight change during the year before the study. These covariates were chosen based on the previous self-weighing studies [22].

Exploratory analyses

A per-protocol analysis was conducted post hoc [35] and adjusted for the same covariates as in the complete-case analysis. In the per-protocol analysis, only the participants that completed the study and adhered to their assigned arm were included. We defined daily self-weighing as weighing at least 70% of the days (5 days/week). This 70% cut point was chosen in accordance with a similar two-year daily self-weighing study conducted by crane et al. To allow for some vacation days when the participants might not bring the scale with them as well as some missing data in the data transmission process [36]. In this study, similar instruction to daily self-weigh and the same type of smart scale (withings) were used. Adherence for the control group was defined as weighing less than daily. Aware of the imbalance that might be caused by the post-randomization exclusion of participants, comparisons in baseline characteristics were conducted between the i) intervention and control groups participants included in the per-protocol analysis; ii) included and excluded intervention group participants based on per-protocol analysis; iii) included and excluded control group participants based on the per-protocol analysis. An additional exploratory analysis was conducted to investigate the relationship between the change in weighing frequency and two-year weight change among control group participants using one-way anova. All analyses were conducted in jmp (version 14, sas institute, north carolina), and the significance level was set to 0.05. The dataset supporting the conclusions of this article is available in the ciser data and reproduction archive [https: //doi.org/10.6077/f5pk-hs90].

Results

Study overview

A total of 522 participants were assessed for eligibility; 286 were randomized, and 258 completed the study. No significant differences in baseline characteristics were found between groups, as shown in Table 1. At baseline, the number of participants that reported using medications that could cause weight loss (2.8%) or weight gain (5.6%) (49) did not differ.

Significantly between groups: Overall, 82.9% of the intervention group participants reported viewing the graphs of their weights in the app or on the website during the study. The average study duration was 733 (range: 715-770) days or about 24 months. The overall retention rate was 90.2% (intervention: 87.2%; control: 93.4%). Supplemental Table 1 and supplemental Table 2 show the baseline characteristics the dropouts and the completers both for the intervention group and the control group. Intervention group participants who dropped out (n=19), as compared to the participants who completed the study, were younger (34.4 ± 8.8 vs. 43.5 ± 11.0, $p<0.0001$), less likely to be married or living with a domestic partner (47.4% vs. 75.4%, $p=0.025$), and had a higher lifetime maximum weight (199.6 ± 51.3 vs. 178.2 ± 40.6, $p=0.041$). There were no significant differences between those who completed and dropped out of the study in the number of obesity-related chronic conditions, eating disorders symptoms, depressive symptoms, or weight-change medications. In the control group, the baseline characteristics did not differ significantly between the participants who completed and dropped out of the study (supplemental Table 1).

Complete-case analysis

Using the complete-case analysis, the mean two-year weight change

Table 1: Descriptive characteristics of participants at baseline.

Participants' Characteristics	Total (n=286)	Intervention (n=149)	Control (n= 137)	P
Age	(284) 43.2 ± 11.0	42.3 ± 11.1	(135) 44.3 ± 10.9	.146
Gender (% female)	74.5	77.2	71.5	.292
Ethnicity (% white)	86.4	87.9	84.7	.424
Body mass index (bmi) (kg/m^2)	27.4 ± 5.5	27.2 ± 5.8	27.6 ± 5.1	.546
Number of days per week physically active ≥30 min	3.8 ± 1.9	3.7 ± 2.0	3.9 ± 1.8	.336
Phq-9 score	4.2 ± 4.0	4.2 ± 3.6	4.3 ± 4.3	.723
Ede-qs score	8.3 ± 5.7	8.0 ± 5.8	8.6 ± 5.7	.310
Tfeq-r18 score				
cognitive restraint	54.7 ± 14.0	55.7 ± 14.2	53.7 ± 13.8	.242
uncontrolled eating	58.1 ± 12.6	59.2 ± 12.4	57.0 ± 12.8	.136
emotional eating	54.6 ± 20.0	56.1 ± 20.7	53.0 ± 19.3	.201
Bmi category (%)				
normal weight (18.5≤ bmi < 25)	37.5	41.9	32.9	
overweight (25 ≤ bmi < 30)	35.4	33.1	38.0	
obese (bmi ≥ 30)	27.0	25.0	29.2	.307
Maximum weight (lbs.)	(281)	(146)	(135)	
male	209.4 ± 38.4 (95.0 ± 17.4kg)	204.8 ± 33.5 (92.9 ± 15.2kg)	213.6 ± 45.5 (96.9 ± 20.6kg)	.360
female	174.8 ± 38.4 (79.3 ± 17.4kg)	173.8 ± 42.5 (78.8 ± 19.3kg)	175.9 ± 33.3 (79.9 ± 15.1kg)	.693
Weighing frequency before the study (%)	(285)	(148)		
less than once a month	30.2	31.8	28.5	
at least once per month	18.3	19.6	16.8	
at least once per week	34.7	33.8	35.8	
at least once per day	16.5	14.2	19.0	.542
Education (%)	(282)	(146)	(136)	
below bachelor's degree	25.9	26.8	24.8	
bachelor's degree and above	72.7	72.2	74.4	.575
Marital status (%)	(281)	(146)	(135)	
never married, divorced, separated, widowed	24.8	26.2	23.4	
married or living with a domestic partner	73.4	71.8	75.2	.793
Annual household income (%)	(251)	(129)	(122)	
less than $60 000	21.0	22.8	19.0	
$60 000-$99 999	29.7	28.9	30.7	
over $100 000	37.1	34.9	39.4	.721
Household size (%)				
1-2	46.2	46.3	46.0	
3-4	43.7	45.0	42.3	
5+	10.1	8.7	11.7	.695
Number of obesity-related chronic conditions[a] (%)				
0 condition	72.7	69.1	76.6	
1 condition	20.3	24.2	16.1	
2 conditions or more	7.0	6.7	7.3	.231
Weight change in the past year (%)				
lost weight	18.5	15.4	21.9	
gained weight	37.4	34.9	40.2	
stayed about the same	42.3	47.0	37.2	
i don't know	1.8	2.68	0.7	.143

Note: None of the characteristics are significantly different between the two groups. The number in parenthesis isthe number analyzed of that characteristic since there are some missing values in some baseline characteristics. Number of obesity-related chronic conditions: the number of chronic health conditions related to obesity, including diabetes, prediabetes, hypertension, prehypertension, cardiovascular diseases, asthma, sleep apnea or obstructive sleep apnea, gallbladder disease, nonalcoholic fatty liver disease, abnormal blood lipid levels (high cholesterol levels/ low hdl/ high ldl). The number of obesity-related chronic conditions was categorized.

for the intervention group was-0.39 kg [95%ci: (-1.27, 0.50)] and for the control group 0.19 kg [95%ci: (-0.56, 0.93)]. Additionally, the result of the test of equivalence among the intervention group participants shows that the baseline and final weights of the intervention group participants were statistically equivalent and not different. The results of the linear regression models showed that there was no significant difference in weight change between control and intervention groups after adjusting for baseline weight, gender, ethnicity, age, education, marital status, weight change the year before the study, and baseline weighing frequency (control-treatment: 0.40 kg p=0.183). The results of the regression model are shown in Table 2. Identifying as male was associated with greater weight loss over two years, as compared to identifying as a female. The mean (±sd) weighing frequency of the intervention group was 80.3 ± 13.3% or an average of 5.6 days/week. The variation in weighing frequency (Figure 2) ranged from 37.6% (2.6 days/week) to 98.5% of days (6.9 days/week). Among control group participants, 18 (14.2%) participants reported daily self-weighing during the study, as shown in Figure 2.

Exploratory analyses

Due to this variation in protocol adherence, a post hoc, exploratory, per-protocol analysis was conducted to explore the efficacy of daily self-weighing in those participants. In the per-protocol analysis, we excluded from analyses 23 intervention group participants who weighed themselves less than daily (<70% weighing days) and 18 control group participants who reported weighing themselves daily, the baseline characteristics of the intervention and control group participants included in the per-protocol analysis were not significantly different.

Table 2: Generalized linear regression table using complete-case and per-protocol analyses.

Variables	Complete-case (n=254)			Per-protocol (n=210)		
	B	Se	P-value	B	Se	P-value
Group[control]	0.400	0.300	0.183	0.591	0.297	0.048*
Age	-0.014	0.028	0.612	-0.019	0.028	0.492
Baseline weight (kg)	0.012	0.019	0.545	0.024	0.020	0.233
Lost or maintained weight during the year before study	-0.598	0.308	0.053	-0.882	0.303	0.004**
Ethnicity (being white)	-0.131	0.477	0.783	-0.180	0.462	0.697
Male	-1.057	0.374	0.005**	-0.776	0.379	0.042*
Baseline weighing frequency (less than weekly)	0.032	0.302	0.916	0.106	0.293	0.719
Education (below bachelor's degree)	0.095	0.354	0.788	-0.144	0.349	0.680
Marital status (married or living with domestic partner)	0.005	0.354	0.989	-0.019	0.346	0.956

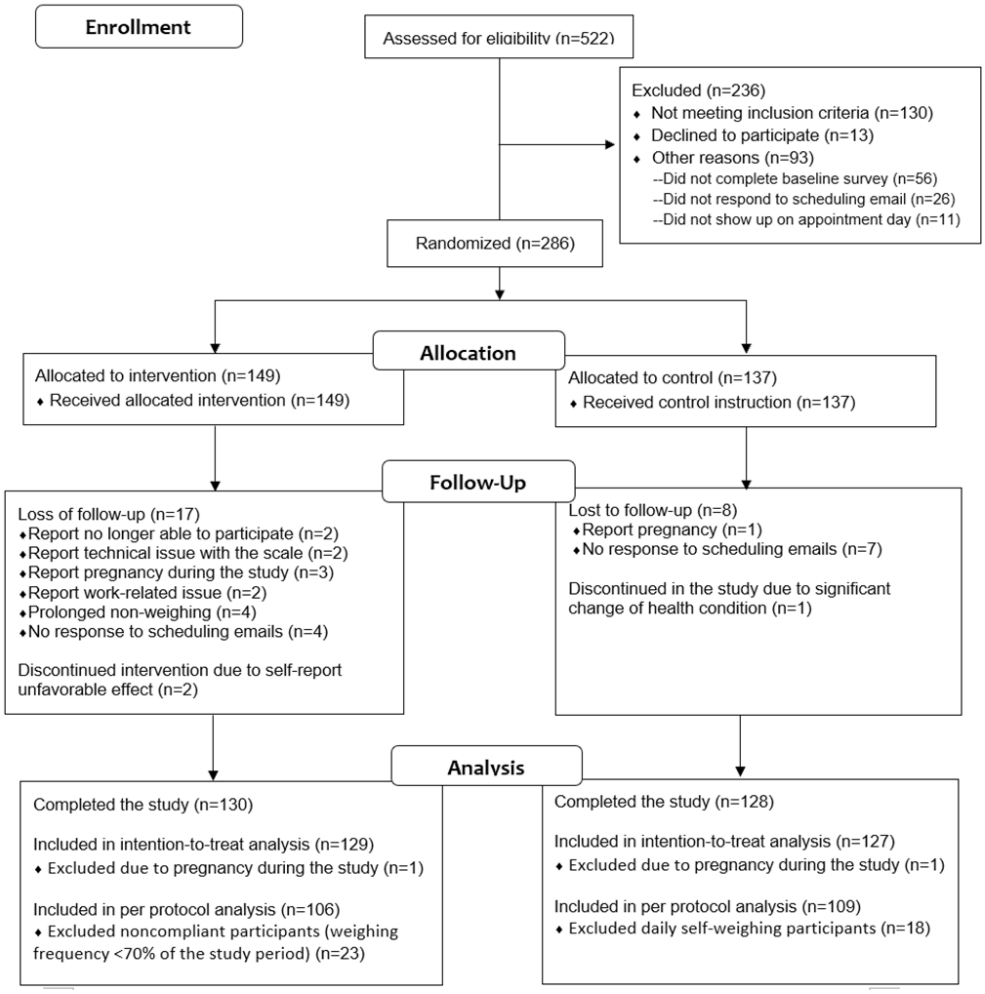

Figure 2: Consort flow diagram.

In the intervention group, compared to the participants included in the per-protocol analysis, the excluded participants were younger (33.2 vs. 44.3 years, p=0.015), had a higher lifetime maximum weight [194.4 lbs. (88.2 kg) vs. 174.8 lbs. (79.3 kg), p=0.036] and had a lower cognitive restraint score (50.0 vs. 56.6, p=0.042). In the control group, the excluded participants did not differ significantly from the included participants except that the excluded ones had a higher proportion of regular (daily and weekly) weighers (94.4 vs. 45.9%, p<0.001) at baseline than the included participants. In the per-protocol analysis, weight did not change significantly over two years in the intervention group [mean (95%ci): weight change (kg)=-0.54 kg (-1.37, 0.28)] or the control group [weight change (kg)=0.23 kg (-0.58, 1.05)]. As shown in Table 2, after adjusting for the covariates, the difference in weight change between groups was statistically significant with a weight difference of 0.59 kg (p=0.048), showing less weight gain in the intervention group than in the controls. Besides being in the intervention group, having lost or maintained weight in the year before the study and identifying as male were associated with less weight gain. Additional analyses were conducted to control for baseline cognitive restraint score in the regression model but adding this variable does not change the results in both complete-case analysis and per-protocol analysis. Over the two years, some control group participants reported a change in

their weighing frequency. An exploratory analysis was conducted to examine the relationship between the change in weighing frequency and two-year weight change among the control group participants. Control group participants who increased their weighing frequency over two years (n=43) lost significantly more weight compared to those in the "stay the same" (n=43) and "decrease" (n=47) categories (-1.52 ± 0.69 kg vs. 0.61 ± 0.64 kg vs. 1.09 ± 0.58 kg, p=0.013). We did not observe any significant increase in depressive symptoms (phq-9 score) or disordered eating symptoms (ede-qs score) among the intervention group participants from baseline to end-of-study. Two intervention group participants self-reported unfavorable psychological effects of daily self-weighing and withdrew from the study voluntarily. Overall, 93% of the intervention group participants responded "yes" to the question "after the study ends, will you continue to weigh yourself?".

Discussion

This randomized controlled trial examined the use of daily self-weighing as a single intervention to prevent age-related weight gain among university employees over two years. Using conventional analytical techniques, no significant difference in weight change between groups was observed. However, when we excluded non-compliers from both a statistically significant between-group difference of 0.6 kg was observed. This weight difference was similar to a two-year weight gain prevention study among participants in a similar age group [13]. Interestingly, that study also failed to find statistical analysis although they no attempt to run a per-protocol procedure. The complete-case analysis includes all the intervention group participants that completed the study in the analysis regardless of their two-year self-weighing frequency, ranging from less than three days/week to daily. The statistically insignificant weight difference between intervention and control groups may have underestimated the effect of daily self-weighing to prevent age-related weight gain. In previous intervention studies targeting weight-related outcomes, adjusting the data for incomplete adherence was rarely performed. For example, in a randomized controlled trial where daily self-weighing was a main component of the weight loss intervention [37], only 60% of the intervention group participants weighed daily, while about 20% of the control group participants started to weigh themselves regularly. All the participants in the study were included in the analysis regardless of their adherence to the group assignment, and researchers failed to observe a significant difference in the six-month weight change between the intervention and control group participants. Likewise, linde et al. [15] found that the adherence in the intervention group dropped from 90% in the first week to 52.5% at the end of six months in a six-month self-directed weight control program, which emphasized self-monitoring behaviors including self-weighing. The researchers included all the participants in the analysis regardless of their weighing frequency and failed to observe a significant between-group difference in weight change when testing the intervention effect. Although not common in nutrition research, per-protocol analysis is used in clinical trials to test the efficacy of treatments rather than the effectiveness [38]. To examine the efficacy of daily self-weighing to prevent age-related weight gain, we used a post hoc, exploratory, per-protocol analysis in this study [35]. Based on the per-protocol analysis results, the intervention group participants who weighed daily achieved statistically better weight gain prevention outcomes than the control group participants who did not weigh daily. Similarly, a significant effect of daily self-weighing was observed in a six-month, daily self-weighing-focused weight loss study, where the adherence rate was high (intervention group participants weighed 6.1 days/week) [39]. These findings suggest that, among those with high adherence, daily self-weighing can promote weight gain prevention. Another result of the post-hoc analysis was observed in the control group. Although the control group participants were instructed to continue their habitual behaviors, 28.3% reported an increase in weighing frequency over two years. These participants showed significantly better weight gain prevention outcomes than those who did not increase their weighing frequency in the control group. Such an observation is consistent with the hypothesis that increased weighing frequency is associated with better weight gain prevention. Furthermore, it also indicates that the control group participants were affected by merely being in the study, and thus might not have displayed the normal age-related weight gain that would have taken place if they had not been in the study. Since the participants were not blinded to their condition, it is possible that the participants talked to each other about their own study conditions, which might have influenced the control group participants' weighing behaviors during the study. However, no data were available to examine this hypothesis. The absence of weight gain in the control group was also observed in previous weight gain prevention studies and maybe one of the major reasons for the failure of previous studies to observe significant weight differences between intervention and control groups in weight gain prevention trials [13,14,17,18,37,39-41]. The studies that found a significant intervention effect observed a significant weight gain among the control group participants [11,12,16,27,42,43]. While in those studies that failed to observe a significant intervention effect of self-weighing, the control group participants generally maintained or lost weight [13, 14, 16, 17, 37]. Such observation was also reported in a systematic review of weight gain prevention interventions (44), suggesting that being in the control group of weight loss study or weight gain prevention study might confer a weight gain prevention effect. Such an effect makes it harder to observe the weight difference between intervention and control groups. The frequent self-weighing (weekly and daily) reported by more than 50% of the control group participants at baseline was probably contributed to a smaller weight gain in the present study. Interestingly, in both the complete-case and per-protocol analyses results, despite being a small proportion of the sample (25.5%), identifying as male was associated with better weight gain prevention than those identifying as female. This finding is consistent with data from weight loss studies that show better outcomes in males versus females [12, 21, 37, 45, 46]. Additional research is needed to confirm and explore the gender difference in weight maintenance studies. It should be pointed out that the retention rate was very high, 90.2%, for those in the intervention group. Those participants who dropped out had higher lifetime maximum weights and were younger. A similar pattern was observed when comparing non-adherent participants and adherent participants in the intervention group. However, these patterns were not observed in the control group participants. Altogether, these observations might suggest that daily self-weighing intervention might be less acceptable among younger participants or participants with higher lifetime maximum weights. One of the major critiques of many effective interventions of previous weight gain prevention studies is that they were labor-intensive, costly, and require constant attention from the researchers [11,21,43,47], possibly limiting the adoption of such measures after the studies ended. Our study indicated the feasibility of using daily self-weighing as a simple intervention to prevent age-related weight gain in this population by showing a high retention rate for sustaining daily self-weighing over two years. Additionally, among intervention group participants that completed the study, 9 out of 10 reported "yes" to a question "after the study ends, will you continue to weigh yourself?", which might imply the acceptability of daily self-weighing as a low-cost, low-intensity intervention among this population. The results of

the current study along with considerable evidence from the literature strongly suggests that self-weighing is quite effective at preventing age-related weight gain. What is responsible for the effectiveness of self-weighing when most attempts to prevent age-related weight gain fail? Several years ago we introduced the term caloric titration method (ctm) to describe the self-weighing technique as a way to reduce age-related weight gain [48]. The ctm uses not only daily weight measurements, but also displays the user's most recent eight weights on a graph displayed on the screen of the scale for the user to view when their current measurement is completed. The ctm emphasizes the use of the scale as a device that allows one to "titrate" the amount of food that will be consumed or the amount of exercise one would do in order to hold body weight to a designated value. Body weight in itself fluctuates on any given day. These daily fluctuations reflect changes in body water, glycogen, and gastrointestinal fill. The value of viewing the graph of the recent history of weights lies in the fact that the participants see that although body weight on any day is variable, the trends in their weights over time more accurately reflect changes in body mass than any individual point. Moreover, seeing the relationship between an action (eating less) and a response (slope of the trend) is negative, may reinforce those behaviors to sustain a reduction in their intake and increases the participant's sense that they are in control of their weight, an important determinant of good mental health and well-being [48,49]. A final property of the ctm that may be responsible for its success to control weight is that it allows each individual to experiment with various eating and exercises conditions that best work for them to sustain for long periods of time. In our previous study with the ctm, we had participants use the ctm to lose weight. At the end of one year, the ctm participants lost an average of 8% of their original weight. What is important is that the participants continued to use the ctm to sustain their lost weight for one year [48-50] strongly suggesting that the ctm may be effective not only in preventing age-related weight gain as suggested in this paper, but also in preventing weight regain as well. Aware of the concerns about developing disordered eating with frequent self-weighing, we excluded individuals with a self-reported history of eating disorders at baseline, and our recruitment advertisement clearly indicated that the study would involve self-weighing. Over two years, two intervention group participants self-reported unfavorable psychological effects and withdrew from the study. The intervention group participants who completed the study and were adherent to the daily self-weighing intervention did not show a significant increase in depressive or disordered eating symptoms, which is consistent with previous findings that daily self-weighing is not associated with adverse psychological outcomes such as depression and disordered eating patterns. There are several strengths of this study. First, a randomized controlled trial design was used, allowing causality to be explored for daily self-weighing to prevent age-related weight gain over two years, which is a relatively long duration in order to test the effect of the daily self-weighing intervention on weight gain prevention. Second, the weight data of the intervention group participants were obtained by automatic transmission from the smart scale, reducing self-report bias. Third, we conducted both complete-case and per-protocol analyses to provide a more comprehensive understanding of the effect of daily self-weighing. Moreover, the retention rate of this two-year study is high for this low-contact, simple intervention, indicating a strong ability to apply the daily self-weighing strategy in real life. In addition, the study was conducted among workplace employees, which is more representative of the general population in age, occupation, and other socioeconomic characteristics than college students. Finally, this study provided a rigorous protocol for conducting a daily self-weighing study with questionnaires to obtain comprehensive information on the factors that could contribute to weight change in addition to the intervention. This study also has several limitations. First, participants were included in the study regardless of their self-weighing practice before the study. At baseline, 54.8% of the control group participants reported weighing themselves daily to weekly, which might contribute to a smaller effect size that this study might not be powered to detect. Additionally, if the weighing frequency to define daily self-weighing (70% of the total weighing days to account for missing data due to scale connection and vacation days of the participants) had been established a priori, it would be more objective, avoiding potential confirmation bias. Furthermore, we obtained only one weight measurement per participant at enrollment and two-year follow-up sessions, which might be easily affected by temporary changes in diet, physical activity, or other factors. Although additional information was obtained through surveys and interviews to help understand the potential weight fluctuation, it would be optimal to obtain the average of participants' weights in three consecutive days at both enrollment and two-year follow-up sessions to reduce the effect of temporary changes. However, such procedures might have reduced the retention rate significantly. Moreover, our participants were primarily white, highly-educated women who were weight conscious, which limits the generalizability of the findings. Therefore, future studies should consider the best methods to recruit a more diverse sample of the employee populations, perhaps through masking the study purpose for recruitment. Moreover, the initial target population was employees between 18-40 years old, when the most rapid age-related weight gain occurs. But due to the limited number of volunteers in that age range, the age criterion was relaxed to achieve the desired sample size. The average age of the participants was 43.2 years old at baseline, which is outside the 18-40 age range. Thus, the rate of weight gain might be lower than 1 pound (0.45 kg) per year, making it harder to be observed.

Conclusions

Although the complete-case analysis found no significant between-group difference in two-year weight change among all participants who completed the two-year study, a post hoc, per-protocol analysis, where participants who did not adhere to their allotted group were removed from the analysis, did demonstrate a statistically significant effect of self-weighing to suppress age-related weight gain. These results suggest that adherence to daily self-weighing is critical in the success of weight gain prevention and might explain many discrepant findings in previous weight gain prevention studies [11,12,13,14,19,20]. These results suggest that daily self-weighing in itself might be a feasible, inexpensive, and low-intensity intervention to prevent age-related weight gain among individuals that can adhere to daily self-weighing for at least 5 days per week in this population. By preventing age-related weight gain, daily self-weighing may decrease the risk of developing obesity, thereby reducing the economic costs caused by those diseases associated with obesity.

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