The Dietary Intervention to Enhance Tracking with Mobile Devices (DIET Mobile) Study: A 6-Month Randomized Weight Loss Trial

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Objective: To examine the use of two different mobile dietary self-monitoring methods for weight loss.

Methods: Adults with overweight ($n = 81$; mean BMI 34.7 ± 5.6 kg/m^2) were randomized to self-monitor their diet with a mobile app (App, $n = 42$) or wearable Bite Counter device (Bite, $n = 39$). Both groups received the same behavioral weight loss information via twice-weekly podcasts. Weight, physical activity (International Physical Activity Questionnaire), and energy intake (two dietary recalls) were assessed at 0, 3, and 6 months.

Results: At 6 months, 75% of participants completed the trial. The App group lost significantly more weight (-6.8 ± 0.8 kg) than the Bite group (-3.0 ± 0.8 kg; group $\times$ time interaction: $P < 0.001$). Changes in energy intake (kcal/d) (-621 ± 157 App, -456 ± 167 Bite; $P = 0.47$) or number of days diet was tracked (90.7 ± 9.1 App, 68.4 ± 9.8 Bite; $P = 0.09$) did not differ between groups, but the Bite group had significant increases in physical activity metabolic equivalents ($+2015.4 \pm 684.6$ min/wk; $P = 0.02$) compared to little change in the App group (-136.5 ± 630.6; $P = 0.02$). Total weight loss was significantly correlated with number of podcasts downloaded ($r = -0.33$, $P < 0.01$) and number of days diet was tracked ($r = -0.33$, $P < 0.01$).

Conclusions: While frequency of diet tracking was similar between the App and Bite groups, there was greater weight loss observed in the App group.

Introduction

One of the cornerstones of behavioral weight loss treatment is dietary self-monitoring (the systematic recording of foods and beverages consumed each day) (1). Adherence to dietary self-monitoring has been associated with greater weight loss (2), but self-monitoring can be burdensome (3) and can decrease over time (2). Self-monitoring smartphone apps have the potential to make diet tracking easier and engaging and therefore improve weight loss (4). However, even use of apps may not prevent a decline in self-monitoring adherence (5). While use of electronic methods of dietary self-monitoring is promising, there is still a law of attrition that occurs in digital health interventions in which users discontinue use of technology-based components over time (6).

Research has demonstrated that accuracy is not as important as frequency and adherence to self-monitoring for weight loss (7); therefore, finding ways to reduce burden to increase the frequency of self-monitoring may be more important than focusing on accurate

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and detailed methods. The field of mobile dietary self-monitoring has still primarily relied on apps that require a user to enter in foods and beverages consumed, either by typing in the names of items, using a bar code scanner, or taking a photograph of the item (8,9). In comparison to diet monitoring, mobile physical activity (PA) tracking has become much more objective and automated, allowing users to wear a device that tracks movement (10).

The goal of the present study was to test a more automated approach to dietary self-monitoring compared to a traditional diet self-monitoring app as part of a 6-month, behavioral, randomized weight loss intervention. The Bite Counter is a wrist-worn device that monitors intake by counting bites through the use of a micro-electromechanical gyroscope (11). Users turn on the device at the start of eating and off at the end. During eating, it displays bite count for the current eating activity and allows users to review total bites consumed throughout the day (12). Because of the more automated nature of the Bite Counter device, we hypothesized that participants randomized to use the Bite Counter would lose significantly more weight by 6 months than those assigned to use a traditional diet mobile app.

Methods

The Dietary Intervention to Enhance Tracking with mobile devices (DIET Mobile) study was a 6-month randomized weight loss trial comparing two diet self-monitoring methods: a traditional diet app (Calorie Counter by FatSecret) and the wearable Bite Counter device. Adults with overweight or obesity (BMI 25-49.9 kg/m^2) who were interested in losing weight, owned an Android or iPhone, were between the ages of 18 and 65 years, had a stable medical status (e.g., no uncontrolled thyroid conditions or diabetes), and were willing to accept a random assignment were recruited through work site email lists, fliers, and newspaper ads. Participants attended an orientation session to complete a consent form and baseline questionnaires.

Questionnaires included demographic questions and the International Physical Activity Questionnaire, which assessed PA as an estimated metabolic equivalent (MET) of energy expenditure in minutes per week (13). Participants also completed a 24-hour dietary recall (representing a weekday) online using the Automated Self-Administered 24-hour Dietary Recall (14). Participants were contacted after the orientation meeting to complete a second unannounced dietary recall (representing a weekend day) from their home or over the phone with study coordinators.

Once all participants completed baseline questionnaires, a study coordinator randomized them to a group using a computerized random-number generator. Prior to revealing assignment, height and weight were assessed by trained assessors who were blinded to study condition at a research university. Weight was measured in light street clothes without shoes using a calibrated digital scale (Seca 869, Hamburg, Germany) accurate to 0.1 kg. Height was measured using a stadiometer (Seca 213). Measures were assessed at baseline and at 3 and 6 months. The University of South Carolina Institutional Review Board approved the study, and all participants gave written informed consent. Participants received a $20 incentive for completion of assessment activities at the 3-month and 6-month time points.

Intervention

The DIET Mobile study was entirely remotely delivered. Participants only attended in-person visits for data collection purposes. Regardless of group assignment, all participants received the same twice-weekly podcasts. The podcasts, which have been used in previous weight loss research and are described elsewhere (15,16), delivered the behavioral content of the program (based on social cognitive theory (17) and the Diabetes Prevention Program) (18). At the baseline assessment visit, participants were instructed on how to download and listen to the podcasts, and they received a test podcast to ensure their mobile device could download and play the files. Participants were emailed a link to a new podcast twice per week, allowing for objective assessment of podcast utilization. There were 48 total podcasts over the course of the 6-month study. Participants were also informed of their group assignment: diet tracking mobile app (App group) or wearable Bite Counter (Bite group).

App group

Participants in the App group received an overview of the FatSecret app in their baseline assessment session. Participants downloaded the app and practiced entering a variety of foods and scanning bar codes of food products. Any technical difficulties were addressed, and participants informed study personnel of their FatSecret username. This allowed study personnel to use FatSecret's professional interface to track usage of the app. Participants were told to record all foods and beverages consumed each day in order to track total daily energy intake. In order to promote weight loss of 1 to 2 lb/wk, participants received a calorie goal for weight loss that has been successfully used in other behavioral weight loss studies (1,200 kcal/d for participants weighing ≤ 90 kg, 1,500 kcal/d for 91-112 kg, and 1,800 kcal/d for ≥ 113 kg) (19). Participants were also encouraged to self-monitor their exercise by tracking steps. Participants were provided with a list of free pedometer apps or were given a pedometer (PedUSA CW Step Pedometer, Pedometers USA, Warminster, Pennsylvania) if they did not want to use an app ($n = 3$ requested one).

Bite group

Bite participants received a Bite Counter device and an overview of how to use the device at their baseline assessment session. The Bite Counter looks like a watch, displays digital time when not in use, and has a square face that measures 1.25 inches on each side. Participants were shown how to download software to their work or home computer that would allow syncing/uploading of their Bite Counter data for objective tracking. Alternatively, participants could attend a monthly in-person visit to have a study staff member sync their device ($n = 4$ chose this). Participants practiced using the Bite Counter by eating a snack and learning how to turn the device on and off and view bites. Participants were instructed to wear the device on their dominant hand and to use their nondominant hand to drink noncaloric beverages such as diet soda. Technical difficulties (syncing issues, assuring display time was correct, etc.) were addressed during this session, and participants were told to turn on the device at the beginning of an eating session and off when finished. Similar to the App group, Bite group participants received a personalized
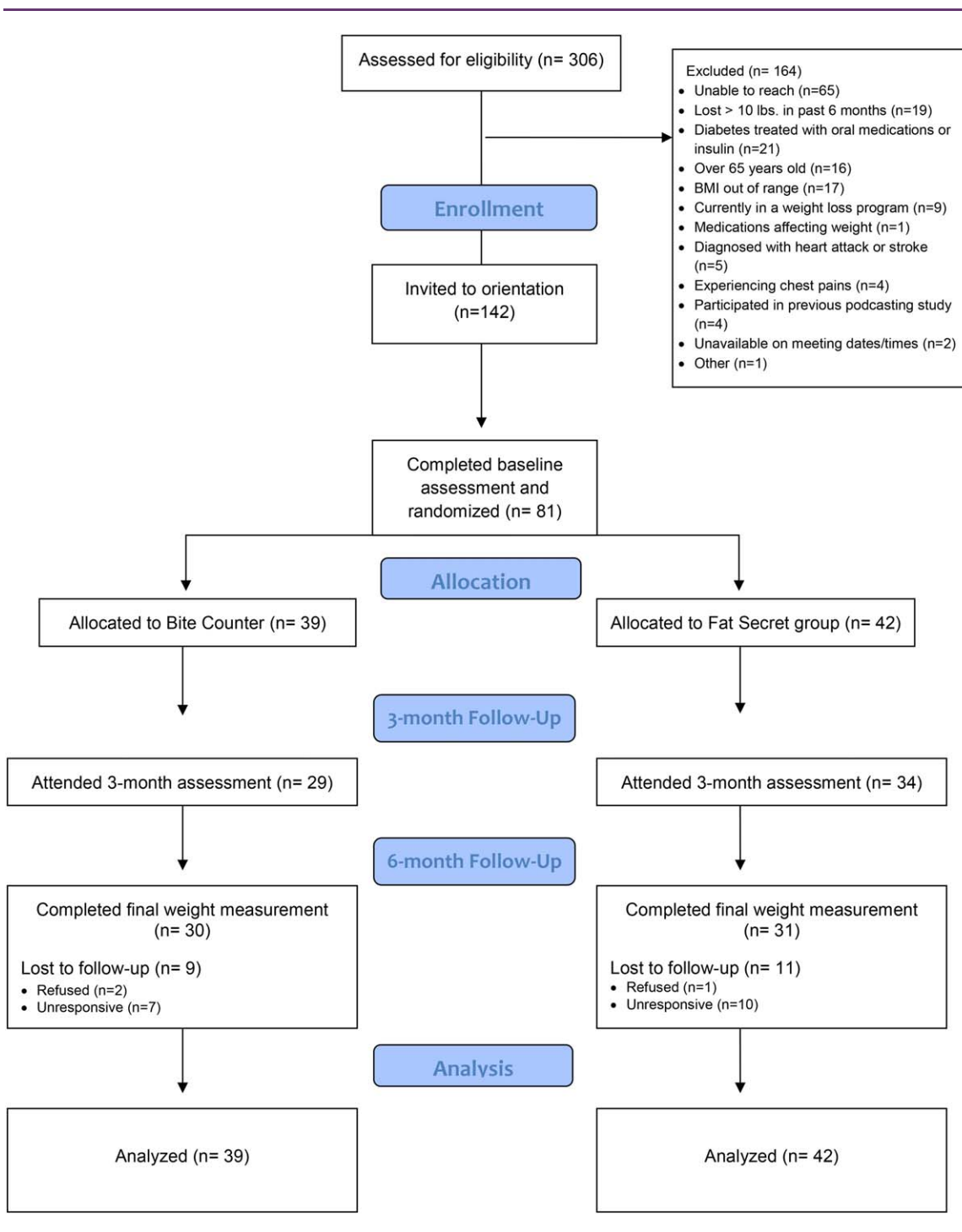
Figure 1 DIET Mobile CONSORT flow diagram. [Color figure can be viewed at wileyonlinelibrary.com]

bites-per-day goal based on the same kilocalories-per-day goal for the App group. Inspired by the Mifflin-St Jeor formula used to calculate resting metabolic rate (20), previous work developed a formula that predicts an individual's kilocalories per bite (KPB) based on demographic variables: KPB (male) $= 0.0967 \times$ height (cm) $+ 0.0992 \times$ weight (kg) $- 0.248 \times$ age; KPB (female) $= 0.0528$ $\times$ height (cm) $+ 0.0640 \times$ weight (kg) $- 0.0534 \times$ age. These equations were developed using previous free-living data in which participants wore the Bite Counter for 2 weeks, recording caloric intake using the Automated Self-Administered 24-hour Dietary Recall (21). With this formula, kilocalories consumed can be estimated as kilocalories $=$ bites $\times$ KPB. This formula was tested on a separate data set

TABLE 1 Baseline demographics and BMI of study participants in the DIET Mobile Study

	App group	Bite group	P value for difference among groups
_n_	42	39	
Mean age ($\pm$SD)	48.6 ± 11.7	47.5 ± 12.3	0.68
Gender (%)			0.88
Female	35 (83.3%)	32 (82.1%)	
Male	7 (16.7%)	7 (17.9%)	
Race (%)			0.90
Black	6 (14.3%)	7 (17.9%)	
White	35 (83.3%)	31 (79.5%)	
Other	1 (2.4%)	1 (2.6%)	
Education (%)			0.50
High school or some college	5 (11.9%)	7 (18%)	
College graduate	18 (42.9%)	19 (48.7%)	
Advanced degree	19 (45.2%)	13 (33.3%)	
Occupation (%)			0.20
No current employment	2 (4.8%)	1 (2.6%)	
Service occupation	5 (11.9%)	4 (10.3%)	
Technical, sales, administrative	4 (9.5%)	9 (23.1%)	
Executive, managerial	2 (4.8%)	3 (7.7%)	
Professional specialty	17 (40.5%)	7 (17.9%)	
Retired	4 (9.5%)	2 (5.1%)	
Other	8 (19%)	13 (33.3%)	
Marital status (%)			0.16
Married	29 (69%)	21 (53.8%)	
Other	13 (31%)	18 (46.2%)	
Mean BMI (kg/m^2) ($\pm$SD)	33.4 ± 4.8	33.4 ± 5.7	0.97
Energy intake (kcal/d) ($\pm$SD)	2,190 ± 886	2,264 ± 925	0.71

of 273 individuals eating a meal in a cafeteria, finding it to estimate calories consumed in an individual meal to ±50 kcal, with no differences in KPB among individuals with normal weight, overweight, or obesity (22). The device has been shown to accurately detect bites with a sensitivity of 75% and a positive predictive value of 89% (23). In a 2-week validation study, 77 participants wore the Bite Counter to assess all eating occasions and completed a 24-hour dietary recall each day. Mean daily bite count and daily kilocalories for each person were moderately correlated at 0.53 (21). In addition to tracking bites, the Bite Counter also had a built-in pedometer, which tracked steps taken each day, and participants were encouraged to use this feature to self-monitor exercise.

Both groups

The kilocalories-per-day and bites-per-day goals for both groups were provided as a starting estimate. If weight loss was less than 0.5 lb/wk, target goals were decreased in order to promote weight loss. The number of days that diet was tracked was objectively assessed during the study for both groups (via professional interface for FatSecret or examining usage of Bite Counter via a researcher interface). A day of tracking was operationalized as a participant having tracked any food or beverage on the app for the day or logging any bites with the Bite Counter, which is similar to methods

used in other weight loss studies (24-27). There were 168 possible days that diet could be self-monitored.

Statistical analyses

For differences in baseline characteristics, independent sample _t_ tests were used for continuous variables and a χ^2 test of independence was used for categorical data and differences between groups for achieving 5% weight loss and meeting recommended energy goals. Intent-to-treat analysis was conducted. Repeated-measures models were estimated for weight and other outcomes using PROC MIXED in SAS (SAS Institute, Cary, North Carolina). The models included time, group, and a time × group interaction with no other covariates. The full information from the available data was used in each model to provide unbiased estimates of the treatment effect in the presence of attrition at the 3- and 6-month time points. Contrasts were constructed comparing weight loss (or change in other outcomes) at 3 and 6 months between groups. For comparing groups on number of podcasts downloaded and days with diet recorded, simple unadjusted _t_ tests were used.

A similar previous 6-month trial was used to conduct sample size calculations ($\alpha = 0.05$ and power $1 - \beta = 80\%$) based on expected differences between groups in self-monitoring frequency (15). In that study, participants who self-monitored for a mean of 6 d/wk

TABLE 2 Weight loss and other outcomes by group presented as means (SE)

	App group (n = 42)	Bite group (n = 39)	P value for difference between groups[a]
Weight change (kg)			
3 months	−4.7 (0.7)[a]	−2.8 (0.8)[a]	0.07
6 months	−6.8 (0.8)[a]	−3.0 (0.8)[a]	0.001
Change in energy intake (kcal/d)			
3 months	−761.4 (147.3)[a]	−479.8 (158.8)[b]	0.20
6 months	−620.7 (157.3)[a]	−456.2 (166.9)[b]	0.47
Change in total metabolic equivalents (METs min/wk)			
3 months	+675.5 (590.5)	+1321.1 (639.6)[c]	0.46
6 months	−136.5 (630.6)	+2015.4 (684.6)[b]	0.02
Total number of podcasts downloaded (out of 48 episodes)	31.0 (2.7)	26.1 (2.8)	0.22
Total number of days diet was recorded (out of 168 possible days)	90.7 (9.1)	68.4 (9.8)	0.09

[a]$P < 0.001$ for within-group changes for App or Bite group participants.
[b]$P < 0.01$ for within-group changes for App or Bite group participants.
[c]$P < 0.01$ for within-group changes for App or Bite group participants.

($n = 10$) lost a mean of $11.6\% \pm 7.1\%$ body weight, compared to those who self-monitored a mean of 3 d/wk ($n = 12$) who lost $2.8\% \pm 4.1\%$ body weight, corresponding to an effect size of 1.5 and seven participants needed per group. However, it was anticipated that the differences in self-monitoring frequency may be lower. Therefore, we also compared weight loss between those who self-monitored for 2 d/wk or less (which was the study mean for self-monitoring frequency; $-0.4\% \pm 3.6\%$ weight loss) and those who self-monitored more than 2 d/wk ($-5.8\% \pm 5.8\%$), which corresponded to an effect size of 0.53 and 45 participants per group. Allowing for 20% attrition at 6 months gave us a minimum of 17 participants for a large effect size and 108 for a moderate effect size.

Results

Data were collected between 2015 and 2016. There were 306 individuals who completed a screening questionnaire online (Figure 1), of whom 164 were excluded (primarily because we were unable to contact them), 142 were invited to orientation, and 81 completed all baseline assessments and were randomized to either the Bite ($n = 39$) or App group ($n = 42$). Attrition was 16% at 3 months and 25% at 6 months, and it did not differ between groups at either 3 ($\chi^2 = 0.51$, $P = 0.48$) or 6 months ($\chi^2 = 0.11$, $P = 0.75$). Baseline characteristics did not differ between groups (Table 1). There were no differences in age, baseline BMI, sex, or race between those who completed the study and those who did not attend the 6-month assessment (Ps all > 0.05). The majority of participants (45%) were assigned a 1,500 kcal/d (or equivalent bite amount) limit, followed by 38% for 1,200 kcal/d and 17% for a 1,800 kcal/d limit. At 6 months, there was no difference in those who met their recommended kilocalorie goal (based

on dietary recalls) between the App (38%) and Bite groups (21%; $\chi^2 = 3.0$, $P = 0.08$).

Results are presented as means $\pm$ SE. Examining both groups combined, participants lost significant weight at both 3 (-3.7 ± 0.5 kg; $P < 0.001$) and 6 months (-4.9 ± 0.5 kg; $P < 0.001$). Weight loss over the study period was significantly different between groups at 6 months but not at 3 months (Table 2). At 6 months, the App group had lost significantly more weight (-6.8 ± 0.8 kg) compared to the Bite group (-3.0 ± 0.8 kg; group × time interaction: $P < 0.001$). In addition, significantly more App group participants achieved a 5% weight loss at 6 months ($n = 18$, 43%) than in the Bite group ($n = 8$, 21%; $\chi^2 = 4.6$, $P = 0.03$). Examining within-group changes, both groups achieved significant weight loss at both 3 and 6 months. Interestingly, changes in reported energy intake did not differ by group at either 3 or 6 months; however, reported energy expenditure did differ. The Bite group had significant increases in reported PA METs ($+2,015.4 \pm 684.6$ min/wk; $P = 0.02$), while there was little change in the App group (-136.5 ± 630.6; $P = 0.02$).

Use of intervention components was also examined (Table 2). There were no differences in total number of podcasts downloaded or days diet was self-monitored between groups, indicating equal levels of engagement in intervention-related activities. Weight loss at 6 months was significantly and moderately correlated with the number of podcasts downloaded ($r = -0.33$, $P < 0.01$) and the number of days diet was tracked ($r = -0.33$, $P < 0.01$). These correlations were also examined in a two-variable regression model that indicated a combined R^2 of 0.13 for number of podcasts and days diet was tracked as simultaneous predictors of 6-month weight loss. Standardized β coefficients were -0.20 for number of podcasts downloaded and -0.20 for days that diet was recorded, with the combined effect being statistically significant

($P = 0.02$). Interpretation of this simultaneous effect is difficult due to the moderately strong correlation ($r = 0.67$, $P < 0.01$) between the predictors, but the correlation coefficients and standardized betas are both very similar, indicating both factors influenced weight loss.

Discussion

Mobile health approaches to obesity treatment have the potential to reach a larger population than traditional face-to-face approaches (4), so it is important to include dietary self-monitoring approaches that are evidence-based, easy to use, and engaging (28,29). The present study examined two different approaches to dietary self-monitoring: the mobile app and the wearable Bite Counter. The study's primary hypothesis was that the Bite group would self-monitor diet more frequently and, in turn, would lose more weight than the App group. The present study did not confirm the primary hypothesis—in fact, the results were in the opposite direction. The App group lost significantly more weight than the Bite group, with no differences in self-monitoring frequency. There were no differences in reported energy intake; however, reported energy expenditure did differ, favoring the Bite group. The Bite group was told to use the built-in pedometer in the Bite Counter, while the App group was provided with a list of free pedometer apps or a wearable pedometer. It is possible that because the pedometer was already built into the Bite Counter device, the Bite group was able to self-monitor PA more effectively, without the requirement of another app or device. There was also no difference between groups in number of podcasts downloaded, indicating that each group received the behavioral content of the intervention at equal rates. In addition, there were no differences in frequency of diet self-monitoring days, indicating that participants adhered to diet self-monitoring equally. However, frequency of self-monitoring and number of podcasts downloaded both appeared to be important for weight loss, regardless of group assignment.

There are a few possible reasons why the App group lost more weight than the Bite group. One reason could be the difficulty of using the Bite Counter, which required participants to remember to turn the device on and off at each eating occasion. Participants frequently mentioned that they either forgot to turn the device on or left the device on well after eating. The inability to edit this data may have left some participants frustrated and less willing to regularly use it. Another possibility is that bite limits were not accurate to promote weight loss. Although personalized limits were calculated based on prior research and bite limits were adjusted based on rate of weight loss, the limits may not have been low enough to promote adequate weight loss. Lastly, tracking energy intake may be a more sensitive feedback mechanism for behavior than tracking bite intake, as the energy amount per bite can vary greatly (23). It is possible that App participants changed the content of their diet more than the Bite group. However, both groups received the same dietary advice via podcast and both reported similar changes in energy intake.

While the App group lost more weight, both groups lost more weight than was observed in a previous 6-month weight loss study examining the use of similar podcasts and comparing paper journal diet tracking to FatSecret tracking (15). In that study, there was no difference between groups, with both groups losing a mean of 2.4 kg, which is less than what was observed in either the Bite or App group. In the present study, participants knew their use of the Bite Counter or the App was being regularly monitored by study personnel, something that was not possible in the previous study (15). Therefore, weight loss was potentially higher in the present study due to participants knowing their self-monitoring behavior was being observed, which can impact behavior (30). The Hawthorne effect, which has been understudied in the area of diet-related behaviors and weight loss, has the potential to impact adherence to recommended behaviors. For example, a previous study found that people use less electricity in their homes just by being reminded they are in a study about electricity use (31). In addition, the weight loss observed in both groups was greater than what has been observed in many other mobile app-based weight loss interventions (32,33). One meta-analysis examined both mobile (text messaging, apps, etc.) and Web-based electronic health (eHealth) weight loss interventions (33). Relevant to the present study, authors of the meta-analysis compared weight loss between participants assigned to a standard eHealth intervention versus eHealth with additional features ($n = 13$ studies), finding the additional features led to a mean difference of 1.46 kg greater loss (33). Of those 13 studies, the majority observed weight losses that were less than what was observed in the present study (33). In addition, frequency of dietary self-monitoring was similar in the present study (54% adherent App, 41% adherent Bite) to other studies using eHealth approaches, finding the percentage of number of days adherent to range between 53% and 60% (24-27).

Regardless of method used, frequency of diet tracking was associated with weight loss. Future studies should consider offering participants a variety of choices for dietary self-monitoring or trying multiple options simultaneously. Providing participants with the opportunity to try several self-monitoring methods may increase user control and decrease cognitive load, both of which have been shown to mediate the relationship between a remotely delivered weight loss intervention and weight loss outcomes (34).

The present study has several strengths. The study compared two active conditions with differing types of feedback using two different mobile methods of dietary self-monitoring; the Bite Counter device was compared to a more traditional mobile app self-monitoring method for diet tracking. Objective data were used to assess device usage, podcast downloads, and weight loss, and data assessors were blinded to condition. The present study also has some limitations. Self-report was used for PA, and use of more objective measures (e.g., accelerometers) would have strengthened this assessment. Energy intake may have been underreported (35). Recruitment was a challenge even using varying recruitment methods. The study fell short of recruiting 108 participants, despite having 142 participants invited to orientation. This was potentially due to a historic flood that occurred in South Carolina during the fall of 2015 as recruitment began (36). Secondary outcomes (energy intake and PA) may have been underpowered to detect differences. In addition, a 20% attrition rate was expected at 6 months, and the study saw a slightly higher attrition rate of 25%. While attrition was greater than intended, 25% attrition is similar to what has been observed in several other remotely delivered weight loss interventions (37-39). No differential attrition rates were observed between groups in the present study.

Conclusion

Dietary self-monitoring is an important component of behavioral weight loss interventions (1), but self-monitoring can be burdensome (3) and can decline over time (2). Therefore, finding ways to make dietary self-monitoring easier and more engaging may improve adherence rates and, in turn, improve weight loss outcomes. Alternately, it is possible that passive monitoring (e.g., Bite Counter) is not as engaging as more active monitoring that requires regularly entering foods. Previous research has indicated that frequent checking of an app can lead to habit formation and more sustained usage (40). This active monitoring may have allowed for App group participants to create a more long-term diet tracking habit and be more engaged.

The present study examined two potential options for dietary self-monitoring, finding that both the App and Bite groups self-monitored at equal rates, with greater weight loss in the App group. Both groups lost weight, however, so future studies should consider providing participants with a choice of self-monitoring methods in order to take preference into account and improve adherence. O

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