

ORIGINAL ARTICLE

Applying a technology-based system for weight loss in adults with obesity

R. J. Rogers¹, W. Lang², B. Barone Gibbs¹, K. K. Davis¹, L. E. Burke³, S. J. Kovacs¹, L. A. Portzer¹ and J. M. Jakicic¹

¹Department of Health and Physical Activity, Physical Activity and Weight Management Research Center, University of Pittsburgh, Pittsburgh, PA USA; ²Division of Public Health Sciences, Department of Biostatistical Sciences, Wake Forest University, Winston-Salem, NC USA; ³School of Nursing, Health and Community Systems, University of Pittsburgh, Pittsburgh, PA USA

Received 8 May 2015; revised 1 October 2015; accepted 14 October 2015

Address for correspondence: RJ Rogers, Department of Health and Physical Activity, Physical Activity and Weight Management Research Center, University of Pittsburgh, 32 Oak Hill Court, Pittsburgh, PA 15261, USA.
E-mail: rjr26@pitt.edu

ClinicalTrials.gov Identifier: NCT01537796

Summary

Objective

The aim of this study was to compare an in-person, group-based behavioral weight loss intervention to technology-based interventions in adults with obesity.

Methods

Adults ($N = 39$; body mass index: $39.5 \pm 2.8 \text{ kg m}^{-2}$; age: 39.9 ± 11.5 years) participated in a 6-month program with randomization to one of three intervention groups: standard behavioral weight loss, a technology-based system combined with a monthly intervention telephone call (TECH) or an enhanced technology-based system combined with a monthly intervention telephone call (EN-TECH). All groups were prescribed an energy-restricted diet and physical activity. Assessments occurred at 0, 3 and 6 months. Separate mixed-effects models using unstructured dependence structure were fit to the outcomes.

Results

Weight loss (least square means \pm standard error) at 6 months was $-6.57 \pm 1.65 \text{ kg}$ in standard behavioral weight loss, $-5.18 \pm 1.72 \text{ kg}$ in TECH and $-6.25 \pm 1.95 \text{ kg}$ in EN-TECH (p -value for time effect ≤ 0.0001). A similar pattern was observed for change in body mass index, waist circumference and percent body fat. There was a decrease in total energy intake ($p = 0.0005$) and percent dietary fat intake ($p = 0.0172$), and physical activity increased ($p = 0.0003$).

Conclusions

Findings provide initial information on the use of technology-based interventions that include wearable devices combined with brief monthly telephone calls for weight loss in adults with obesity.

Keywords: e-health, m-health, obesity, weight loss.

Introduction

The prevalence of adults with obesity (body mass index [BMI] $\geq 30 \text{ kg m}^{-2}$) in the USA is approximately 35%, with approximately 15% classified with a BMI $\geq 35 \text{ kg m}^{-2}$ (1). The health-related consequences of increased BMI are

of public concern as excess body weight has been shown to be associated with higher rates of mortality, chronic diseases and other health consequences (2,3). Lifestyle interventions that focus on reducing energy intake and increasing energy expenditure have been shown to be effective in reducing body weight when combined with behavioral strategies to facilitate engagement in and maintenance of these behaviors (4) The reductions in body weight elicited from these interventions have

ClinicalTrials.gov Identifier: NCT01537796

demonstrated improvements in health consequences associated with obesity (3,5–7).

Lifestyle interventions for weight reduction are typically intensive and require in-person group or individual sessions, with these sessions typically occurring weekly for a period of 3 to 6 months. This intensive approach, while effective for weight loss, may not be appealing to individuals who are unable or unwilling to attend these intervention sessions. Thus, there is a need to provide alternative intervention options for individuals seeking weight loss. These alternative interventions may require a model that utilizes a less intensive and more practical approach while retaining key behavioral strategies, such as self-monitoring and feedback, within the context of the intervention.

As an alternative to in-person interventions, there has been an increase in the application of technology to deliver weight loss interventions. Recent technology-based intervention approaches have utilized web-based portals (8–11), text messaging (12), smartphone or mobile apps (13) and podcasts with social media (14,15). The mean BMI in the majority of these studies was $<35 \text{ kg m}^{-2}$ (8–12,14,15). Thus, there are limited data on whether technology-based interventions can be used to facilitate weight loss in individuals with higher levels of obesity. This may be of clinical importance because more intensive in-person interventions have been shown to be equally effective for weight loss across a wide range of obesity (16), and confirming this pattern in less intensive technology-based interventions would provide additional treatment options.

Wearable technologies that provide feedback on physical activity or energy expenditure may provide an additional intervention option. Recently, Martin *et al.* (17) incorporated the use of an activity monitor to track steps walked within the context of a smartphone technology-based intervention. This intervention also included feedback and treatment recommendations using email, text messages and telephone contact equivalent to approximately 10 contacts per month from a weight loss counsellor. The mean weight loss was 9.4% of initial body weight in a group of 19 participants with a mean BMI of 30.2 kg m^{-2} . There have been a few studies in which wearable technology has also been incorporated into interventions with less frequent contact with a weight loss counsellor. Pellegrini *et al.* (18) utilized a wearable monitor to facilitate feedback on energy expenditure to individuals with obesity ($33.7 \pm 3.6 \text{ kg m}^{-2}$), and the group receiving this technology combined with a monthly telephone contact with a counsellor achieved weight loss of 5.8 kg at 6 months. While these results are promising, these findings require replication and should be examined in a sample of individuals representing a higher level of obesity to

determine if whether this form of wearable technology can be used as a clinical weight loss intervention option.

Therefore, the purpose of this study was to extend the findings of Pellegrini *et al.* (18) and to provide additional insight on the use of wearable technology combined with low frequency telephone contact with a counsellor on weight loss in adults with obesity.

Methods

Participants

Thirty-nine participants between 21 and 55 years of age were randomized to this study. Participants were included if they were sedentary (exercising $<60 \text{ min week}^{-1}$), deemed safe to participate in physical activity by stratification of low to moderate risk (19), had a BMI between 35.0 and 45.0 kg m^{-2} and had a compatible smartphone and access to the Internet with a computer. Participants were excluded if they were pregnant, had a physical limitation that prevented engagement in physical activity, were taking medications that affected blood pressure or body weight, had a history of chronic disease (diabetes, heart disease), were being treated for psychological problems (i.e. depression, bipolar disorder and others) or taking psychotropic medications within the previous 12 months, currently being treated for an eating disorder, were currently or recently enrolled in a weight loss study or commercial weight loss programme, had lost $>5\%$ of current body weight in the previous 3 months or had undergone bariatric surgery. After providing written informed consent, participants provided medical clearance from their physician prior to being eligible to undergo baseline assessments and randomization. All study procedures were approved by the University of Pittsburgh Institutional Review Board.

Intervention

This study used a randomized pretest and post-test design, with the intervention being 6 months in duration. Eligible participants were randomized to one of three intervention groups: standard behavioral weight loss (SBWL), a technology-based system combined with a monthly intervention telephone call (TECH), or an enhanced technology-based system combined with a monthly intervention telephone call (EN-TECH).

Intervention components common to all randomized groups

Participants were prescribed an energy-reduced diet based on body weight, with caloric intake prescribed at

1,200 kcal d⁻¹ for participants <79.4 kg, 1,500 kcal d⁻¹ for participants 79.4 to <99.8 kg, 1,800 kcal d⁻¹ for participants 99.8 to <113.4 kg and 2,100 kcal d⁻¹ for participants ≥113.4 kg. In addition, dietary fat was prescribed at 20% to 30% of the total daily calories. The physical activity component included unsupervised home-based exercise, and was recommended at a moderate intensity defined as 3–6 metabolic equivalents, which is similar to brisk walking. Duration was initially prescribed at 100 min week⁻¹ and progressed to 200 min week⁻¹ by the 9th week of the intervention.

Standard behavioral weight loss

Standard behavioral weight loss attended weekly group meetings that were approximately 30–45 min in duration. These sessions addressed barriers associated with physical activity and dietary intake. If a session was missed, an attempt was made to schedule a make-up session prior to the next scheduled group session. Participants were provided with written materials at each meeting to supplement group discussions. Assessment of body weight occurred on an individual basis at the weekly meeting. Self-monitoring of dietary intake and physical activity was encouraged with the use of a paper diary in which the intervention staff provided weekly feedback regarding goal progress.

Technology-based system

Technology-based system did not attend the weekly group sessions. However, the identical intervention materials provided to SBWL were also provided to TECH, with these materials mailed each week. Participants in TECH were provided with a technology-based system. The BodyMedia® FIT System (Jawbone, Pittsburgh, PA) was utilized because the components of the technology can potentially facilitate self-monitoring, which has been shown to be important for weight loss (20–22). The technology included a wearable device worn on the upper arm that monitored physical activity and energy expenditure. This device has been previously validated for assessing energy expenditure by utilizing multi-sensor technology and a 3-axis accelerometer to provide estimates of energy expenditure from measures of galvanic skin response, skin temperature, heat flux and motion (23–25). Data from this wearable device could be viewed in real-time on a portable digital display that provided basic feedback on total energy expenditure and moderate-to-vigorous physical activity. Within the context of the intervention, participants used their personal computer to upload activity monitor data to a web-based portal to obtain more detailed information on energy expenditure

and physical activity. The web-based portal also allowed for self-monitoring of dietary intake and self-report of body weight. At the beginning of the intervention, one introductory in-person session was included to instruct participants on the technology components specific to TECH, and to review the common goals (dietary, physical activity) of the weight loss intervention. Participants in the TECH group received a scheduled intervention telephone call one-time per month. This telephone call was scheduled for approximately 10 min, and interventionists had access to the diet, physical activity and weight data from the participants' web-interface. This allowed for review of dietary, physical activity, energy expenditure and body weight progress prior to discussing behavioral change strategies with participants during the monthly telephone calls.

Enhanced technology-based system

Enhanced technology-based system received the same intervention as TECH. However, participants in EN-TECH were provided with an enhanced technology-based system to increase the capacity for temporal proximity of self-monitoring and feedback on key weight loss behaviors (energy intake and energy expenditure). The BodyMedia® FIT System with the LINK activity monitor (Jawbone, Pittsburgh, PA) was chosen because it used the same technology as the previous described FIT System, but also included Bluetooth® capability, which allowed for calories expended and physical activity time and intensity to be directly transmitted from the activity monitor to a smartphone app. The smartphone app also allowed for self-monitoring of dietary behaviors and self-report of body weight. Consistent with TECH, an introductory in-person session was included to instruct participants on the EN-TECH technology components, and to review the common goals (dietary, physical activity) of the weight loss intervention. EN-TECH also received the intervention telephone call one-time per month. Identical to TECH, the interventionist was able to access the participants' web-interfaces to review dietary, physical activity, energy expenditure and body weight progress prior to facilitating behavioral interactions with participants during the monthly telephone calls.

Outcome measures

Assessments were performed at baseline, 3 and 6 months as described subsequently.

Height, body weight and body mass index

Height and weight were measured in a lightweight hospital gown. Height was measured to the nearest 0.1 cm

using a wall-mounted stadiometer, and body weight was measured to the nearest 0.1 kg on a digital scale. BMI was calculated as kilograms per square meter.

Waist circumference

Waist circumference was assessed in a lightweight hospital gown and measured in duplicate to the nearest 0.1 cm using a Gulick tape measure. Waist circumference was taken horizontally at the peak of the iliac crest, with the average of two measures differing by ≤ 1.0 cm used for analysis.

Body composition

Body composition was assessed using bioelectrical impedance analysis. Measurements were taken with jewelry removed and the body in a supine position. Lean body mass was estimated using the equation proposed by Segel *et al.* (26) Percent body fat was computed as $[(\text{weight} - \text{lean body mass})/\text{weight}] \times 100$.

Physical activity

Leisure-time physical activity was assessed using the Paffenbarger Physical Activity Questionnaire (27,28). An interviewer queried on daily brisk walking performed for the purpose of transportation or exercise, flights of stairs climbed per day and participation in other forms of activity (sport, recreational and fitness activities). Participants reported this activity based on a typical week. Brisk walking and flights of stairs were converted to kcal of energy expenditure based on the procedures previously described (27,28). Other forms of physical activity were classified as light, moderate or vigorous based on the Compendium of Physical Activity (29,30) and then converted to kcal based on procedures previously described (27,28).

Dietary intake and eating behaviors

Dietary intake was assessed using a Food Frequency Questionnaire (Block, 2005.1) (31,32). The Eating Behavior Inventory was used to measure eating behaviors that may be related to successful weight loss such as self-monitoring of intake, refusing food, shopping practices and emotional eating (33).

Process measures

Data on process measures related to the intervention were obtained. Intervention contacts were recorded by intervention staff for weekly group attendance (SBWL) and

monthly telephone call completion (TECH, EN-TECH). Self-monitoring of dietary intake was defined as the number of days any intake was recorded in paper diaries (SBWL) or through the web interface (TECH, EN-TECH). Self-monitoring of physical activity was defined as the number of days activity was recorded in paper diaries (SBWL) or by wearing the activity monitor (TECH, EN-TECH).

Statistical analyses

IBM-SPSS (version 21.0) was used to compare groups on baseline descriptive data and for self-monitoring and intervention engagement data across the intervention period. Baseline comparisons were completed using a one-way analysis of variance or chi-square analysis for categorical variables. A one-way analysis of variance was used to compare self-monitoring components (diet, physical activity) between the intervention groups, with post-hoc comparisons performed using the Bonferroni procedure. An independent sample *t*-test was used to compare the completion of intervention telephone calls in TECH versus EN-TECH.

Separate mixed-effects models using unstructured dependence structure were fit to the outcomes using SAS version 9.4 (SAS Institute, Cary, NC). All randomized participants were included in these analyses with missing data assumed to be missing at random. Outcomes included weight, BMI, percent body fat, waist circumference, eating behaviors and dietary intake and physical activity. For each of these variables, the measurement at baseline, 3 and 6 months were analysed using a mixed-effects model with 3 time points. Inferences were focused on the main effects of weight change groups, time and the interaction effect between these two. Weight changes from baseline at 3 and 6 months were calculated and analysed using a mixed-effects model with baseline weight adjusted in the model as covariate. Least square means were obtained from the model and plotted to illustrate group by time interaction effect. The type I error rate is fixed at 0.05.

Results

Thirty-nine adults with obesity were randomized to the interventions described earlier (Table 1). Of the 39 participants randomized, 34 provided data at 3 months and 27 provided data at 6 months. The CONSORT diagram is provided in Figure 1.

Standard behavioral weight loss completed $74.0 \pm 26.8\%$ of the expected intervention contacts. TECH completed $83.3 \pm 22.5\%$ of the telephone calls compared

Table 1 Demographic characteristics of participants

Variable	Participant status	Total	SBWL	TECH	EN-TECH	p -value [†]
Number of participants	Randomized	39	14	12	13	
	Completing 3 months	34	13	12	9	0.052 [‡]
	Completing 6 months	27	10	9	8	0.748 [‡]
Weight (kg)*	Randomized	111.5 ± 11.5	110.9 ± 9.1	112.2 ± 10.5	111.6 ± 15.0	0.959
	Completing 3 months	110.7 ± 11.2	110.5 ± 9.4	112.2 ± 10.5	108.8 ± 15.0	0.799
	Completing 6 months	112.5 ± 11.0	113.0 ± 9.2	112.6 ± 12.1	111.6 ± 13.3	0.967
Body mass index (kg m ⁻²)*	Randomized	39.5 ± 2.8	39.5 ± 2.6	39.7 ± 2.9	39.3 ± 3.2	0.950
	Completing 3 months	39.5 ± 2.8	39.4 ± 2.6	39.7 ± 2.9	39.4 ± 3.4	0.946
	Completing 6 months	39.3 ± 2.7	39.1 ± 2.1	39.0 ± 2.8	39.8 ± 3.3	0.791
Age (years)*	Randomized	39.9 ± 11.5	39.7 ± 10.4	40.6 ± 9.5	39.5 ± 9.7	0.957
	Completing 3 months	40.5 ± 9.1	41.1 ± 9.5	40.6 ± 9.5	39.6 ± 9.0	0.931
	Completing 6 months	42.0 ± 9.0	43.6 ± 9.2	42.0 ± 9.0	39.9 ± 9.5	0.700
Gender (% female)	Randomized	79.5	85.7	75.0	76.9	0.766 [‡]
	Completing 3 months	82.4	84.6	75.0	88.9	0.685 [‡]
	Completing 6 months	77.8	80.0	66.7	87.5	0.574 [‡]
Ethnicity (% Caucasian/White)	Randomized	71.8	64.3	75.0	76.9	0.734 [‡]
	Completing 3 months	73.5	69.2	75.0	77.8	896 [‡]
	Completing 6 months	74.1	70.0	77.8	75.0	926 [‡]

*Data presented as mean ± standard deviation.

[†] p -value for randomized group.

[‡] p -value based on chi-square analysis.

EN-TECH, enhanced technology-based system; SBWL, standard behavioural weight loss; TECH, technology-based system.

with 62.8 ± 34.1% of the telephone calls in EN-TECH ($p = 0.088$). Duration of these calls was 11.3 ± 0.5 min in TECH and 11.5 ± 1.6 min in EN-TECH ($p = 0.677$).

Standard behavioral weight loss returned 12.4 ± 8.9 weekly self-monitoring diaries and self-monitored their diet for 84.6 ± 62.3 d. TECH and EN-TECH self-monitored their diet 80.0 ± 56.4 and 70.1 ± 66.9 d, respectively ($p = 0.828$). TECH wore the activity monitor 117.8 ± 106.3 d and EN-TECH wore the activity monitor 106.3 ± 66.7 d ($p = 0.624$). The activity monitor was worn for 11.2 ± 6.7 h d⁻¹ in TECH and 9.5 ± 7.1 h d⁻¹ in EN-TECH ($p = 0.550$). SBWL self-monitored their physical activity participation in the diary provided for a total of 56.4 ± 51.8 d.

Weight loss occurred in all intervention conditions across 6 months ($p < 0.0001$) (Table 2 and Figure 2). Weight loss (least square means ± standard error) at 3 months was -3.39 ± 1.04, -5.06 ± 1.08 and -4.76 ± 1.25 kg in SBWL, TECH and EN-TECH, respectively. Weight loss at 6 months was -6.57 ± 1.65 kg in SBWL, -5.18 ± 1.72 kg in TECH and -6.25 ± 1.95 kg in EN-TECH. A similar pattern was observed for change in BMI, waist circumference and percent body fat, with these outcomes showing a reduction across the 6-month intervention (Table 2). These findings were consistent when data were also analysed with baseline data carried forward for missing data or for only those participants

who provided data at all assessment periods (data not shown).

Energy expenditure in physical activity increased across the 6-month intervention ($p < 0.0001$) (Table 3). Data were reanalyzed with flights of stairs removed from the computation of energy expenditure, and a similar pattern of results was observed. Dietary intake showed a reduction in total energy intake and percent dietary fat intake ($p < 0.001$), with an increase observed for the Eating Behavior Inventory (Table 3).

Discussion

This study examined the use of TECH, EN-TECH and SBWL across 6 months in adults with Class II and Class III obesity. Within technology-based interventions, the wearable device used in this study was similar to that worn in prior studies conducted in adults classified as overweight or moderately obese (18,34,35). The technology used in TECH and EN-TECH was combined with a brief monthly intervention telephone call with a member of the intervention team. Results showed that weight loss was achieved across all treatment conditions (Table 2).

The magnitude of weight loss of adults in the current study with a mean BMI of 39.5 ± 2.8 kg m⁻² was comparable with that reported by Pellegrini *et al.* (18) in adults with

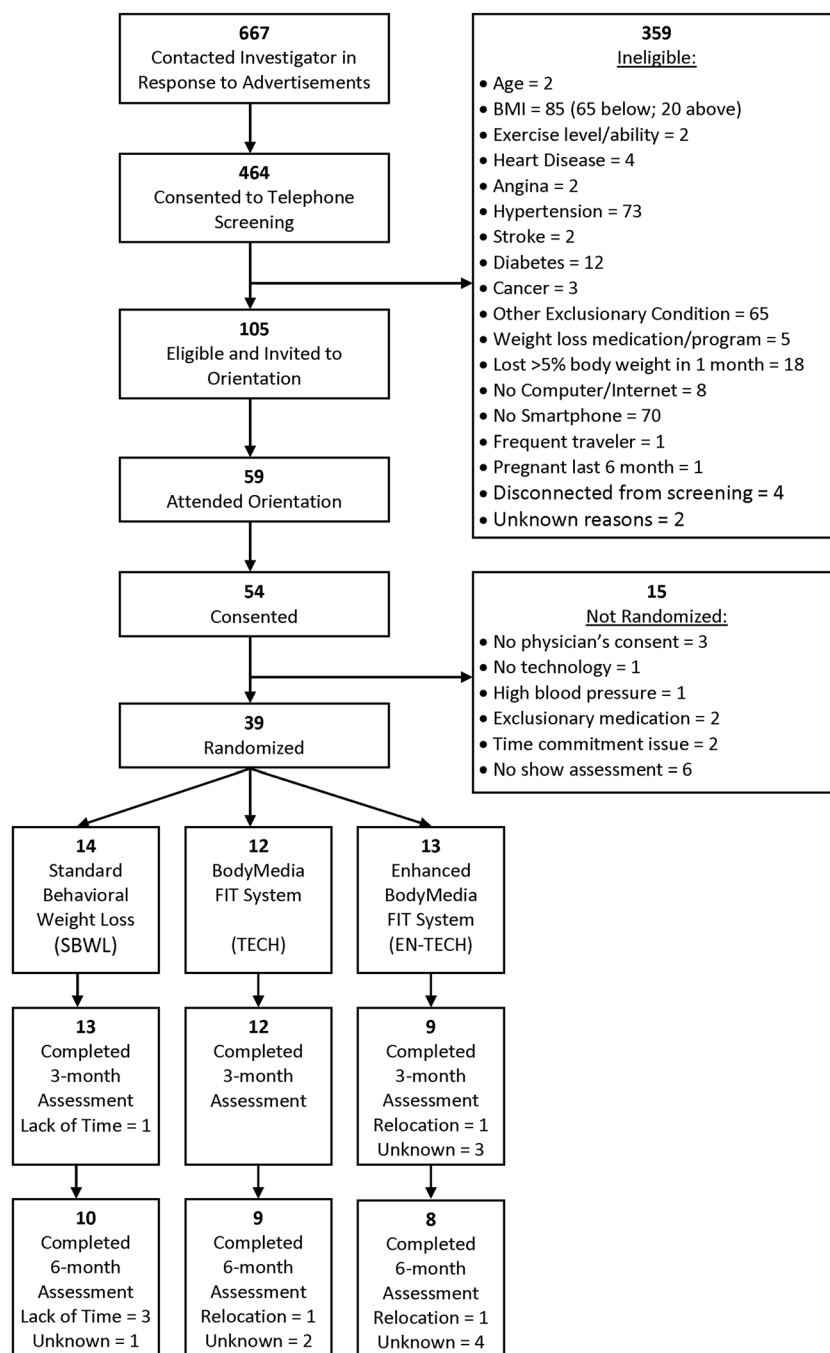


Figure 1 CONSORT diagram.

a mean BMI of $33.7 \pm 3.6 \text{ kg m}^{-2}$. In the current study, the weight loss achieved in both the TECH and EN-TECH interventions exceeds the weight loss at 4 and 9 months achieved with a similar technology system reported in a study of adults with a mean BMI of 35.7 kg m^{-2} (35). This may be a result of the current study combining the technology in TECH and EN-TECH with a brief once per month telephone call delivered by the intervention staff,

whereas telephone contact was not included in the intervention implemented by Shuger *et al.* (35) This may suggest that the weight loss achieved with the wearable technology system used in TECH and EN-TECH may be improved when combined with brief monthly telephone intervention contact.

While this study is not able to disentangle the influence of the technology from the telephone calls, as proposed

Table 2 Change in weight, waist circumference and body composition (least square mean \pm standard error)

Variable	Group	Assessments periods			Group effect	p-values	
		Baseline	3 months	6 months		Time effect	Group \times Time
Weight (kg)	SBWL	110.9 \pm 3.1	107.5 \pm 3.3	104.4 \pm 3.5	0.9652	<0.0001	0.0997
	TECH	112.2 \pm 3.4	107.2 \pm 3.6	107.1 \pm 3.7			
	EN-TECH	111.6 \pm 3.3	106.8 \pm 3.5	105.3 \pm 3.7			
BMI (kg m ⁻²)	SBWL	39.5 \pm 0.7	38.3 \pm 0.9	37.2 \pm 1.0	0.9530	<0.0001	0.1540
	TECH	39.7 \pm 0.8	37.9 \pm 0.9	37.8 \pm 1.1			
	EN-TECH	39.3 \pm 0.8	37.6 \pm 0.9	37.3 \pm 1.1			
Waist circumference (cm)	SBWL	119.1 \pm 2.4	115.5 \pm 2.6	115.1 \pm 3.0	0.7713	0.0002	0.6681
	TECH	122.8 \pm 2.6	116.4 \pm 2.8	118.2 \pm 3.2			
	EN-TECH	122.3 \pm 2.5	116.6 \pm 2.9	115.3 \pm 3.3			
Fat mass (kg)	SBWL	51.1 \pm 1.8	48.5 \pm 2.1	46.2 \pm 2.4	0.8966	<0.0001	0.5152
	TECH	51.3 \pm 1.9	48.0 \pm 2.3	47.7 \pm 2.5			
	EN-TECH	50.6 \pm 1.8	46.8 \pm 2.3	45.4 \pm 2.6			
Lean body mass (kg)	SBWL	59.7 \pm 2.2	59.0 \pm 2.3	58.3 \pm 2.2	0.9400	<0.0001	0.2297
	TECH	60.9 \pm 2.4	59.2 \pm 2.4	59.3 \pm 2.4			
	EN-TECH	61.0 \pm 2.3	60.0 \pm 2.3	59.4 \pm 2.3			
Percent body fat (%)	SBWL	46.2 \pm 1.1	45.1 \pm 1.3	44.2 \pm 1.5	0.7921	0.0005	0.7894
	TECH	45.8 \pm 1.2	44.7 \pm 1.4	44.4 \pm 1.6			
	EN-TECH	45.4 \pm 1.1	43.6 \pm 1.4	42.9 \pm 1.6			

BMI, body mass index; EN-TECH, enhanced technology-based system; SBWL, standard behavioural weight loss; TECH, technology-based system.

by DiClemente *et al.* (36), the telephone calls may have increased accountability, engagement and motivation of the participants. This may have resulted in improved weight loss compared with what would have been achieved with the technology when not coupled with the telephone calls. Other studies have also reported that the addition of personalized intervention contact to a technology-based intervention improves weight loss when compared with a technology program alone. For example, within the context of a web-based intervention, Tate *et al.* (37) found greater weight loss after 6 months when personalized feedback was provided via email from

a counsellor compared with automated computer feedback delivery.

The SBWL in the current study targeted both a reduction in energy intake and an increase in physical activity, and this resulted in weight loss of 6.6 \pm 1.7 kg at 6 months in this sample of adults with obesity. By comparison, Goodpaster *et al.* (38) reported weight loss of 10.9 kg at 6 months in adults with a BMI \geq 35 kg m⁻² in response to a group-based program that included both a diet and physical activity component. The greater weight loss observed in comparison with the current study may be a result of a number of factors. For example, Goodpaster *et al.* (38) provided commercially available meal replacements (shakes, nutrition bars) to study participants as part of the prescribed diet, which may have contributed to the improved weight loss. In addition, participants in the current study were required to have access to a computer, the Internet and a smartphone to be eligible, but participants in SBWL did not receive an intervention that involved the use of those technologies, which may have impacted compliance or engagement in a manner that influenced weight loss.

Self-monitoring is an important strategy for weight loss (20–22). This study showed that the technology used in TECH and EN-TECH did not improve self-monitoring of diet compared with the non-technology form of self-monitoring used in SBWL. However, it appears that the use of the wearable device to monitor physical activity occurred more often than a non-technology form of self-

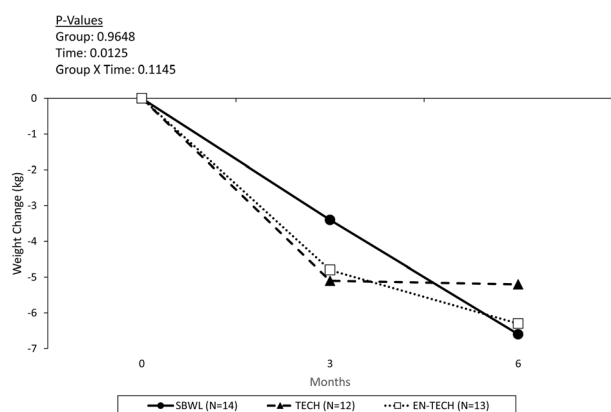
**Figure 2** Change in weight by intervention group.

Table 3 Change in dietary intake and physical activity (least square mean \pm standard error)

Variable	Group	Assessments periods			Group effect	<i>p</i> -values	
		Baseline	3 months	6 months		Time effect	Group \times time
Calories (kcal d ⁻¹)	SBWL	1897.5 \pm 260.2	1506.8 \pm 212.3	1477.7 \pm 222.0	0.6415	0.0005	0.6100
	TECH	2076.8 \pm 281.0	1804.1 \pm 224.7	1558.5 \pm 235.9			
	EN-TECH	2227.3 \pm 270.0	1931.5 \pm 232.4	1561.3 \pm 241.9			
Percent dietary protein intake (%)	SBWL	16.6 \pm 0.7	16.4 \pm 0.8	16.7 \pm 0.9	0.5002	0.3553	0.1248
	TECH	15.9 \pm 0.8	16.9 \pm 0.9	15.6 \pm 1.0			
	EN-TECH	14.5 \pm 0.7	15.0 \pm 0.9	16.8 \pm 1.0			
Percent dietary carbohydrate intake (%)	SBWL	44.7 \pm 2.0	47.3 \pm 1.8	50.1 \pm 2.1	0.5473	0.1741	0.5703
	TECH	45.0 \pm 2.1	46.5 \pm 1.9	47.8 \pm 2.2			
	EN-TECH	49.1 \pm 2.0	48.7 \pm 2.0	48.8 \pm 2.3			
Percent dietary fat intake (%)	SBWL	38.5 \pm 1.6	37.0 \pm 1.7	34.1 \pm 1.7	0.1857	0.0172	0.8421
	TECH	39.8 \pm 1.7	37.2 \pm 1.8	36.8 \pm 1.8			
	EN-TECH	35.6 \pm 1.6	33.5 \pm 1.9	33.6 \pm 1.9			
Eating behaviour inventory	SBWL	71.7 \pm 1.7	86.1 \pm 3.4	87.1 \pm 3.1	0.0942	<0.0001	0.9913
	TECH	65.7 \pm 1.9	80.5 \pm 3.5	81.3 \pm 3.2			
	EN-TECH	64.8 \pm 1.8	80.4 \pm 4.0	79.6 \pm 3.6			
Physical activity (kcal week ⁻¹)	SBWL	530.2 \pm 129.0	1294.9 \pm 314.5	1407.7 \pm 293.8	0.8694	0.0003	0.0870
	TECH	913.6 \pm 139.3	1135.2 \pm 330.0	1048.7 \pm 308.7			
	EN-TECH	444.5 \pm 133.8	1188.9 \pm 367.7	1933.3 \pm 335.0			

EN-TECH, enhanced technology-based system; SBWL, standard behavioural weight loss; TECH, technology-based system.

monitoring that was used by SBWL, but it does not appear that this resulted in greater changes in physical activity between the intervention conditions. Of interest is that enhancements in the technology included with EN-TECH may have allowed for improved temporal proximity of self-monitoring and feedback on energy balance. However, this did not improve weight loss, dietary changes or physical activity beyond that achieved with TECH or SBWL. These results may suggest that there are options for how to effectively self-monitor that may include non-technology (e.g. paper diaries) and technology options. This should be considered when implementing self-monitoring strategies within a clinical weight management intervention.

This study was conducted to provide insight on engaging adults with obesity in a technology-based intervention that included a wearable device, a web-interface or use of a mobile device and a monthly telephone call. However, there are limitations to this study that should be considered. The sample size is small, which limits our ability to make definitive conclusions regarding efficacy or effectiveness of the interventions that were examined. Moreover, given the inclusion and exclusion criteria, the participants may not reflect the demographic characteristics of the general population seeking weight loss treatment. Thus, there is a need to conduct additional studies using a larger sample that includes participants with characteristics and medical co-morbidities that may better reflect the general population, which may therefore enhance generalizability. Moreover, this study was limited to 6 months in duration, and additional research is needed

to understand the long-term effects of these interventions on weight loss in adults with obesity. This study also intentionally recruited participants that had access to a computer, the Internet and a compatible mobile device, which may have impacted the findings. The wearable device and the associated web or mobile interface are commercially available (BodyMedia Fit and LINK systems), and it is unclear whether similar results would be observed if other commercially available systems were used.

In summary, this study demonstrated that short-term technology-based interventions combined with brief monthly telephone calls resulted in weight loss in adults with obesity. The weight loss achieved with the technology-based interventions appears to be comparable in magnitude with what was achieved with an in-person intervention; however, because of the sample size in this study, there is limited statistical power to determine with certainty that the weight loss achieved was not different between the intervention groups. Weight loss was also accompanied by reductions in BMI, body fatness and waist circumference. Both the in-person and technology-based interventions resulted in reduced energy intake and dietary fat intake, increased engagement in weight loss strategies and increased leisure-time physical activity. These findings provide initial evidence that short-term weight loss interventions can be successfully implemented in a variety of ways in adults with obesity, which suggests that there are options for delivering weight loss interventions in this population group. Whether these interventions

can be equally effective for weight loss, if length of intervention beyond 6 months will alter the magnitude of weight loss achieved, if there are difference in response to these interventions by subgroups (men vs. women, different race/ethnic groups, BMI category, etc.) or if there are differences in cost-effectiveness of these interventions, warrants further investigation. These results provide promise for implementing non-surgical or non-pharmacological interventions that focus solely on lifestyle modification for weight loss in adults with obesity, and these interventions may not require extensive in-person contact.

Conflict of Interest Statement

Dr Rogers was the Principal Investigator on a research grant from Weight Watchers International awarded to the University of Pittsburgh. Dr Barone Gibbs was the Principal Investigator on a research grant from Human Scale awarded to the University of Pittsburgh. Dr Jakicic received an honorarium for serving on the 2015 Scientific Advisory Board for Weight Watchers International, was the Principal Investigator on a grant to examine the validity of activity monitors awarded to the University of Pittsburgh by Jawbone, Inc., and was a co-investigator on research grants received from Weight Watchers International, Human Scale and Ethicon/Covidien awarded to the University of Pittsburgh.

Funding

An unrestricted gift from Google, Inc., supported this study.

Author contributions

Conception and design were carried out by R. J. R., J. M. J., B. B. G., K. K. D. and L. E. B.; data acquisition was carried out by R. J. R., J. M. J., S. J. K. and L. A. P.; R. J. R., W. L. and J. M. J. analysed and interpreted the data; drafting manuscript or critical revision was carried out by R. J. R., J. M. J., W. L., B. B. G., K. K. D., L. E. B., S. J. K. and L. A. P.; J. M. J. obtained funding; administrative, technical and material support were given by R. J. R. and J. M. J.; and R. J. R. and J. M. J. supervised the study.

References

- Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 2014; **311**: 806–814.
- Jensen MD, Ryan DH, Apovian CM, et al. AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines, and The Obesity Society. *Circulation* 2013; **129**(25 Suppl 2): S102–S138.
- National Institutes of Health National Heart Lung and Blood Institute. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults – the evidence report. *Obes Res* 1998; **6**: 70–80.
- Wing RR. Behavioral weight control. In: Wadden TA, Stunkard AJ (eds). *Handbook of Obesity Treatment*. New York: The Guilford Press; 2002, pp. 301–316.
- Diabetes Prevention Program Research Group. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* 2002; **346**: 393–403.
- Look AHEAD Research Group. Reduction in weight and cardiovascular disease risk factors in individuals with type 2 diabetes: one-year results of the Look AHEAD trial. *Diabetes Care* 2007; **30**: 1374–1383.
- Look AHEAD Research Group. Long-term effects of a lifestyle intervention on weight and cardiovascular risk factors with type 2 diabetes: four year results of the Look AHEAD trial. *Arch Intern Med* 2010; **170**: 1566–1575.
- Gold BC, Burke S, Pintauro S, Buzzell P, Harvey-Berino J. Weight loss on the web: a pilot study comparing a structured behavioral intervention to a commercial program. *Obesity* 2007; **15**: 155–164.
- Patrick K, Calfas KJ, Norman GJ, et al. Outcomes of a 12-month web-based intervention for overweight and obese men. *Ann Behav Med* 2011; **42**: 391–401.
- Tate DF, Wing RR, Winett RA. Using internet technology to deliver a behavioral weight loss program. *JAMA* 2001; **285**: 1172–1177.
- Thomas JG, Leahey TM, Wing RR. An automated internet behavioral weight-loss program by physician referral: a randomized controlled trial. *Diabetes Care* 2015; **38**: 9–15.
- Patrick K, Raab F, Adams MA, et al. A text message-based intervention for weight loss: randomized controlled trial. *J Med Internet Res* 2009; **11**: e1.
- Thomas JG, Wing RR. Health-E-Call, a smartphone-assisted behavioral obesity treatment: pilot study. *JMIR Mhealth Uhealth* 2013; **1**: e3.
- Turner-McGrievy GM, Campbell MK, Tate DF, et al. Pounds Off Digitally study: a randomized podcasting weight-loss intervention. *Am J Prev Med* 2009; **37**: 263–269.
- Turner-McGrievy GM, Tate DF. Tweets, apps, and pods: results of the 6-month Mobile Pounds Off Digitally (Mobile POD) randomized weight-loss intervention among adults. *J Med Internet Res* 2011; **13**: e120.
- Unick JL, Beavers D, Jakicic JM, et al. Effectiveness of lifestyle interventions for individuals with severe obesity and type 2 diabetes. *Diabetes Care* 2011; **34**: 2152–2157.
- Martin CK, Miller AC, Thomas DM, et al. Efficacy of SmartLoss, a smartphone-based weight loss intervention: results from a randomized controlled trial. *Obesity* 2015; **23**: 935–942.
- Pellegrini CA, Verba SD, Otto AD, et al. The comparison of a technology-based system and an in-person behavioral weight loss intervention. *Obesity* 2012; **20**: 356–363.
- American College of Sports Medicine. In: LS Pescatello (ed.). *ACSM's Guidelines for Exercise Testing and Prescription*, 9th edn. Wolters Kluwer/Lippincott Williams & Wilkins: Baltimore, 2014.
- Baker RC, Kirschenbaum DS. Self-monitoring may be necessary for successful weight control. *Behav Ther* 1993; **24**: 377–394.

- 21 Boutelle KN, Kirschenbaum DS. Further support for consistent self-monitoring as a vital component of successful weight control. *Obes Res* 1998; **6**: 219–224.
- 22 Burke LE, Wang J, Sevick MA. Self-monitoring in weight loss: a systematic review of the literature. *J Am Diet Assoc* 2011; **111**: 92–102.
- 23 Jakicic JM, Marcus MD, Gallagher KI, et al. Evaluation of the SenseWear Pro Armband™ to assess energy expenditure during exercise. *Med Sci Sports Exerc* 2004; **36**: 897–904.
- 24 Mignault D, St-Onge M, Karelis AD, Allison DB, Rabasa-Lhoret R. Evaluation of the portable HealthWear armband. *Diabetes Care* 2005; **28**: 225–227.
- 25 St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. *Am J Clin Nutr* 2007; **85**: 742–749.
- 26 Segal KR, Gutin B, Presta E, Wang J, Van Itallie TB. Estimation of human body composition by electrical impedance methods: a comparative study. *J Appl Physiol* 1985; **58**: 1565–1571.
- 27 Paffenbarger RS, Blair SN, Lee I-M, Hyde RT. Measurement of physical activity to assess health effects in free-living populations. *Med Sci Sports Exerc* 1993; **25**: 60–70.
- 28 Paffenbarger RS, Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* 1986; **314**: 605–613.
- 29 Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 Compendium of physical activities: a second update of codes and MET values. *Med Sci Sports Exerc* 2011; **43**: 1575–1581.
- 30 Ainsworth BE, Haskell WL, Leon AS, et al. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 1993; **25**: 71–80.
- 31 Block G, Hartman AM, Dresser CM, et al. A data-based approach to diet questionnaire design and testing. *Am J Epidemiol* 1986; **108**: 161–175.
- 32 Block G, Woods M, Potosky A, Clifford C. Validation of a self-administered diet history questionnaire using multiple diet records. *J Clin Epidemiol* 1990; **43**: 1327–1335.
- 33 O'Neil PM, Currey HS, Hirsch AA, et al. Development and validation of the eating behavior inventory. *Journal of Behavioral Assessment* 1979; **1**: 123–132.
- 34 Polzien KM, Jakicic JM, Tate DF, Otto AD. The efficacy of a technology-based system in a short-term behavioral weight loss intervention. *Obesity* 2007; **15**: 825–830.
- 35 Shugar SL, Barry VW, Sui X, et al. Electronic feedback in a diet- and physical activity-based lifestyle intervention for weight loss: a randomized controlled trial. *Int J Behav Nutr Phys Act* 2011; **8**: 41–49.
- 36 DiClemente CC, Marinelli AS, Singh AS, Bellino LE. The role of feedback in the process of health behavior change. *Am J Health Behav* 2001; **25**: 217–227.
- 37 Tate DF, Jackvony EH, Wing RR. A randomized trial comparing human e-mail counseling, computer-automated tailored counseling and no counseling in an Internet weight loss program. *Arch Intern Med* 2006; **166**: 1620–1625.
- 38 Goodpaster BH, DeLany JP, Otto AD, et al. Effects of diet and physical activity interventions on weight loss and cardiometabolic risk factors in severely obese adults: a randomized trial. *JAMA* 2010; **304**: 1795–1802.