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Can multimodal technologies promote healthier behaviors and psycho-social wellbeing among overweight young adults? A secondary analysis of the SMART (Social Mobile Approaches to Reduce weighT) Parallel Group Randomized Control Trial

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Can multimodal technologies promote healthier behaviors and psycho-social wellbeing among overweight young adults? A secondary analysis of the SMART (Social Mobile Approaches to Reduce weighT) Parallel Group Randomized Control Trial

A thesis submitted in partial satisfaction of the requirements for the

Master's degree

in

Public Health

by

Anahi M. Ibarra

Committee in charge:
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- Professor Eric Craig Leas

2020

The Thesis of Anahi M. Ibarra is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California San Diego

2020

DEDICATIONS

To my mother who immigrated to this country in search for a better future for my sister and I, and to my sweet Spencer –thank you for your all love and support.

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ABBREVIATIONS

SMART	Social Mobile Approaches to Reducing weighT
SWM	Strategies for Weight Management
GPAQ	Global Physical Activity Questionnaire
MET	Metabolic Equivalent of Task
SBQ	Sedentary Behavior Questionnaire
QWB-SA	Quality of Well-Being- Self Administered
DHQIII	Diet History Questionnaire III
NHANES	National Health and Nutrition Examination Surveys
HEI	Healthy Eating Index
SSB	Sugar Sweetened Beverage
CES-D 10	Center for Epidemiologic Studies Depression Scale 10
EDI-BD	Eating Disorder Inventory- Body Dissatisfaction
QWB-SA	Quality of Wellbeing- Self Administered questionnaire

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The author thanks all of the investigators and staff involved in Early Adult Reduction of weight through LifestYle intervention (EARLY) trials. We also thank the staff and participants of Project SMART for their important contributions.

ABSTRACT OF THESIS

Can multimodal technologies promote healthier behaviors and psycho-social wellbeing among overweight young adults? A secondary analysis of the SMART (Social Mobile Approaches to Reduce weighT) Parallel Group Randomized Control Trial

By

Anahi M. Ibarra

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Professor Job Gideon Godino, Chair

Background: We assessed the efficacy of the two-year SMART intervention, a digitally delivered, multi-modal weight loss program, on change in self-reported health behaviors and psychosocial measures.

Methods: In total, 404 overweight obese university students and staff(aged 18–35 years) from three colleges in San Diego, CA, USA were enrolled. Participants were randomly assigned (1:1) to either the SMART weight loss intervention (n=202) or general information via website and email (n=202). Self-reported health behaviors and psychosocial measures, including physical activity, sedentary behaviors, overall nutritional intake, sugar sweetened beverage consumption, strategies for weight management, depression, body image and quality of life, were assessed every six months for the two-year study period. Between group differences were evaluated using linear mixed effects regression within an intention-to-treat framework. To assess the potential effect of missing data on all the outcomes of interest, a sensitivity analysis was done using multiple imputation. The trial is registered with ClinicalTrials.gov, number NCT01200459.

Results: There were statistically significant differences in self-reported use of the number of strategies for weight management (6.76 [95% CI 2.02 to 11.40], p=0.001) adjusted for sex, ethnicity, and college in the SMART intervention group compared with the control group at 24 months. There were no other differences in self-reported health behavior and psychosocial outcomes observed at the end of the 2-year study period.

Conclusion: A 2-year intervention that delivered theory- and evidence-based weight loss content delivered via Facebook, mobile apps, SMS, and the internet was effective at changing self-reported utilization of strategies of weight management, but not other health behaviors and psychosocial outcomes hypothesized to be important for weight loss.

INTRODUCTION

Emerging adulthood is a critical period within the developmental lifespan. It is an important time in establishing independence, as many individuals will live on their own for the first time, attend college and begin a career.[1] Importantly, it is also a time in which young individuals adopt life-long habits, often unhealthy behaviors, and undergo peak psychosocial distress.[2–6]

Low physical activity, frequent sedentary behaviors, and poor diet quality are well documented behavioral patterns among young adults. Longitudinal cohort data indicate that although most adolescents fail to meet national guidelines for physical activity (33.6%), even fewer meet these guidelines as young adults (12.7%). [7] Other studies have found similar decreases in moderate and vigorous physical activity and observed increased daily sedentary hours during the transition between adolescence and young adulthood.[8,9] With regards to nutritional intake, college students typically consume a poor-quality diet that is deficient in fruits, vegetables and low-fat dairy products, and high in fat, sodium and sugar, including sugary sweetened beverages (SSB).[10–13] Each of these behaviors are associated with weight gain and obesity, a growing problem among young adults in the U.S.[14]

Further compounding the issue of adopting unhealthy behaviors is the fact that the adolescent-adult transition marks a peak in psycho-social distress. Up to 74% of mental health diagnoses have their first onset before the age of 24.[15] Among college students, more than half of individuals report symptoms of anxiety and depression that was so severe individuals reported difficulty functioning in the previous year.[16] In light of the physical, psychological, and social transitions occurring during emerging adulthood, body image is also a significant developmental concern for young adults. Body image is one of the most consistent and robust risk factors for eating disorders and a significant predictor of low self-esteem, depression, and obesity.[17,18]

In order to address each of aforementioned risk factors for overweight and obesity, researchers are increasingly looking to digital technologies to promote weight loss—a new wave of behavioral health interventions. These interventions are cost-effective, flexible, and widely accessible, and have the ability to deliver engaging, interactive, and contextualized communications.[19] Such attributes support the promotion of using smartphones in lifestyle interventions targeting modifiable health risk factors in individuals that can establish long lasting healthy behaviors and psychosocial wellbeing.[20] One set of risk reducing behaviors are encompassed by the Strategies for Weight Management (SWM), which include 35 different strategies that measure the use of weight management behavioral studies by targeting one of four distinct domains: (1) energy intake, (2) energy expenditure, (3) self-monitoring, and (4) self-regulation. This is consistent with previous research which has shown that use of strategies targeting reduced energy intake and increased energy expenditure,[21–23] self-monitoring,[24,25] and self-regulation[26–28] are associated with better weight management.

The SMART intervention was a two-year clinical trial delivered via Facebook, mobile apps, SMS, and the internet to provide an engaging lifestyle-based program promoting increased physical activity, decreased caloric consumption, and overall wellbeing among obese and overweight college students.[29] These behaviors were specifically targeted through SWM's via tailored and contextualized intervention material delivered using the web-based platforms. The trial stimulated modest reductions in weight and BMI for at least 12 months compared to the control group; however, intervention effects were not sustained after two years. While SMART targeted multiple health behaviors and psychosocial outcomes, the intervention effects on these outcomes remain unclear. We here investigate the efficacy of the SMART intervention on health behaviors including physical activity, sedentary behavior, diet, strategies for weight management, and psycho-social measures including body image, quality of life and depression. We hypothesized that the SMART intervention would lead to meaningful change in psycho-social outcomes and a significant difference in health behaviors at 2 years compared to the control group.

METHODS

Study design and participants

The SMART study was a parallel group randomized controlled trial done in San Diego, CA, USA. The study methods have been described elsewhere, and a detailed research protocol is included in the appendix. This was one of seven trials funded by the National Heart, Lung, and Blood Institute of the National Institutes of Health to evaluate the efficacy of technology-based interventions for weight control in young adults. Students were recruited at the three college campuses via a combination of print (e.g., newspapers, flyers, posters, and magnets) and digital (e.g., emails, electronic bulletins, websites, and Facebook) advertisements. Additionally, in-person recruitment was done at student orientations and health fairs and was coordinated with real-time monitoring of online interest form submissions. All recruitment channels directed students to the study website where they could view detailed information and complete an eligibility survey. Eligible students were adults aged 18–35 years. They had a BMI of between 25·0 kg/m^2 and 34·9 kg/m^2, used Facebook or were willing to begin, owned a personal computer, owned a smartphone, used text messaging, and were willing to attend measurement visits in San Diego over 2 years. Exclusion criteria included having a clinically diagnosed eating disorder, orthopedic disorder, sleep apnea, pseudotumor cerebri, diabetes, or a psychiatric or medical condition that prohibited compliance with the study protocol. Students were also excluded if they had been recently prescribed dietary or physical activity changes, were enrolled in or expecting to enroll in a weight loss program within 2 years, were taking medications that alter weight, or were pregnant or expecting to become pregnant within 2 years. Study staff reassessed the inclusion and exclusion criteria in person before the start of the baseline measurement visit, and all eligible participants provided written informed consent. The study procedures were approved by the University of California, San Diego Institutional Review Board (approval number 091040) in cooperation with the institutional review boards of

San Diego State University and California State University, San Marcos. The trial is registered with ClinicalTrials.gov, number NCT01200459.

Randomization and masking

After completing the baseline measurement visit, a statistician allocated participants (1:1) to the intervention or control group using computer-based permuted-block randomization with block sizes of four that were stratified by sex, ethnicity, and college. Allocation was concealed from the participants, study staff, and investigators until the intervention was assigned. It was not possible to mask participants or the study staff that delivered the intervention. However, study staff who measured participants and investigators who analyzed study outcomes remained masked to the allocation throughout the study. Participants received an incentive of US$40 at baseline and $50 at 6 months.

Procedures

The SMART intervention was remotely delivered via six modalities: Facebook, three study-designed mobile apps, text messaging, emails, a website with blog posts, and technology-mediated communication with a health coach (up to ten brief [5–15 min] interactions). Intervention participants were instructed to use at least one or more modalities a minimum of five times per week throughout the 24 months of the intervention. The intervention was adaptively delivered in that new components were developed and released throughout the study in response to patterns of use and participant feedback. The intervention also provided participants with a high level of choice and allowed for changes in technological preference. Participants were able privately or publicly set individually tailored physical activity and diet goals and then choose how (i.e., via their preferred modality) and when to track these behaviors, receive feedback, and participate in goal review. Real- time location-based prompts were sent via text message to reinforce self-regulatory techniques. The health coach-initiated challenges and campaigns that were often culturally themed and promoted changes to weight- related behaviors (e.g., avoid overeating during Thanksgiving celebrations). Participants were then encouraged to make a pledge to participate and set appropriate goals. They were asked to share these with their existing social networks to promote social support, accountability, and the formation of healthy social norms about weight-related behaviors

Demographic information on age, sex, ethnicity (Hispanic, non-Hispanic), and race were self-reported through a survey collected at baseline.

Health Behavior Outcomes

The Global Physical Activity Questionnaire (GPAQ) was developed and validated by the World Health Organization to systematically monitor global physical activity levels[30]. Information on the duration and frequency of physical activity was assessed during work, transportation, and leisure time. Participants were asked to report only activities lasting 10 minutes or longer. All activities were assigned a value based on the metabolic equivalent of task (MET) for the task. Minutes per week of physical activity was calculated by adding all activity domains and expressed as MET minutes per week.

To quantify time spent in sedentary behaviors (i.e. sitting), participants were asked to complete the nine-item Sedentary Behavior Questionnaire (SBQ) –a validated tool for use among overweight adults[31]. Individuals estimated time spent sitting while doing multiple behaviors (i.e., (1) watching TV, (2) playing video or computer games, (3) listening to music, (4) talking on the phone, (5) doing paperwork or office work, (6) reading, (7) playing an instrument, (8) doing artwork, and (9) traveling) on a typical weekday and a typical weekend. Responses were solicited on an 9-category time scale (i.e., none = 1, less than15 min = 2, 30 min = 3, 1 h = 4, 2 h = 5, 3 h = 6, 4 h = 7, 5 h = 8, or, greater than 6 h = 9) and were subsequently recoded to obtain daily estimates. Weekday and weekend values were multiplied by 5 and 2, correspondingly, and combined to obtain weekly estimates. A higher SBQ score indicated longer time spent participating in sedentary activities over a week.

To analyze the composition of participants diet during the previous 30 days, a portion-size version of the food frequency questionnaire by the National Institutes of Health – Diet History Questionnaire III (DHQ-III) was used[32]. Nutritional items included food, beverage and supplement provided from National Health and Nutrition Examination Surveys (NHANES). The questionnaire analysis was performed using the computer program Diet Calc (National Cancer Institute, Bethesda, USA). Values resulted in a Healthy Eating Index (HEI), which designates standard levels of food quality for each component of the DHQIII. Aggregate scores of the twelve components ranged from 0 to 100 whereby the latter score reflected an optimal diet as defined by recommendations from the Dietary Guidelines for Americans.

Sugar Sweetened Beverage (SSB) consumption was assessed using a validated food frequency questionnaire adapted from the DHQIII[32]. SSB questions assessed the type (i.e., (1) soda, (2) fruit drinks, (3) sports drinks, and (4) energy drinks) and frequency (i.e. never = 0; ≤1 per month = 1; 2–3 per month = 2; 1 per week = 3; 2–4 per week = 4; 5–6 per week =5; 1 per day = 6; 2–3 per day = 7; 4–5 day = 8; ≥6 per day = 9), of SSB intake over the previous 30 days. Participants were also prompted with a question to determine the proportion of times their reported drinks were "sugar free". Responses were recorded using a 5 Point Likert scale (i.e., never = 1; 1/4 of the time = 2; 1/5 of the time = 3; 3/4 of the time = 4, and always or almost always = 5). To determine frequency of beverage intake value responses were recoded: the category six or more beverages per day was coded as six beverages per day and all other drink item ranges were coded to the midpoint (e.g., a response of "1 time per month or less" was reported as 0.5 beverages per month). Monthly estimates were divided to obtain weekly values and were then multiplied by the reported "sugar free" frequency of given beverage—this estimated total amount of sugary beverage intake. Higher values indicated greater SSB consumption in a week.

The Strategies for Weight Management (SWM), a validated tool among overweight young adults[33], was used to assess implementation of recommended strategies related to weight management. The SWM includes 35 items that are categorized within the following subscales: (1) energy intake, (2) energy expenditure, (3) self-monitoring, and (4) self-regulation. It solicits responses based on behaviors from the ‘‘last 30 days” and is rated on a five-point Likert scale (i.e., “never or hardly ever”=1, “some of the time”=2, “about half of the time”=3, “much of the time”=4, “always or almost always”=5). Total scores are calculated by summing all items that result in a range from 35-175, with higher scores indicating reduced energy intake and increased energy expenditure .

Psychosocial Outcomes

The presence of depressive symptoms was assessed by the Center for Epidemiologic Studies Depression Scale 10 (CES-D 10) survey, a simplified 10 question item form of the CES-D[34], with high internal consistency, test-retest reliability, convergent validity in various populations[35–37]. Participants were asked how frequently they experienced depressive symptoms during the past week, on a four-point Likert scale (i.e., rarely = 0, sometimes = 1, often = 2, at all times = 3). Depression scores were obtained by calculating the total score of the 10 items, which ranged from 0 to 30, with a higher score indicating more severe depressive symptoms.

Body image was measured using the 9-item subscale of the Eating Disorder Inventory (EDI-BD)[38]. This tool assessed the belief that specific body parts are too large or “fat”(e.g., hips, thighs, buttocks). Individuals indicated how true each statement was on a 6-point Likert scale (i.e., always = 1, usually = 2, often, = 3, sometimes = 4, rarely =5, and never = 6). The most extreme or anorectic response (i.e. “always” or “never”), depending on the keyed direction, earned a score of 3, the immediately adjacent response 2, the next response 1, and the final three response choices received no score. Scores were added and ranged from 0-27 , with a higher score indicating more concern or preoccupation with body weight and shape.

The Quality of Wellbeing- Self Administered questionnaire (QWB-SA) is a comprehensive measure of health-related quality of life[39]. The QWB-SA includes 71 items categorized in into one the following five sub-sections: (1) specific acute or chronic physical and mental health symptoms, (2) self-care activities, (3) mobility, (4) physical functioning, and (5) performance of usual activity. The QWB-SA score is calculated using a preference-weighted average of functioning in the previous 3 days (i.e. indicating if symptom was present yesterday, 2 days and/or 3 days ago) with respect to symptoms and the function scales. The most heavily weighted item in each of the 3 days from every section were recorded and were subsequently combined across all three days to arrive at a summary score for each subsection. Domain scores were further combined and averaged into a single index score ranging from 0 (i.e. death) to 1.0 (i.e., asymptomatic full function). A higher score indicated a higher self-reported life well-being.

Statistical Analysis

All statistical analyses were done using R Studio version 1.2.0 (The R Foundation, Vienna, Austria) and two-tailed p-values with the predefined cutoff for statistical significance set at 0·05. Descriptive statistics (proportions, means, and SD) described key demographic characteristics. Differences between groups were assessed with linear mixed-effects regression models for all continuous outcomes. Models were adjusted for sex, ethnicity, and college (the factors used in the stratified randomization) and were specified with a between-subject factor of treatment group, a within-subject factor of time treated categorically, and a treatment group by time interaction. Statistical significance of the treatment group by time interaction effect indicated differential between-group change in the outcome and estimated marginal means and corresponding 95% CIs of outcomes were computed at each timepoint. All analyses were a test of a treatment group by time interaction effect on each predefined outcome and were carried using an intention-to-treat framework that included all participants. Parameter estimates were based on maximum likelihood estimation or a generalized estimating equation, which allows for the inclusion of participants with missing data. This approach increases power compared with a complete case analysis and uses all available data

To assess the potential effect of missing data on all the outcomes of interest, a sensitivity analysis was done. These missing data were imputed using the Amelia II algorithm in R with 5 imputed datasets, and by assuming a missing at random pattern. The imputation procedure included the following variables: treatment group, time, age, sex, race, ethnicity, college, physical activity, sedentary behaviors, weight management strategies, dietary intake, sugar-sweetened beverage consumption; quality of life, depression. Results were pooled using Barnard-Rubin adjusted degrees of freedom for small samples. Imputation diagnostics suggested the Amelia II algorithm provided imputed values that accurately predicted the observed values for the majority of the continuous values (Supplementary Fig. 1). All statistical analyses were done using R Studio version 1.2.0 (The R Foundation) and two-tailed p-values with the predefined cutoff for statistical significance set at 0·05.

RESULTS

Figure 1 shows the flow of participants from recruitment through to the final assessment at 24 months. The SMART intervention group and control group did not differ according to key demographic characteristics (Table 1). Participants had a mean (SD) age of 22.2 (3.8) years and most were female (284 [70%]). All participants were English speaking and had diverse ethnic and racial backgrounds (125 [31%] Hispanic and 169 [42%] white). Most participants were recruited from University of California, San Diego (204 [50%]), followed by San Diego State University (152 [38%]), and California State University, San Marcos (48 [12%]). Of the randomly assigned

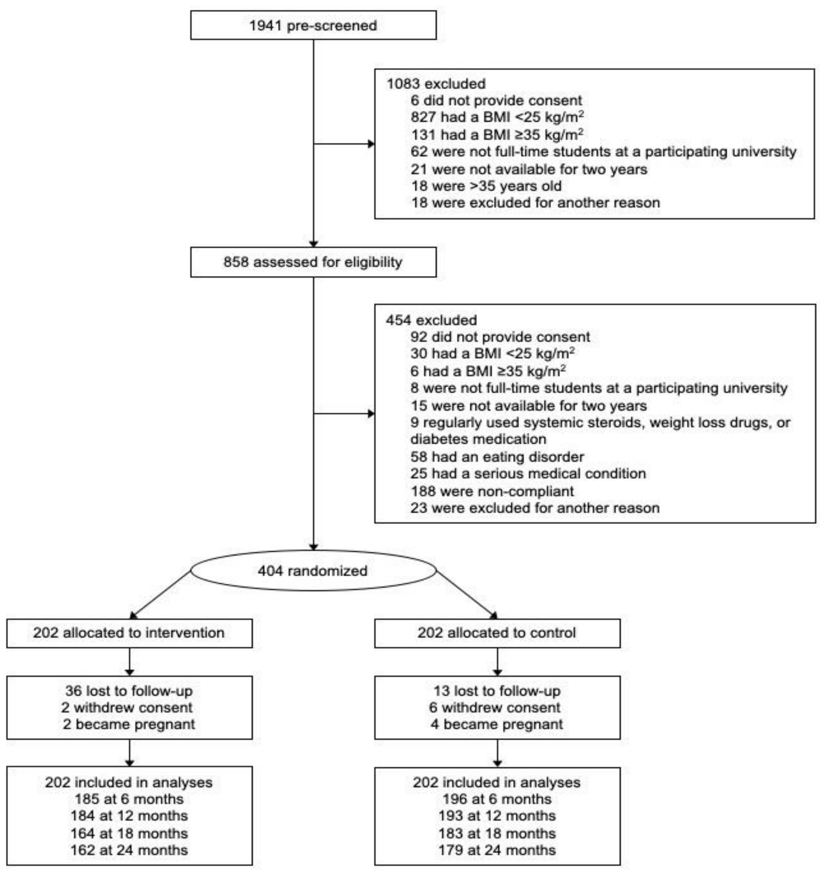

Figure 1: Flow diagram of SMART study for health behaviors and psycho-social measures.

participants, 326 (80.7%) were assessed for activity measures (GPAQ and SBQ), 330 (81.7%) were assessed for dietary intake (SSB and DHQ III), 325 (80.4%) were assessed for depression

Table 1: Project SMART Demographic Summary by Study Arm

	SMART (n=202)	**Control (n=202)**
Age (years)	22.1 (3.8)	22.3 (3.8)
Sex		
Male	59 (29.2%)	61 (30.2%)
Female	143 (70.8%)	141 (69.8%)
Ethnicity:		
Non-Hispanic	139 (68.8%)	140 (69.3%)
Hispanic	63 (31.2%)	62 (30.7%)
Race:		
White	87 (43.1%)	83 (41.1%)
Black/African American	6 (3.0%)	9 (4.5%)
Asian	46 (22.8%)	50 (24.8%)
American Indian, Alaskan, Native, Hawaiian Native, Pacific Islander	4 (1.0%)	2 (0.5%)
Multiple	16 (7.9%)	20 (9.9%)
Other	43 (21.3%)	38 (18.8%)
College:		
UCSD	103 (51.0%)	102 (50.5%)
SDSU	76 (38.1%)	75 (37.1%)
CSUSM	23 (11.4%)	25 (12.4%)
Income:		
<$24,999	153 (81.8%)	158 (85.9%)
$25,000-$74,999	30 (16.0%)	23 (12.5%)
>$75,000	4 (2.1%)	3 (1.6%)
Sedentary Behavior (min/week)	84.0 (30.0)	82.1 (30.0)
GPAQ total physical activity (MET min/week)	2292.7 (2652.3)	2386.7 (2983.5)
DHQIII healthy eating index (scale 0-100)	61.7 (10.7)	63.4 (11.4)
SSB consumption (total drinks/week)	2.6 (3.6)	2.0 (2.8)
SWM (scale 37-175)	83.8 (19.1)	86.5 (20.5)
Body Dissatisfaction (scale 0-27)	16.9 (5.8)	17.1 (6.3)
QWB-SA (0.0-1.00)	0.689 (0.100)	0.682 (0.115)
CES-D (scale 0-30)	6.1 (4.3)	5.9 (4.4)

*Data are n (%) or mean (SD). UCSD=University of California, San Diego. SDSU=San Diego State University. CSUSM=California State University,San Marcos. GPAQ=Global Physical Activity Questionnaire #. DHQIII = Dietary Questionnaire III# . SSB=sugar-sweetened beverage#. SWM = Strategies for Weight Management#. Body image assessed with the body dissatisfaction subscale of the Eating Disorder Inventory#. QWB-SA = Quality of Well-being Self-Administered Scale#. CES-D=Center for Epidemiologic Studies Depression Scale

Table 2: Estimated marginal means, probabilities, and between-group differences for the comparison of health behavior and psycho-social measures between the SMART intervention group and control group over 24 months from linear mixed-effects regression models for continuous outcomes , all adjusted for sex, ethnicity, and college.

	SMART Intervention	Control	Between Group Differences (95% CI)	p-value
CES-D 10				
Baseline	6.26 (5.34, 7.19)	6.02 (5.10, 6.93)		
6 months	6.22 (5.28, 7.15)	6.23 (5.31, 7.15)	-0.26	0.62
12 months	6.24 (5.30, 7.17)	6.49 (5.57, 7.41)	-0.50	0.35
18 months	5.35 (4.40, 6.31)	5.98 (5.05, 6.90)	-0.87	0.11
24 months	4.77 (3.81, 5.73)	6.00 (5.07, 6.94)	-1.48	0.01
SSB				
Baseline	3.19 (2.56, 3.83)	2.56 (1.93, 3.18)	-	-
6 months	2.57 (1.93, 3.21)	2.93 (2.30, 3.55)	-0.99	0.02
12 months	2.67 (2.03, 3.31)	2.36 (1.73, 2.99)	-0.32	0.45
18 months	2.79 (2.13, 3.44)	2.31 (1.67, 2.95)	-0.16	0.72
24 months	2.52 (1.85, 3.18)	2.61 (1.96, 3.25)	-0.72	0.10
DHQ III				
Baseline	59.1 (56.8, 61.4)	60.4 (58.2, 62.7)	-	-
6 months	61.3 (58.9, 63.6)	60.9 (58.6, 63.2)	1.72	0.19
12 months	60.3 (57.9, 62.6)	60.4 (58.1, 62.7)	1.23	0.35
18 months	61.3 (58.9, 63.7)	61.0 (58.6, 63.3)	1.71	0.20
24 months	60.1 (57.7, 62.5)	59.3 (56.9, 61.6)	2.17	0.11
BD-EBI				
Baseline	14.9 (13.7, 16.1)	15.1 (13.9, 16.3)	-	-
6 months	13.4 (12.2, 14.6)	14.2 (13.0, 15.4)	0.63	0.21
12 months	12.9 (11.6, 14.1)	13.3 (12.1, 14.5)	-0.34	0.50
18 months	13.2 (11.9, 14.4)	12.5 (11.3, 13.7)	0.80	0.12
24 months	12.8 (11.5, 14.0)	13.4 (12.2, 14.7)	-0.56	0.29
SBQ				
Baseline	91.3 (85.7, 96.9)	88.0 (82.5, 93.5)	-	-
6 months	86.8 (81.2, 92.4)	84.3 (78.8, 89.9)	-0.82	0.80
12 months	83.9 (78.3, 89.5)	81.4 (75.9, 87.0)	-0.84	0.79
18 months	82.5 (76.8, 88.3)	80.6 (75.0, 86.2)	-1.35	0.68
24 months	78.7 (72.9, 84.5)	81.3 (75.7, 87.0)	-5.96	0.07
GPAQ				
Baseline	2581 (2049, 3113)	2705 (2183, 3227)	-	-
6 months	2591 (2057, 3126)	2843 (2317, 3368)	-126.37	0.73
12 months	2539 (2003, 3075)	2215 (1685, 2746)	447.87	0.22
18 months	2605 (2047, 3164)	2392 (1852, 2932)	338.28	0.37
24 months	1922 (1361, 2483)	2255 (1712, 2798)	-208.35	0.58
QWB-SA				
Baseline	0.690 (0.666, 0.715)	0.684 (0.660, 0.708)	-	-
6 months	0.694 (0.670, 0.719)	0.715 (0.691, 0.740)	-0.03	0.05
12 months	0.713 (0.688, 0.738)	0.722 (0.698, 0.747)	-0.02	0.26
18 months	0.737 (0.712, 0.763)	0.742 (0.717, 0.767)	-0.01	0.45
24 months	0.758 (0.732, 0.783)	0.745 (0.720, 0.770)	0.01	0.64
SWM				
Baseline	83.5 (79.1, 87.9)	85.9 (81.6, 90.2)	-	-
6 months	97.9 (93.4, 102.3)	91.5 (87.2, 95.9)	8.77	0.0002
12 months	97.2 (92.8, 101.6)	91.0 (86.7, 95.4)	8.59	0.0003
18 months	97.5 (93.0, 102.0)	91.3 (86.9, 95.7)	8.63	0.0004
24 months	96.9 (92.3, 101.4)	90.8 (86.4, 95.2)	8.48	0.0005

(management strategies (SWM). By the 24-month visit, data missingness was present in all outcomes ranging from 16.6-19.6 across both arms. Missingness between participants in the SMART and control groups differed; missingness in the intervention arm was between 8.1%-8.7% greater in the intervention arm, across all health behaviors and psycho-social measures. All participants were included in the analyses. Table 2 shows the estimated marginal means and 95% CIs for weight at each study timepoint. There were significant differences in SWM (8.48 [95% CI 6.02 to 10.2], p= 0.0005), and CES-D scores (-1.48 [95% CI –1.45 to -1.51], p=0.01) adjusted for sex, ethnicity, and college in the SMART intervention group compared with the control group at 24 months. There were no other differences in self-reported health behavior and psychosocial outcomes observed at the end of the 2-year study period. However, adjusted SSB and QWB-SA were significantly improved in the SMART intervention group compared with the control group at 6 months (–0.99 [95% CI –0.93 to –1.·06], p=0·02 and –.03[95% CI –0.2 to –0.4 correspondingly) but were not sustained at 12,18 and 24 months. Sensitivity analysis showed that not all results were robust to imputation methods (Supp. Table 1). There were no statistically significant differences in change in SSB (2.42 [95% CI –1.74 to 6.7], p>0.05) and QWB-SA measures (0.007 [95%CI –0.026 to 0.011], p>0.05) at 6 months, nor were there differences in CES-D scores at 24 months (-0.667 [95% CI –1.541 to 0.254). However, results for the SWM remained at 12, 18, and 24 months (6.76 [95% CI 2.02 to 11.40], p=0.001)

Table 3 : Percent missingness among SMART and control participants by study outcome over the 24-month study period.

	SHQ	SSB	CES-D	GPAQ	QWB-SA	SWM	Body Image	DHQIII
Baseline	0	0	0	2.47	0	0	0	0
6 months	6.93	6.44	8.17	6.93	6.93	6.93	7.91	7.18
12 months	8.66	8.42	9.9	8.91	8.91	8.91	9.41	7.67
18 months	14.6	14.85	15.84	17.82	14.85	14.85	15.1	14.36
24 months	19.31	18.32	19.55	19.8	18.07	18.07	18.81	16.58

DISCUSSION

A theory-based weight loss intervention delivered to overweight or obese college students via social and mobile technologies, commonly used among young adults, was only associated with significant increases in SWM after 2 years, compared with general health information provided via a website and email. Linear mixed effects models also showed significant decreases in CES-D scores in the intervention arm at 24 months compared to the control group, however these results were sensitive to the choice of addressing missingness with multiple imputation rather than analyzing complete-cases. Notably, while physical activity, sedentary behaviors and diet quality were not associated with the SMART intervention, significant differences in self-reported SWM's at 12, 18 and 24 months show that energy intake, energy expenditure, self-monitoring and self-regulations were improved and remained over time.

While the SWM were significantly associated with the SMART intervention, other measures of energy expenditure and energy intake such as the GPAQ and the DHQIII were not. Notably, findings may not be conclusive due to biases resulting from non-objective measurement of physical activity and diet. A robust meta-analysis that included 173 studies over 35 years showed that, despite their extensive use, physical activity questionnaires were both higher and lower than objective measured levels of physical activity, and demonstrated weak accuracy and reliablility.[40] Poor validity is also observed to great extents in self-reported dietary assessments. A recent meta-analysis comparing the self-reported dietary intake to the doubly labeled water method, a standard for measuring energy expenditure in nutritional research, showed that energy intake under reporting from the food frequency questionnaire ranged from 4.6-42% compared to the standard.[41] Importantly, under reporting was greatest among females and among those who were overweight— the same demographics that comprised a majority of the SMART population. Utilization of self-reported questionnaires, thus, may have resulted in a weaker signal, ultimately affecting the degree by which change could accurately be determined.

Moreover, lack of between group differences in health behaviors and psychosocial outcomes are consistent with the primary results of the intervention which did not find significant differences in weight loss at 24 months. Nevertheless, the study was only powered to detect differences in the primary outcome (i.e., weight) and the final sample size was smaller than suggested. Thus, secondary findings that the SMART intervention and control arms are not different may be subject to a high likelihood of a type II error.

The study had limitations. This was a study in which the entire sample resided in San Diego County and were primarily (77%) female, which may limit the generalizability of the findings particularly because differences in psychosocial measures such as depression and body image are experienced at very different rates in young women compared to their male counterparts. Moreover, two types of contamination could have affected the results. The first, between-group social influence, is suggested by participant Facebook data which revealed that at least 61 (30%) participants in the control group were friends with one or more participants in the SMART intervention group. Depending on individual privacy settings, the control group could have viewed intervention-related posts, comments, or likes. The second, utilization of non-study-related modalities, is suggested by the use of commercially available apps for weight loss, some of which incorporate evidence-based strategies for weight loss. The control group was not prohibited or discouraged from using commercial apps and several participants in both the control and intervention groups anecdotally expressed they were doing so in exit interviews. Future studies of technology-based health behavior interventions should attempt to measure contamination directly (e.g., quantify the amount of interaction between the study groups and usage of non-study-designed apps throughout the intervention) to better show how these variables affect internal validity

A strength of this study is that the intervention was delivered via an automated SMS system and connected mobile applications which encompasses a highly scalable approach to the delivery of theory- and evidence-based health behavior change content. Also, it is widely understood that selective reporting of trial outcomes impacts the generalizability of readily available knowledge and the validity of subsequent meta-analyses.[42,43] Thus, we contribute to the knowledge and depth of digital multimodal health interventions by non-selective reporting of prespecified secondary outcomes of the SMART intervention, as is recommended by guidelines for reporting on randomized controlled trials.

Conclusion

A 2-year intervention that delivered theory- and evidence-based weight loss content delivered via Facebook, mobile apps, SMS, and the internet to provide an engaging lifestyle-based program only resulted in significant differences in strategies for weight management among the intervention group compared to the control group at the end of the study period. Future studies should provide sufficient power for analysis of secondary outcomes, utilize objective measures of behavior, and investigate strategies for balanced retention of participants in randomized control trials with long-term interventions.

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Supplementary table 1: Estimated between-group differences for the comparison of health behavior and psycho-social measures between the SMART intervention group and the control group over 24 months from generalized estimating equations for continuous outcomes using multiple imputation, all adjusted for sex, ethnicity, and college.

	CES-D 10	SSB	DQHIII	BD-EBI	SBQ	GPAQ	QWB-SA	SWM
6 months	0.06 (-0.63, 0.74)	0.3 (-0.15, 0.78)	-0.57 (-2.31, 1.16)	-0.34 (-1.21, 0.66)	2.46 (-1.78, 6.93	971 (-1541, 6592)	-0.005 (-0.023, 0.013)	2.32 (-1.1, 5.6)
12 months	-0.19 (-0.89, 0.56)	0.31 (-0.11, 0.77)	0.11 (-1.74, 1.90)	-0.003 (-0.91, 0.92)	2.04 (-2.07, 6.56)	1346 (-982, 7789)	-0.003 (-0.021, 0.013)	3.9 (0.5, 7.1)
18 months	-0.42 (-1.21, 0.32)	0.3 (-0.18, 0.80)	0.67 (-1.41, 2.71)	-0.26 (-1.36, 0.80)	1.79 (-2.73, 6.56)	1834 (-909, 10355)	-0.0002 (-0.0200, 0.0197)	5.4 (1.7, 9.0)
24 months	-0.68 (-1.61, 0.29)	0.31 (-0.26, 0.89)	1.33 (-1.01, 3.74)	0.35 (-0.96, 1.62)	1.17 (-4.40, 6.98)	2256 (-1667, 11445)	0.0008 (-0.0210, 0.0246	7.0 (2.2, 11.9)