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Gamifying accelerometer use increases physical activity levels of individuals pre-disposed to type II diabetes

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ABSTRACT

Physical activity is important for preventing obesity and diabetes, but most obese and pre-diabetic patients are not physically active. We developed a Fitbit-based game called MapTrek that promotes walking. We recruited obese and pre-diabetic patients. Half were randomly assigned to the control group and given a Fitbit alone. The others were given a Fitbit plus MapTrek. The MapTrek group participated in 6 months of weekly virtual races. Each week, participants were placed in a race with 9 others who achieved a similar number of steps in the previous week's race. Participants moved along the virtual route by the steps recorded on their Fitbit and received daily walking challenges via text message. Text messages also had links to the race map and leaderboard. We used a Bayesian mixed effects model to analyze the number of steps taken during the intervention. A total of 192 (89%) participants in the control group and 196 (91%) in the MapTrek group were included in the analyses. MapTrek significantly increased step counts when it began: MapTrek participants walked almost 1,700 steps more than the control group on the first day of the intervention. We estimate that there is a 97% probability that the effect of MapTrek is at least 1,000 additional steps per day throughout the course of the 6-month intervention and that MapTrek participants would have walked an additional 81 miles, on average, before the effect ended. Our MapTrek intervention led to significant extra walking by the MapTrek participants.

1. Introduction

Incidence of obesity and type two diabetes (T2D) is rising. Between 1999 and 2018, the obesity rate for American men increased from 28% to 43%, and from 33% to 42% for women. (Ogden et al., 2020) The prevalence of T2D has increased from 10% in 1988 to 12% in 2012. (Menken et al., 2015) Also, individuals with T2D and obesity often have sedentary lifestyles. (Morrato et al., 2007; Colberg et al., 2010; Nwasuruba et al., 2007; Jakicic et al., 2010; Krug et al., 1991; Bankoski et al., 2011)

Physical activity (PA) is associated with improved blood glucose control in people with T2D (Chen et al., 2015, Lin et al., 2015) and may prevent or delay the onset of T2D among patients with pre-diabetes. (Schellenberg et al., 2013) Participating in regular PA can also reduce the risk and severity of several other chronic diseases, such as cardiovascular disease, cancer, osteoporosis, hypertension, and depression (Flegal et al., 2002) as well as improve lipid profiles, decrease adipose tissue, and lower blood pressure (Colberg et al., 2010; Swartz et al., 2003; Boulé et al., 2001; Snowling and Hopkins, 2006; Mahar et al., 2006; Knowler et al., 2002; Laaksonen et al., 2005; Li et al., 2008; Tuomilehto et al., 2001; Eriksson et al., 1994; Hu et al., 2001; Hu, 2003; Thorp et al., 2011; Levine et al., 1999; Van Dijk et al., 2012; Sigal et al.,

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2006). The Physical Activity Guidelines for Americans recommend that adults engage in at least 150 to 300 min of moderate-intensity PA, 75 to 150 min of vigorous-intensity PA, or an equivalent combination each week to achieve health benefits. (Piercy et al., 2018) However, even light-intensity PA is beneficial: an increase of 1,000 steps per day has been associated with increased glycemic control in patients with T2D (Kooiman et al., 2018).

One approach to increase PA behaviors has been through game-based interventions. Gamification strategies (e.g., points, goals, leaderboards, teams, levels, challenges, rewards, etc.) have been demonstrated as effective approaches for increasing extrinsic motivation in a fun and rewarding way. (Theng et al., 2015) Gamification strategies have demonstrated promise when applied in diabetes self-management interventions (Theng et al., 2015; Games and Health Education, 2020; Höchsmann et al., 2019) but have been limited by small sample sizes, short durations, declines in user participation over time, and a lack of rigorous evaluation within randomized controlled trials. (Theng et al., 2015) High-quality studies investigating the long-term effectiveness of gamified interventions for improving PA behaviors of adults with obesity and T2D are needed. (Höchsmann et al., 2016)

We created an exercise intervention called MapTrek to promote PA, chiefly walking, in a game-like format requiring only a Fitbit and no expensive specialized equipment. In a recent study, we found sedentary office workers increased the number of steps taken when playing MapTrek over 10 weeks. (Gremaud et al., 2018) However, neither the long-term effectiveness of MapTrek nor the effectiveness among participants at risk for T2D have been evaluated. The objective of this study was to determine the effectiveness of MapTrek for increasing PA in people at elevated risk of T2D over six months in a randomized controlled trial.

2. Methods

2.1. Subjects and Design

We recruited adults with elevated risk for T2D (either BMI $\geq$30 kg/m^2 (Menken et al., 2015) or a BMI $\geq$25 kg/m^2 plus a hemoglobin A1C value between 5.7 and 6.4%). Participants were recruited from the Internal Medicine clinic, a university-wide mass e-mail, and a hospital-wide newsletter. All participants visiting the clinic were screened via review of their electronic medical record. Those responding to advertisements completed an online eligibility survey, followed by a review of their electronic medical record. Exclusion criteria were: 1) age less than 21 years or greater than 80 years, 2) not fluent in English, 3) not owning a smartphone, 4) previous participation in a MapTrek research study, 5) pregnancy or planned pregnancy, 6) prisoner status, 7) not having an electronic medical record at the University of Iowa Hospitals and Clinics, or 8) being diagnosed with diabetes or taking any diabetic medications. Participants identified as eligible completed a baseline visit and were enrolled in the study on the same day, while eligible participants who responded to the advertisements were contacted to schedule an appointment. This study was approved by the Human Subjects Office Institutional Review Board (IRB# 201505733), registered on clinicaltrials.gov (NCT03193229), and voluntary written informed consent was obtained from each participant.

2.2. Intervention

At the baseline visit, participants were randomized (1:1 ratio) to one of two groups: 1) Fitbit-only (control) group or 2) Fitbit + MapTrek. Both groups were provided with a Fitbit Zip activity monitor and were shown how to wear and sync the activity monitor to their smartphone. Participants were instructed to wear the monitor during all waking hours (except when bathing/swimming) for 6 consecutive months (up to a week of baseline and 24 weeks of races). Participants in both groups were able to interact with the standard Fitbit app as they wished, including viewing their step totals for the current and previous days. Following any day with no recorded steps, an automated text message was sent to the participant reminding them to wear and sync their Fitbit device (e.g., “You didn’t record any steps yesterday. Please remember to wear your Fitbit today.”).

During the first week (baseline), both groups were instructed to wear their Fitbit during waking hours, but no games were started for the MapTrek group. After the first week, participants randomized to MapTrek were provided access to the game. MapTrek is a platform-independent web app accessed by URL links sent by text message. It automatically sends and receives text messages via a commercial web-to-SMS gateway (http://www.twilio.com). As part of the game, players are sorted into weekly races along virtual courses and challenged to be the first to the finish line. Participants can walk whenever and wherever is convenient; steps taken are recorded by the Fitbit. All interaction with the game is done via text messages and a web-based app where they can view the course and current rankings. MapTrek was designed considering several demonstrated health behavior change techniques and strategies of persuasive system design. (Carpenter et al., 2017; Team SD, 2018) Specifically, MapTrek supports self-monitoring of PA by sending users a daily text message of their steps and place in the race. MapTrek provides contingent rewards by entering participants into a series of competitions that they have an opportunity to win. MapTrek also provides opportunities for social comparisons by illustrating each user’s PA alongside other participants on a leaderboard and game board.

Each Monday morning, users received a message that a new race had begun. From Tuesday to Sunday, participants received an automated, tailored text message that prompted participants to self-monitor their daily steps and provided feedback on their performance in the weekly race. Specifically, the daily messages informed the participant of his or her place in the race and their average daily steps for the week. In order to promote engagement with the game and further motivate PA, players were randomly issued rewards-based step-goal challenges with bonus steps being added or deducted from their total based on whether they completed the accepted challenges. For example, some challenges encouraged the participant to increase their day’s step volume by a specified amount. Other daily challenges focused on maintenance, increasing peak intensity, or reducing the number or duration of sedentary periods. Examples include “For the next 20 min, each step is worth 2 steps on the game board;” “If you take 1,000 steps in the next hour, you will receive 200 bonus steps;” or “If all sedentary periods in the next three hours are less than 20 min, you will receive 300 bonus steps.” The intensity of the challenge and the amount of the bonus were based on the participant’s past performance.

Each race followed a pre-determined route. Within MapTrek, participants were able to see where they were on the route on Google Maps and Google Street View. Each participant was represented by a stick figure that advanced along the route based on the number of steps recorded by the Fitbit. The participant’s position automatically updated each time their Fitbit synced to their smartphone (Fig. 2).

To facilitate social comparisons with their peers and competition, MapTrek participants were placed into a weekly league (maximum 10 participants per league) based on their average daily steps during the previous week. The purpose of the activity-based leagues was to maintain strong competition amongst similarly active participants in order to minimize discouragement and provide all players a chance of winning. (Locke and Latham, 2002) To minimize discouragement from being placed in a less-active league, participants were purposefully not informed of their league placement. Users could view a leaderboard with the average number of steps taken per day, position on the route, bonus steps achieved, and total steps accumulated during each race for those participants placed into their weekly league.

We assumed the smallest clinically meaningful mean difference in step counts would be 1,000 steps per day. Based on prior work with MapTrek, we estimated the standard deviation in the mean number of steps taken to be 3,250 steps per day. (Carr et al., 2016) Based on these values, in order to have 80% power to detect a change of 1,000 steps per day in the mean number of steps at the 0.05 level of significance using a two-sample, two-tailed *t*-test, 167 people were needed in each group. To account for potential dropouts, the sample was increased by approximately 25% to 215 participants per group, or 430 total participants.

2.3. Measures

The primary outcome for the study was total number of daily steps as objectively measured by the Fitbit Zip activity monitor. A secondary outcome was the number of minutes per day with at least 100 steps (active minutes). The Fitbit Zip is a small (3.56 × 28.9 × 9.6 mm) triaxial accelerometer-based activity monitor that estimates daily steps taken at the minute level, previously demonstrated as a valid measure of daily steps when compared to the ActiGraph GT3X+ (r = 0.99; ICC = 0.98) (Saint-Maurice et al., 2020). A single replaceable watch battery provides 4–6 months of use. Participants were provided with a new battery in their Zip at enrollment, plus an additional battery in case the original died before the study concluded. Additional batteries were provided by the study team. Participants kept the Fitbit Zip after the study ended. Minute-level step data were downloaded via the Fitbit application programming interface (API) for both groups for the entire 6-month intervention. Only raw steps (i.e., no bonus steps) were included in the analysis.

Additionally, at baseline, the following data were collected from each participant's medical record: age, sex, race, ethnicity, marital status, insurance type, and body mass index (BMI).

After the study was over, MapTrek participants were sent a text message with a link to a post-intervention survey. They were asked to respond to several statements using a 7-point Likert-type scale from Strongly Agree to Strongly Disagree. These statements consisted of things like: "I thought the MapTrek race was fun."; "I thought the MapTrek race was easy to use."; "I thought the MapTrek race motivated me to be more active."; "I would like to continue to have access to MapTrek in the future."; and "The presence of other participants in the race motivated me to be more active." They were also asked to offer any suggestions for future improvements of MapTrek in an open text field.

2.4. Statistical analysis

2.4.1. Assessment of randomization

The adequacy of randomization was assessed via a series of two-sample t-tests for continuous variables (e.g., age, BMI) and a Pearson chi-squared test for categorical variables (e.g., sex, race, marital status). Additionally, the average number of daily steps at baseline was compared between the two groups using a two-sample *t*-test.

2.4.2. Modeling

We used a Bayesian mixed effects model to describe the number of steps taken during the intervention phase. Using the Bayesian framework, we can make probabilistic statements about the scale of the effect, and about the effect remaining above some threshold over the duration of the intervention. All estimation was performed using R (Team RC, 2018) and the rstan package. (Team SD, 2018) Stan and the No U-Turns Sampler (Carpenter et al., 2017; Team SD, 2018) were used to perform the Hamiltonian Monte Carlo (HMC) sampling to fit the model.

We have two outcome variables: the total number of steps per day and the number of active minutes (defined as minutes with 100 or more steps) per day. Only data collected after the start of the intervention were used in model estimation. Both outcomes were modeled using the same set of predictors and prior distributions. The models included independent variables of the number of days since the start of the intervention, group membership (MapTrek versus control), and an indicator for weekends as step counts are generally lower on weekends compared to weekdays (Steeves et al., 2015; Carr et al., 2016). Because we expected differences between people's baseline activity levels and differences in their response to MapTrek, we included subject-specific random intercepts (baseline activity levels) and random slopes (different responses). Because the subject-specific random intercepts and random slopes might be correlated, we modeled these as a bivariate normal distribution allowing for both the possibility of independence between the random intercepts and slopes or some degree of correlation. See the technical appendix for more detail about the model specification and priors.

3. Results

A total of 2,982 individuals were assessed for eligibility due to scheduled appointments in the participating clinics or response to the mass email or newsletter expressing interest in the study. Once their electronic medical records were screened, 1,443 were determined to be eligible and 430 (215 in each group) consented to participate in the study (Fig. 1). All baseline visits occurred between May and October of 2017. Of the 430 enrolled, 212 of the 215 intervention participants and 209 of the 215 control participants confirmed their number with the texting service. Nine participants (1 intervention, 8 control) were lost because they never registered nor synced their Fitbit. A total of 19 participants (15 intervention, 4 control) asked to be removed from the study; however, 4 of these (3 intervention, 1 control) were already excluded for never confirming their phone number or registering their Fitbit. A total of 397 participants (199 intervention, 198 control) were consented, completed the enrollment steps, and synced their Fitbit at least once. Of the 397 participants, 388 had data during the intervention period (196 intervention, 192 control). Based on the 215 participants consented for each arm, we expected to have 34,615 participant-days (215 participants × 168 days) in each arm, excluding the baseline run-in phase. We observed valid non-zero step data on 22,436 (64.8%) of participant-days in the intervention group and 18,158 (50.3%) of the participant-days in the control group. There were no differences between groups for any baseline variables (Table 1).

Fig. 3 shows the compliance rate, median number of steps, and median number of active minutes by day throughout the one-week run-in phase and the six-month intervention for both the MapTrek and control groups. Compliance rates for wearing and syncing the Fitbits were consistently 15 percentage points higher in the MapTrek group relative to the control group after the start of the intervention. Daily median step counts were similar during the baseline period but were consistently greater in the MapTrek group than the control group after the start of the intervention. On average, the MapTrek group achieved approximately 5 additional active minutes with more than 100 steps per minute per day during the first few months of the intervention.

Posterior probability distributions for the effects of the main parameters on total steps per day are summarized in Table 2. Compared to the control group, immediately after starting the intervention the MapTrek group walked an additional 1,697 (95% credible interval: 996 – 2,403) mean steps per day. There was significant variability in step counts between people (standard deviation between participants of 3,455 steps per day, 95% credible interval: 3,212 – 3,720) and over time (standard deviation with a participant day-to-day step counts of 3,396 steps per day, 95% credible interval: 3,373 – 3,420).

The posterior probability that the MapTrek effect is at least as large as a threshold between 0 and 3,000 steps per day is shown in Fig. 4. According to the posterior probability, there is a 50% probability that the true MapTrek effect exceeds 1,696 steps, a 97% probability that the effect exceeds the minimally clinically relevant threshold of 1,000 steps per day, and a 20% probability that the effect exceeds an additional mile (2,000 steps) per day.

Using the estimated parameters of the MapTrek effect and the additional rate-of-decay among the MapTrek group, there is a 50% probability the MapTrek group walked at least 162,800 additional steps (95% credible interval: 63,088 to 323,612), or, assuming 2,000 steps per mile, walked 81.4 (95% credible interval: 31.5 to 162) additional miles from the start of the intervention until the MapTrek effect ended, which

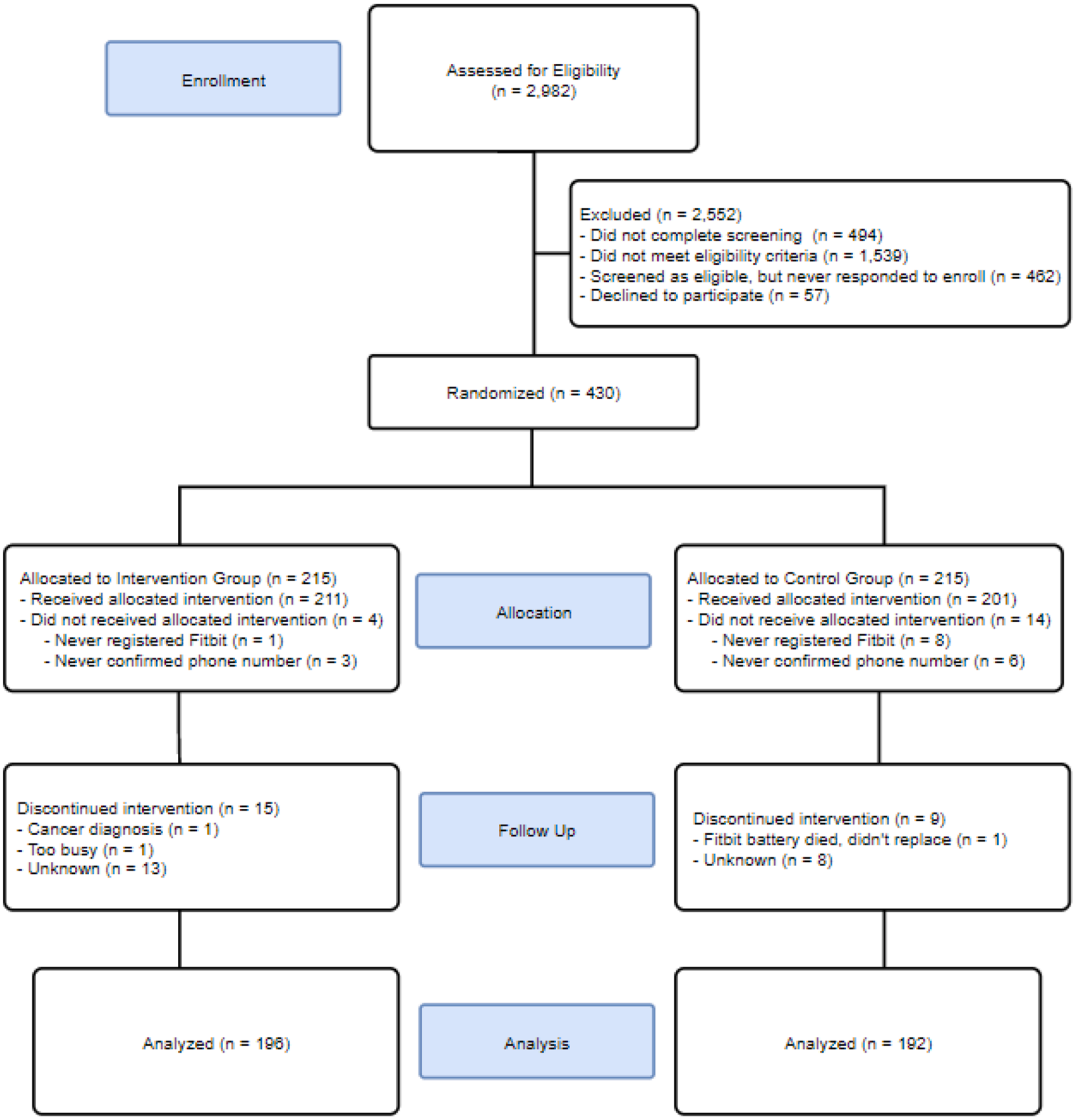

Fig. 1. CONSORT flow diagram.

differed by participant. The posterior distribution of the additional miles walked is shown in Fig. 5. The posterior probability that the MapTrek effect exceeded 1,000 steps per day is above 50% until day 78 and was positive until day 189.

Posterior probability distributions for the effects of the main parameters on active minutes per day are summarized in Table 3. Compared to the control group, at the start of the intervention, the MapTrek group achieved on average 8.0 (95% credible interval: 4.5 – 11.5) additional minutes with at least 100 steps per day. There was significant variability in active minute counts between people with an inter-participant standard deviation of 17.2 min per day (95% credible interval: 16.0 – 18.5) and a within-subject, between-day standard deviation of 17.4 min per day (95% credible interval: 17.3 – 17.6). Over the course of the six-month intervention, the average participant in the MapTrek group achieved an additional 849 min with at least 100 steps (95% credible interval: 345 – 1,742).

4. Discussion

Our MapTrek intervention led to significantly more walking by the MapTrek participants: we estimate that there is a 97% probability that the effect of MapTrek is at least 1,000 additional steps per day during the 6-month intervention. This difference decreased during the study by about 5.8 steps per day, but we estimate that the MapTrek participants would have walked an additional 81 miles, on average, before the effect of MapTrek ended. In addition, MapTrek participants had an additional 849 min of moderate-to-vigorous activity over the course of the study. Overall, most participants thought that MapTrek was fun, easy to use and motivated them to be more active, and 76% agreed that they would like to continue to have access to MapTrek in the future.

A recent paper found that step counts, but not exercise intensity was associated with reductions in mortality risk, and mortality rates decreased, corresponding to increasing step counts until around 12,000 steps per day. (Saint-Maurice et al., 2020) Another recent study found

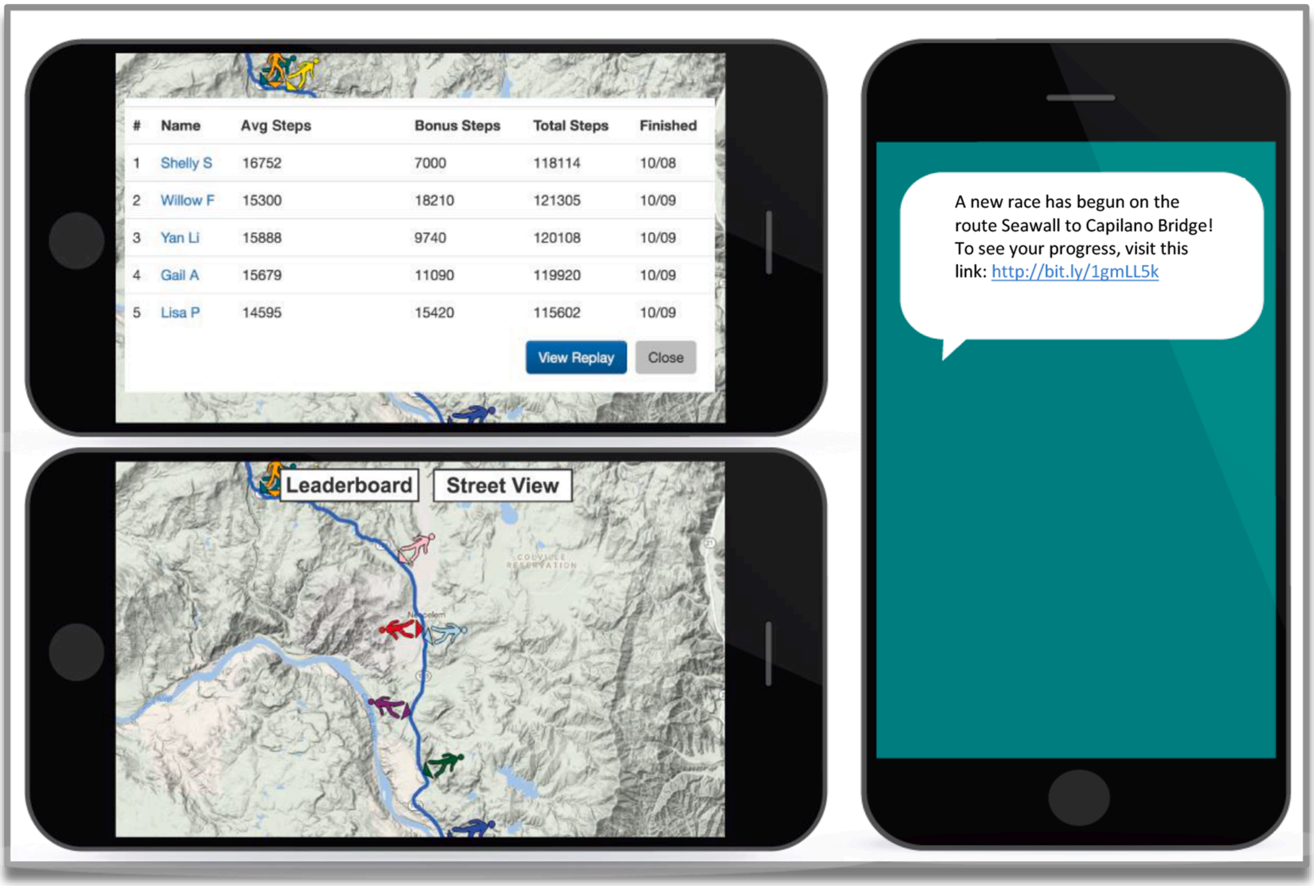

Fig. 2. Screenshots of MapTrek Leaderboard, map route, and text message link.

Table 1
Demographics and baseline activity levels between the MapTrek and control groups. Values are mean (standard deviation) or count (percent) depending on whether the variable is continuous or discrete. Values in square brackets denote the number of missing observations.

	MapTrek (n = 196)	Control (n = 192)	p-value
Female	152 (77.6%)	147 (76.6%)	0.817
Age	46.9 (13.2)	45.8 (13.8) [1]	0.415
Race			
White	177 (90.3%)	166 (86.5%)	0.168
Black	7 (3.6%)	11 (5.7%)	0.322
Other	9 (4.6%)	13 (6.8%)	0.362
Missing	3 (1.5%)	2 (1.0%)	
Hispanic Ethnicity	6 (3.1%) [3]	8 (4.2%) [3]	0.567
BMI	36.4 (6.2)	37.0 (6.8)	0.372
Enrollment Based on HbA1C	25 (12.8%)	34 (17.7%)	0.169
Health Insurance Type			
Private	137 (69.9%)	141 (73.4%)	0.439
Medicaid	12 (6.1%)	8 (4.2%)	0.386
Medicare	21 (10.7%)	20 (10.4%)	0.924
Other	20 (10.2%)	19 (9.9%)	0.920
None	6 (3.1%)	4 (2.1%)	0.546
Baseline Period Steps (weighted by number of baseline days)	6,867 (3,455)	6,272 (3,397)	0.086

older women walking 4,400 steps/day had a 41% lower mortality rate compared to women walking 2,700 steps/day. (Arem et al., 2015) The effect of MapTrek wore off over time but still resulted in a 1,000 step/day improvement. This amount of activity has been associated with significant improvements in glycemic control. (Kooiman et al., 2018)

Unlike interventions in supervised clinical settings, MapTrek was specifically designed to work outside clinical settings, but it retains a social element. MapTrek was designed to increase motivation for PA by placing patients in competitive leagues with others of similar activity levels. We hypothesized that the presence of players that were similarly active would encourage participants to walk more: other research has found evidence of the Kohler discrepancy effect - that the presence of others that are just slightly more advanced increases motivation. (Messé et al., 2002) Indeed, 79% of MapTrek participants agreed that the presence of other participants in the race motivated them to be more active.

Data collected from our post-intervention questionnaire provided several suggestions for improvement. One participant commented that he would have liked to have been able to communicate with other players in order to promote mutual motivation. This suggestion is consistent with social support theory-based behavior change techniques and persuasive systems design strategies that encourage providing social support to motivate behavior change. (Abraham and Michie, 2008; Oinas-Kukkonen and Harjumaa, 2009) For example, social support theories including Festinger's Social Comparison Theory (Festinger, 1954) and Bandura's Social Learning Theory, (Bandura and McClelland, 1977) support the application of buddy systems or teams that provide individuals with emotional (e.g., encouragement to be more active) or companionship (e.g., walking with a friend or teammate) support. Future versions of MapTrek will test whether introducing emotional and/or companionship support functions are effective for increasing the efficacy of MapTrek.

In MapTrek, the route changed each week, and there were a variety of challenges issued. However, one participant commented that they would have liked more routes that were "off the beaten path" and another wanted more local routes. Still others commented that they would have liked facts about the areas where they were walking. Future

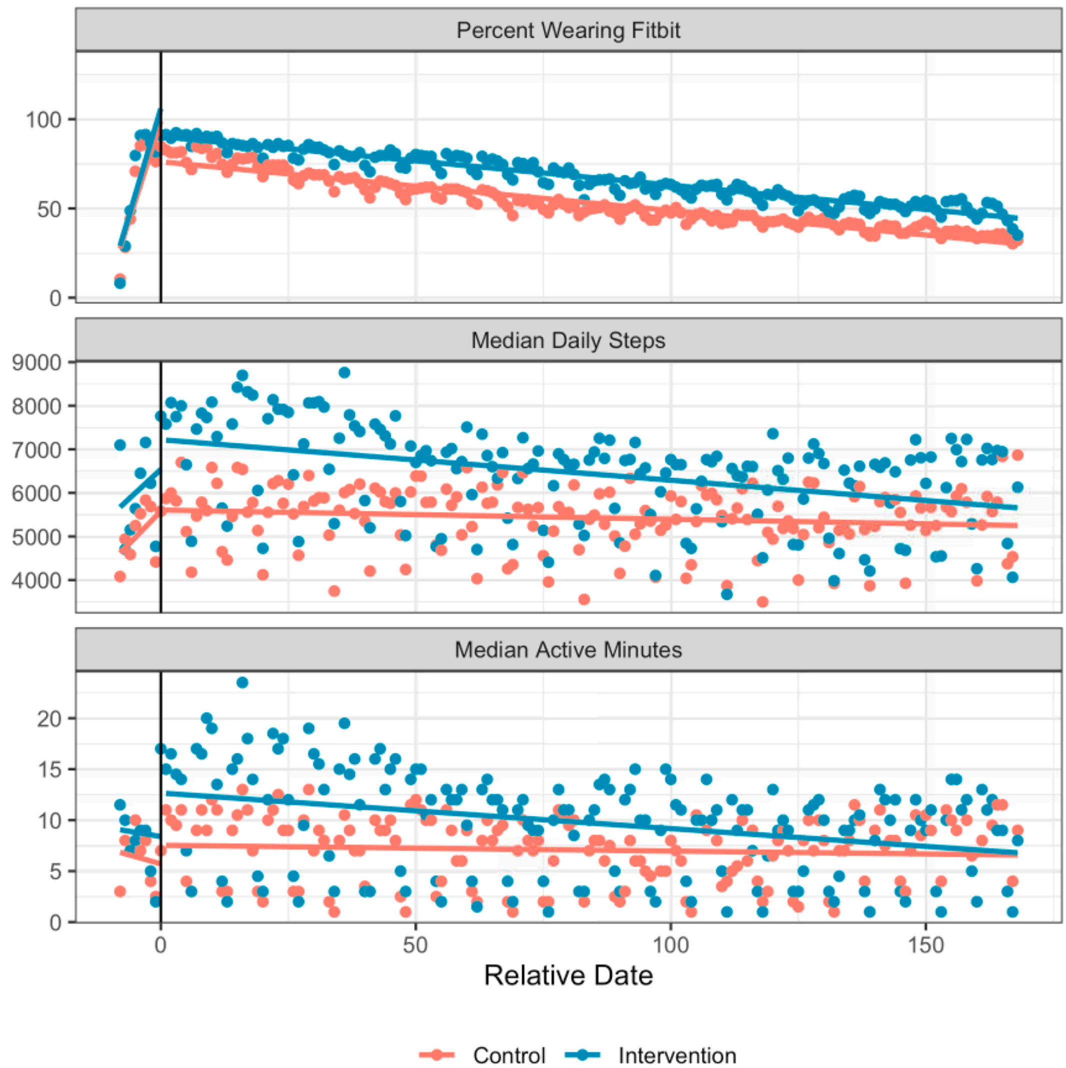

Fig. 3. Daily Compliance and Median Steps by Group. The vertical line denotes the start of the intervention.

Table 2
Model Results for Total Number of Steps.

Term	Mean	SD	95% Credible Interval
Intercept	6,769.38	256.09	6,265.84, 7,271.59
Decay Per Day	−5.77	1.51	−8.74, −2.82
MapTrek Effect	1,697.48	359.14	996.43, 2,402.74
MapTrek Decay Per Day	−8.96	2.03	−12.95, −4.99
Weekend Effect	−1,684.97	38.41	−1,760.52, −1,609.78
SD within-person, between days	3,396.07	12.02	3,372.60, 3,419.74
SD between-person, average steps (random intercept)	3,454.86	129.58	3,212.35, 3,719.86
SD between-person, trend (random slope)	16.30	0.86	14.69, 18.06

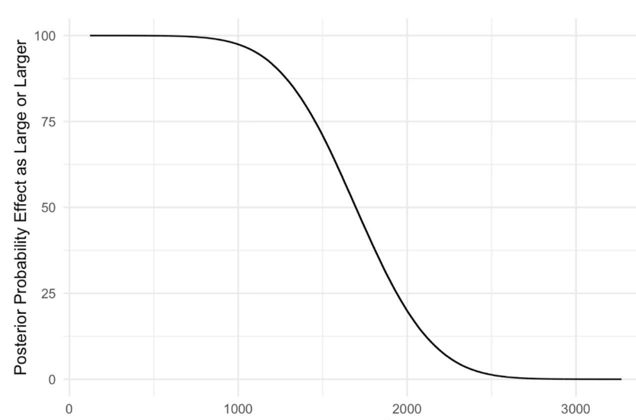

Fig. 4. Posterior probability that the MapTrek effect on Day 0 is at least as large as a threshold ranging from 0 to 3,000 steps per day relative to control participants immediately after starting the intervention.

versions of MapTrek could incorporate different challenges that change with the seasons. Indeed, variety is associated with game engagement and may be important for minimizing the lack-of-novelty effect that is common among exercise games (Zhao et al., 2017; Theng et al., 2015)

Our study has some limitations. First, Fitbit compliance rates fell during the study. Around 50% of participants in the MapTrek group and less than 50% of participants in the control group were consistently wearing and syncing their Fitbits at the end of the study (Fig. 3). Thus, our results may be less generalizable at the end of the study. Second, our results may not be generally applicable to all pre-diabetic participants because pre-diabetic participants who are interested in exercise may

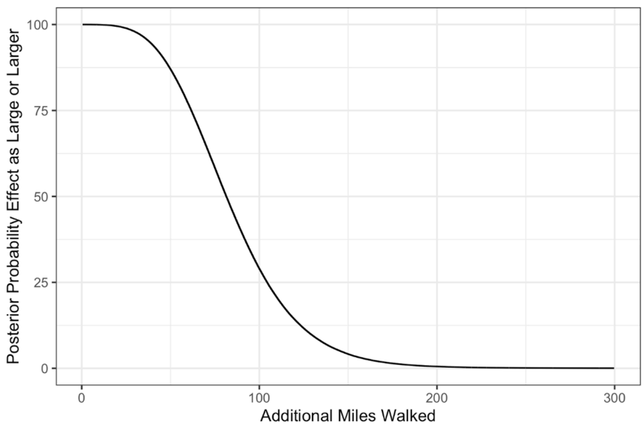

Fig. 5. Posterior probability distribution for the cumulative additional miles walked by participants randomized to the MapTrek group before the effect decayed to 0 relative to participants randomized to the control group.

Table 3
Model Results for Number of Active Minutes Per Day.

Term	Mean	SD	95% Credible Interval
Intercept	16.81	1.28	14.29, 19.32
Decay / Day	−0.03	0.01	−0.05, −0.01
MapTrek Effect	7.99	1.79	4.48, 11.52
MapTrek Decay / Day	−0.04	0.01	−0.06, −0.02
Weekend Effect	−9.14	0.20	−9.53, −8.75
SD within-person, between days	17.43	0.06	17.31, 17.55
SD between-person, average steps	17.19	0.65	15.98, 18.51
SD between-person, trend	0.10	0.00	0.09, 0.11

have been more likely to participate. However, the mean number of steps per day for our participants during the baseline period was around the U.S. average (Tudor-Locke et al., 2009) Finally, our study population may not be representative of the pre-diabetic U.S. population. Most of our participants were privately insured, most were female, and most were non-Hispanic whites.

5. Conclusions

Compared to a control group of pre-diabetic participants using Fitbits, our MapTrek intervention led to increased PA for 6 months. However, more interventions to encourage PA among obese and pre-diabetic participants are needed.

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CRediT authorship contribution statement

Shelby L. Francis: Conceptualization, Methodology, Investigation, Resources, Writing - original draft, Supervision, Project administration. **Jacob E. Simmering:** Methodology, Data curation, Formal analysis, Writing - original draft. **Linnea A. Polgreen:** Conceptualization, Methodology, Writing - original draft. **Nicholas J. Evans:** Software. **Katie R. Hosteng:** Investigation. **Lucas J. Carr:** Conceptualization, Writing - original draft. **James F. Cremer:** Software. **Sarah Coe:** Investigation. **Joe E. Cavanaugh:** Methodology, Formal analysis. **Alberto M. Segre:** Conceptualization, Software, Funding acquisition. **Philip M. Polgreen:** Conceptualization, Methodology, Resources, Writing - original draft, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2021.101426.

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