A Multicomponent Mobile Health Intervention to Reduce Sedentary Time After Knee Replacement: Randomized Controlled Trial

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Abstract

Background: Total knee replacement (TKR) is a common surgery for end stage knee osteoarthritis. Although reductions in pain and improvements and mobility occur after surgery, physical activity levels often do not change. Given the challenges of increasing physical activity in this population, targeting reductions in sedentary behavior may be a first step; however, no prior studies have examined the feasibility and effects of a sedentary reduction intervention after TKR.

Objective: This study examined the effects of a 2-month multicomponent mHealth sedentary reduction intervention on sedentary time in adults with TKR.

Methods: Adults (65.3 ± 9.4 years, 32.7±6.9 kg/m2, 74.7% female, 77.1% white) with a TKR ?1 year ago were randomized to NEAT!2 (n=42) or an attention-matched control group (n=41). The NEAT!2 intervention focused on reducing sedentary time via a smartphone app designed to interrupt prolonged bouts (?30 min) of sedentary behavior and 5 coaching calls emphasizing goal setting and problem solving. The control group focused on surgery recovery via an app/website and 5 educational calls. Multiple linear regression models with generalized estimating equation (GEE) examined intervention effects and differences between groups at each time.

Results: Retention was 96% and 95% at 2 and 5 months, with no differences between groups. NEAT!2 participants completed 4.95±0.2 calls, used the app on 40.3±13.8 days (out of 56 days), and received an average of 9.6±6.0 notifications/day. The NEAT!2 intervention did not result in significant effects on any of the study's outcomes at 2 or 5 months and no differences were observed between groups. However, more days of using the app was associated with greater increases in moderate-to-vigorous intensity physical activity (r = 0.335, 95% CI 0.017, 0.585, p= 0.037).

Conclusions: This study highlights the challenges of reducing sitting time in adults with TKR. Future studies should explore alternative behavior change techniques across different levels of influence (e.g., environmental, social) in future interventions within the first year after TKR. Clinical Trial: NCT04482400

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Conflicts: J. Benjamin Jackson III reports a relationship with Vilex Inc that includes: consulting or advisory

Abstract

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TKR ≤1 year ago were randomized to *NEAT!2* (n=42) or an attention-matched control group (n=41). The *NEAT!2* intervention focused on reducing sedentary time via a smartphone app designed to interrupt prolonged bouts (≥30 min) of sedentary behavior and 5 coaching calls emphasizing goal setting and problem solving. The control group focused on surgery recovery via an app/website and 5 educational calls. Multiple linear regression models with generalized estimating equation (GEE) examined intervention effects and differences between groups at each time.

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Trial registration: This study is registered at www.clinicaltrials.gov NCT04482400.

Keywords: arthroplasty, sedentary behavior, mhealth

Introduction

Total knee replacement (TKR) is one of the most common surgical procedures performed in the United States, and its prevalence is expected to continue rising rapidly [1,2]. TKR is considered an effective treatment for severe knee osteoarthritis, with most patients experiencing reduced pain and improved physical function and quality of life following the procedure [3–5]. However, post-operatively, most adults struggle to increase physical activity [6], further increasing their risk for all-cause mortality, cardiovascular disease, and disability.

In addition to struggling to increase physical activity, adults with TKR continue to spend excess time in sedentary behaviors [7,8]. Sedentary behavior is defined as any waking behavior in a seated or reclining position at ≤ 1.5 METS [9]. Independent from physical activity, increased time spent sitting increases the risk of all-cause mortality [10] and diabetes [11]. Given the low levels of physical activity after surgery, targeting reductions in sedentary behavior may be a more feasible, first-step approach to increasing overall activity in this population. Sedentary reduction interventions tailored to other populations, such as office workers, have been shown to be effective [12,13], and a recent study demonstrated multicomponent sedentary behavior interventions to be well-accepted and effective in older adults [14]; however, no prior studies have examined the feasibility and effects of a sedentary reduction intervention after TKR.

The purpose of this study was to examine the effects of a multicomponent mHealth sedentary reduction intervention on sedentary time in adults with TKR at the end of the intervention (2 months) and following a 3-month maintenance period. Changes in physical activity, physical function, and pain were also examined at each time. Additionally, this study examined the dose-response relationship between adherence to the mHealth program and changes in sedentary time, physical activity, physical function, and pain.

Methods

This study was a randomized clinical trial and full study details have been previously published [15]. Participants with TKR were randomized to either the intervention (*NEAT!2*) or an attention control group. Outcomes were assessed at baseline, the end of the intervention (2 months), and following a 3-month maintenance period. All study procedures were approved by the University of South Carolina's Institutional Review Board and participants provided written informed consent before participation. The trial was preregistered on Clinicaltrials.gov (NCT04482400).

Participants

Participants were recruited and enrolled between August 2020 and April 2024. Initially, participants were recruited at least 7 days prior to knee replacement and then started the program 4 weeks after surgery; however, due to recruitment challenges as a result of the COVID-19 pandemic, recruitment and eligibility criteria were modified in October 2021. Following the change, participants were eligible if they had a unilateral TKR <1 year from the baseline assessment. Additional inclusion criteria included age 40-79 years, have a smartphone that was accessible and near them the majority of the day, be willing to download the study smartphone applications, self-report spending at least 7 hours/day sitting, and be English-speaking. Participants were excluded if they had any contraindications to activity, had a mobility limiting comorbidity (e.g., spinal stenosis), were scheduled for surgery (e.g., TKR on contralateral knee) within the next 6 months, or did not have ≥4 days of valid ActiGraph accelerometer (≥10 hours/day) wear at baseline. There was no racial or gender bias in the selection of participants.

Participants were primarily recruited from orthopedic centers within a local health care system in Columbia, SC. Study candidates were contacted via postcards, mailings, emails, or telephone calls. Additional recruitment strategies included flyers posted on the

university campus or local businesses or clinics, emails to university faculty and staff, and social media. All recruitment material directed interested candidates to complete an online or telephone screening with study staff. Eligible candidates were invited to an in-person session to review complete study details and complete the written informed consent process if interested and eligible.

Randomization

After completing the baseline assessment and verifying accelerometer wear time, participants were contacted via telephone to remind them of the study details. Additionally, to promote retention and prevent differential attrition, the benefits and barriers to both general research study participation and specific study participation were reviewed and participants were asked to discuss their personal perspectives on the pros and cons of being randomized to either study condition [16]. Participants who expressed continued interest in participating were randomized to one of two conditions: (1) *NEAT!2*, or (2) Control. Randomization, which was created by the biostatistician, was stratified by age, <65 years and ≥65 years and done on a rolling basis using randomly permuted blocks

Randomized Conditions

NEAT!2

Participants randomized to *NEAT!2* received the mHealth and coaching intervention guided by the Dual-Process Theory [17,18]. Participants were given goals to reduce sedentary time, starting with a reduction of 30 minutes/day and progressing every 2 weeks to the final goal of reducing sedentary time by 90 minutes/day. To help participants reach this goal, the *NEAT!2* app was turned on after randomization and displayed the overall daily goal. The app was designed to detect prolonged sedentary time using the accelerometer and activity recognition libraries on the participant's Android or iOS device. Specifically, when 30 minutes of continuous inactivity time was detected, the app generated a

sound/vibration and placed a notification on the participant's phone (Figure 1). The notifications varied in content but each instructed participants to take a break from sitting, either by standing or walking for at least 2 minutes. The *NEAT!2* prompts were designed to target automatic (implicit) processes.

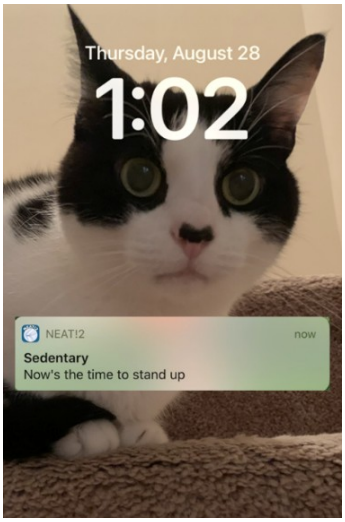

Figure 1. Screenshot of an example *NEAT!2* app notification

In conjunction with the *NEAT!2* app, controlled (conscious) processes were targeted through goal setting, education, problem solving and behavioral feedback. Participants received a coaching call every 2 weeks during the 2-month intervention (5 total). Calls were intended to last 10-15 minutes and focused on use of the app, goal setting and problem-solving around reducing sedentary time, with coaches guided by semi-structured call scripts. All coaches had a background in exercise science, psychology, public health or a related field.

Between the 2- and 5-month assessments, participants received monthly phone calls from research staff members who did not conduct the coaching calls. These calls focused solely on surgery recovery and were designed to help with retention during the follow-up period. Participants were given the option to continue using the *NEAT!2* app during this period, however, use of the app or sedentary time were not discussed on calls.

Attention matched control

Participants randomized to the control group received an attention-matched education program focused on surgery recovery which included a smartphone application or website (My Knee Guide®) and regular calls. Control participants were encouraged to use the app or website to plan recovery activities and read about others' experiences after TKR. Participants also received calls from the study coaches every 2 weeks (5 total) to discuss surgery recovery and education after TKR (e.g., dealing with fatigue, emotional self-care, reducing injuries at home). If participants brought up unintended content (e.g., sedentary behavior or physical activity), coaches were trained to redirect the conversation.

Similar to *NEAT!2* participants, control participants received monthly phone calls on surgery recovery between the 2- and 5-month assessments. Following the 5-month assessment, the control group was offered access to the *NEAT!2 app.*

Treatment Fidelity.

For both groups, all coaching sessions were audiotaped, and a 15% sample of calls were rated every quarter. Fidelity evaluated unintended and intended content based on randomized condition. If fidelity fell below 80% or coaches discussed unintended content, coaches were retrained.

Measures

Assessments were completed either in an orthopedic clinic or campus research center at baseline, 2- and 5-months. Study assessors were blinded to group allocation and had undergone training on all assessment procedures. All questionnaires were completed online via REDCap (Research Electronic Data Capture) [19]. Participants received $15 for completing the 2- and 5-month assessments ($30 total).

Outcomes

Sedentary Time and Physical Activity. At each assessment, participants were asked to wear an ActiGraph GT9X Link (Pensacola, FL) waist-worn accelerometer for 7

days during waking hours (except water-based activities). A minimum of 4 days valid wear time consisting of at least 10 hours/day was required for inclusion in analyses [20]. Non-wear time was defined as ≥90 minutes with zero activity counts, allowing for up to 2 minutes of <100 counts/min [21]. Sedentary time was defined as <100 counts/min and total activity as ≥100 counts/min [20]. Average daily sedentary time (minutes/day), percentage of the waking day spent in sedentary time, and weekly total physical activity (light, moderate, and vigorous intensity activity) were calculated within the ActiLife 6 software.

In addition to ActiGraph monitors, the activPAL (Glasgow, UK) and SIT-Q [22] were used as exploratory measures of sedentary time at each time point. The activPAL monitor was waterproofed and taped on to participants' thighs using waterproof tape. Participants were asked to wear the monitor for 24 hours/day during each 7-day period. A minimum of 4 days of valid wear time, defined as 24 hours, were required for inclusion in analyses. The time spent sitting/lying, standing, and walking, transitions and step counts were determined using the ActivPAL software v8. The SIT-Q [22] was also administered and is a self-reported measure of habitual sedentary behavior. The average number of hours per day spent sitting on weekdays and weekends were calculated.

Physical Function. Physical function was assessed using the Chair Stand Test, Timed Up and Go, and Six-Minute Walk Test. All physical function tests were completed following Osteoarthritis Research Society International (OARSI) recommended procedures [23]. During the Chair Stand Tests, participants were asked to complete as many chair stand repetitions as possible during a 30-second period. The Timed Up and Go Test assessed the time in seconds taken to rise from a chair, walk 3-meters, turn, walk back to the chair, and sit down. The Six-Minute Walk Test evaluated the maximal distance in feet a participant could walk during a 6-minute period.

Patient-Reported Outcomes. Pain and related self-reported outcomes were

assessed using the Western Ontario and McMaster Universities Arthritis Index (WOMAC) [24] and Knee Injury and Osteoarthritis Outcome Score (KOOS).[25] The WOMAC is a 15-item survey assessing pain, stiffness, and functional limitations over the last 48-hours on a 5-point Likert scale. Scores range from 0-20 for pain, 0-8 for stiffness, and 0-68 for physical function, with higher scores presenting more symptoms. The KOOS assesses overall knee health and includes 5 subscales: pain, symptoms, activities of daily living, sport and recreation, and knee-related quality of life. Scores on each subscale range from 0 (no knee issues) to 100 (extreme knee issues). General health, sleep disturbance, and mobility were also assessed using Patient-Reported Outcomes Measurement Information System (PROMIS) computer adaptive tests via REDCap. Each survey generates a T-score, where scores below 50 indicate poorer outcomes, while scores above 50 reflect better outcomes.

Habit strength was assessed with 4 items for sitting, stretching, and exercising from the Self-Report Habit Index [26]. Participants were asked to rate each behavior from 1 (strongly disagree) to 7 (strongly agree) on the following items: “I do automatically,” “I do without having to consciously remember,” “I do without thinking,” and “I start doing before I realize I'm doing it.” Higher scores indicate higher habit strength.

Demographic and Intervention Adherence

Demographics and medical history were obtained at baseline. Height (m) and weight (kg) were measured in light clothing and without shoes at each time point. Body mass index (BMI) was subsequently calculated as kg/m^2.

Adherence to the *NEAT!2* intervention was assessed by the percentage of coaching calls completed (total calls/5 calls), total days the *NEAT!2* app was used (56 possible days) and the response to *NEAT!2* notifications. Total days the *NEAT!2* app was used was determined as the number of unique days participant’s received notifications through the app. The response to *NEAT!2* notifications was determined by the percentage of

notifications in which movement/activity was detected by the app within 5 minutes of a notification delivery.

Adverse Events

Injuries and illnesses were assessed at each assessment, as well as on follow-up calls. All adverse events were monitored and rated based on their severity, expectedness, and relatedness to the study.

Statistical analysis

Descriptive statistics were used to describe participants' baseline characteristics. Multiple linear regression with generalized estimating equation (GEE) methodology was used to evaluate whether the NEAT!2 sedentary reduction intervention led to greater improvements in sedentary time (ActiGraph minutes/day and percentage of the day in sedentary time), physical activity, physical function, and pain than the Control group at 2 and 5 months. Estimated regression coefficients and corresponding 95% confidence intervals (CIs) were computed for each outcome. To examine the dose-response relationship between adherence to the *NEAT!2* intervention and changes in outcomes (sedentary time, physical activity, physical function, and pain), Spearman correlation coefficients and corresponding 95% CI were computed. All hypothesis tests were 2-sided with a statistical significance at $p<.05$. No adjustments were made for multiple comparisons. All statistical analyses were performed in SAS V9.4 (Cary, NC).

The sample size calculations have been reported previously [15]. In brief, having 40 participants per group complete the 2- and 5- months assessments would provide 90% power to detect a difference of 8.1% reduction in sedentary time (i.e. effect size of 0.7) between participants in the *NEAT!2* and Control groups.

Results

Participant Characteristics, Retention, and Safety

Of the 502 individuals screened for eligibility, 103 (20.5%) were eligible and were consented (Figure 2). The primary reasons participants were excluded were not interested (n=310), report sitting <7 hours/day (n=22), or had a mobility limiting comorbidity (n=17). Following consent, 83 participants were eligible and continued on to be randomized (n=42 to *NEAT!2* and n=41 to Control). Retention was 96% and 95% at 2- and 5-months, respectively, with no differences between groups at either time point.

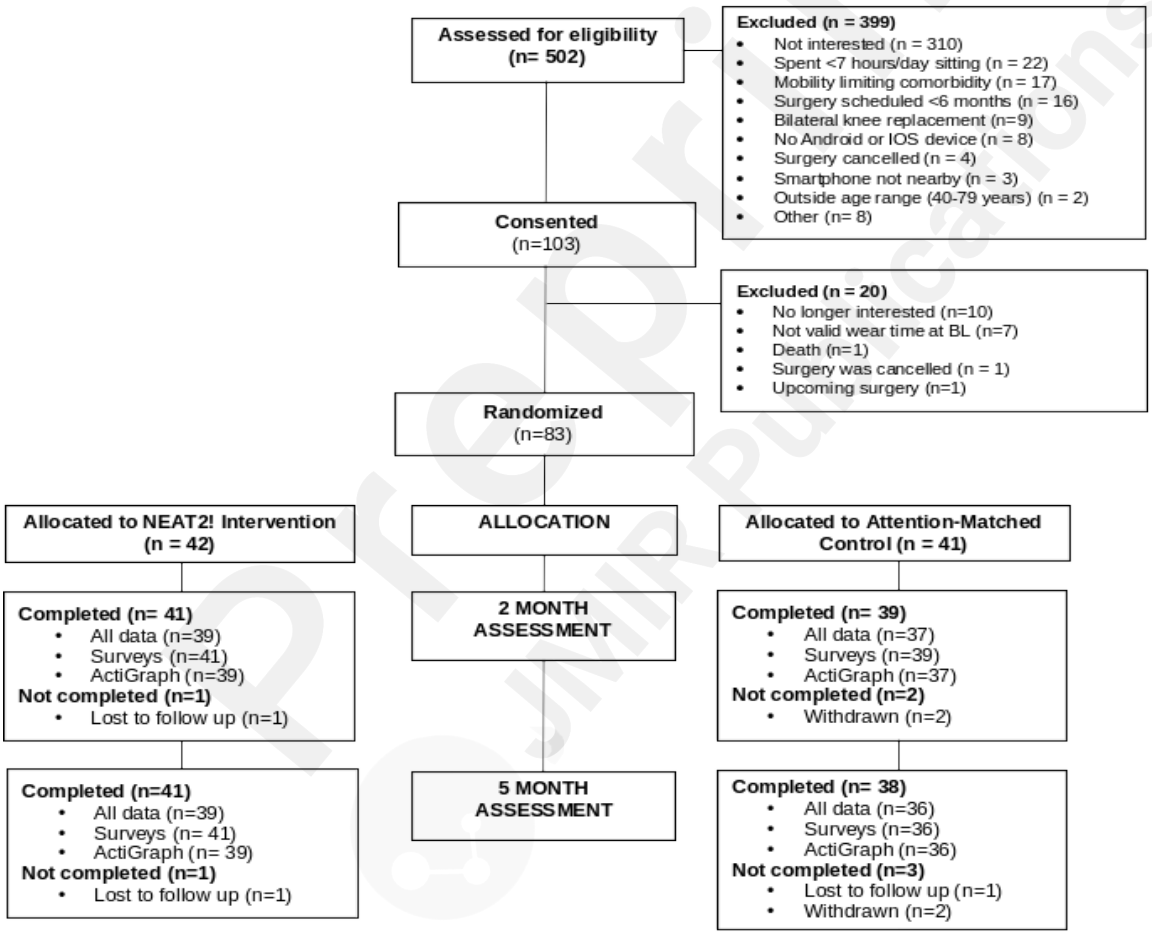

Figure 2. Participant Consort Diagram

Participants in the *NEAT!2* and Control groups had similar characteristics at baseline (Table 1). Participants were aged 65.3 ± 9.4 years, primarily female (74.7%) and White (77.1%), with an average BMI of 32.7 ± 6.9 kg/m^2. Most participants (50.6%) were full or part-time employed. The most common medical conditions included hypertension (57.8%),

depression or anxiety (32.5%), sleep apnea (26.5%), and diabetes (21.7%). Nine participants were recruited prior to surgery (12.0 ± 3.5 days before surgery) and 74 participants were recruited on average 198.1±108.6 days after surgery. During the study period, 32 adverse events (2 prior to randomization, 8 in control and 22 in *NEAT!2*) and 6 serious adverse events (3 in control and 1 in *NEAT!2)* occurred. The serious adverse events included 1 death and 5 surgeries/hospitalizations. Only one adverse event (nerve entanglement in back) was deemed possibly related to the intervention; all others were deemed unrelated to the study.

Table 1. Baseline characteristics of participants by full sample and group allocation

Demographics	**Total Sample (n=83)**	***NEAT!2* (n=42)**	**Control (n=41)**
Age (years), mean (SD)	65.3 (9.4)	65.5 (9.8)	65.1 (9.0)
Sex, n (%)			
Female	62 (74.7)	32 (76.2)	30 (73.2)
Male	21 (25.3)	10 (23.8)	11 (26.8)
Body Mass Index (kg/m^2), mean (SD)	32.7 (6.9)	33.7 (7.1)	31.7 (6.6)
Days since knee surgery, mean (SD)	175.3 (121.8)	192.8 (122.6)	157.4 (119.8)
Race, n (%)			
White	64 (77.1)	31 (73.8)	33 (80.5)
Black or African American	19 (22.9)	11 (26.2)	8 (19.5)
Ethnicity, n (%)			
Not Hispanic or Latino	83 (100)	42 (100)	41 (100)
Marital status, n (%)			
Married	51 (61.4)	30 (71.4)	21 (51.2)
Not Married	32 (38.6)	12 (28.6)	20 (48.8)
Education, n (%)			
<College Degree	26 (31.3)	11 (26.2)	15 (36.6)
≥College Degree	57 (68.7)	31 (73.8)	26 (63.4)
Employment, n (%)			
Full Time	33 (39.8)	17 (40.5)	16 (39.0)
Part Time	11 (13.3)	5 (11.9)	6 (14.6)
Retired or Not Working	39 (47.0)	20 (47.6)	19 (46.3)
Household income, n (%)			
<$100,000	41 (49.4)	22 (52.4)	19 (46.3)
≥$100,000	33 (39.8)	16 (38.1)	17 (41.5)

Prefer not to answer	9 (10.8)	4 (9.5)	5 (12.2)
Comorbidities, n (%)			
Diabetes	18 (21.7)	9 (21.4)	9 (22.0)
Cancer	12 (14.5)	8 (19.0)	4 (9.8)
Depression and/or Anxiety	27 (32.5)	15 (35.7)	12 (29.3)
High Blood Pressure	48 (57.8)	24 (57.1)	24 (58.5)
Thyroid Problems	17 (20.5)	10 (23.8)	7 (17.1)

Intervention effects on primary and secondary outcomes

The intervention effects on sedentary behavior and physical activity outcomes are shown in Table 2. At baseline, the percentage of the waking day spent in sedentary time was 73.26% ± 7.47% in *NEAT!2* participants and 74.13% ± 6.17% in the control participants. The *NEAT!2* intervention did not result in statistically significant effects on any of the sedentary behavior or physical activity outcomes at 2 or 5 months and no differences were observed between groups. The intervention effects on physical function and patient-reported outcomes are shown in Table 3. There were also no significant effects across time or by group.

Table 2. Sedentary Behavior and Physical Activity Outcomes at Baseline, 2 and 5 Months by Group Allocation

Outcome	**Time**	***NEAT!2* (n=42) Mean (SD)**	**Control (n=35) Mean (SD)**	**Group*Time Interaction Effects in GEE Models**		
				Coefficient Estimate	**95% CI**	***P value***
ActiGraph % of time sedentary	BL	73.26 (7.47)	74.13 (6.17)			
	2M	73.37 (7.06)	73.71 (6.03)	0.03	-2.26, 2.31	0.982
	5M	74.56 (7.36)	73.32 (6.79)	1.82	-0.45, 4.08	0.116
ActiGraph Sedentary Time, min/day	BL	659.41 (78.75)	658.46 (82.16)			
	2M	659.52 (75.70)	638.24 (75.56)	13.56	-16.09, 43.22	0.370
	5M	674.17 (77.60)	638.62 (78.31)	29.87	-3.74, 63.48	0.082
ActiGraphTotal Physical Activity, minutes/week	BL	1642.76 (510.24)	1472.18 (433.77)			
	2M	1553.03 (447.69)	1424.41 (447.76)	-37.89	-214.76, 138.98	0.675
	5M	1532.41 (510.40)	1442.08 (478.67)	-95.18	-260.66, 70.29	0.260
ActiGraph Moderate to Vigorous Physical Activity, minutes/	BL	78.67 (86.06)	51.08 (71.06)	-		

week						
	2M	58.51 (74.62)	49.76 (60.68)	-20.37	-44.42, 3.67	0.097
	5M	60.67 (89.10)	57.81 (65.74)	-23.69	-46.87, -0.51	0.045
ActiGraph Wear Time, minutes/week	BL	6135.88 (696.68)	5683.43 (1082.25)			
	2M	5878.54 (989.87)	5416.14 (1019.57)	18.05	-11.64, 47.74	0.234
	5M	6003.08 (871.71)	5411.36 (1118.51)	19.95	-13.88, 53.78	0.248
activPal sitting time, minutes/day	BL	625.96 (120.19)	632.53 (116.71)			
	2M	634.02 (114.46)	608.57 (120.69)	25.37	-21.56, 72.29	0.289
	5M	629.05 (109.06)	615.36 (116.69)	4.74	-31.16, 40.64	0.796
activPal standing time, minutes/day	BL	212.99 (79.89)	189.60 (55.76)			
	2M	219.49 (94.47)	199.24 (73.55)	0.50	-23.64, 24.64	0.968
	5M	221.27 (82.10)	210.34 (73.23)	-8.34	-30.66, 13.98	0.464
activPal walking time, minutes/day	BL	79.99 (32.76)	73.02 (25.48)			
	2M	79.29 (30.49)	73.78 (27.13)	-2.43	-10.21, 5.35	0.540
	5M	80.16 (30.74)	76.96 (29.24)	-3.97	-12.80, 4.87	0.379
activPal Sit to stand transitions, transitions/day	BL	45.88 (13.68)	47.03 (10.30)			
	2M	48.38 (13.71)	46.94 (10.00)	3.38	0.004, 6.75	0.050
	5M	47.68 (13.53)	45.22 (10.76)	4.11	-0.09, 8.32	0.055
activPal steps, steps/day	BL	5980.90 (2725.07)	5318.68 (2041.63)			
	2M	5937.00 (2469.10)	5318.49 (2025.06)	-117.74	-726.43, 490.96	0.705
	5M	6086.73 (2632.99)	5661.11 (2381.95)	-293.74	-1019.63, 432.15	0.428
SIT-Q Sitting time on weekday, hours/day	BL	11.66 (4.82)	11.31 (4.20)			
	2M	10.27 (3.85)	9.70 (3.69)	0.22	-1.83, 2.26	0.834
	5M	9.98 (3.77)	10.15 (4.89)	-0.52	-2.68, 1.64	0.637
SIT-Q Sitting Time on weekend, hours/day	BL	10.34 (4.55)	10.42 (4.80)			
	2M	9.53 (4.05)	9.19 (4.44)	0.42	-1.92, 2.76	0.724
	5M	9.58 (3.63)	9.32 (4.23)	0.34	-2.05, 2.72	0.783

BL: Baseline. 2M: 2 months. 5M: 5 months.

Table 3. Physical Function and Patient-Reported Outcomes at Baseline, 2 and 5 Months by Group

Outcome	Time	*NEAT!2* (n=42)	Control (n=35)	Group*time interaction effects in GEE models		
		Mean (SD)	Mean (SD)	Coefficient Estimate	95% CI	*p*-value
6 Minute Walk Test, feet	BL	1231.36 (270.92)	1207.42 (340.37)			
	2M	1324.72 (295.61)	1337.48 (309.14)	-7.40	-30.12, 15.31	0.523
	5M	1338.67 (271.20)	1340.04 (342.75)	-5.83	-30.20, 18.54	0.639
30 Second Chair Stand Test,	BL	9.48 (2.51)	9.34 (2.90)			

repetitions						
	2M	10.90 (2.74)	10.32 (3.01)	0.35	-0.47, 1.17	0.401
	5M	10.59 (2.71)	10.39 (2.92)	-0.01	-0.86, 0.84	0.986
Timed Up and Go, seconds	BL	10.28 (2.88)	10.20 (2.77)			
	2M	9.52 (2.48)	9.39 (2.02)	0.02	-0.73, 0.76	0.965
	5M	9.22 (2.06)	9.51 (2.26)	-0.38	-1.29, 0.53	0.413
WOMAC Pain	BL	5.21 (4.24)	5.37 (3.68)			
	2M	2.93 (2.94)	3.68 (3.17)	-0.53	-1.64, 0.57	0.344
	5M	3.05 (3.47)	3.00 (3.04)	0.20	-1.05, 1.45	0.751
WOMAC Stiffness	BL	3.07 (1.89)	3.15 (1.84)			
	2M	2.54 (1.60)	2.18 (1.78)	0.46	-0.18, 1.09	0.161
	5M	2.27 (1.75)	1.95 (1.69)	0.42	-0.36, 1.20	0.288
WOMAC Function	BL	17.95 (12.81)	16.68 (11.27)			
	2M	11.88 (10.11)	12.43 (10.11)	-1.74	-5.40, 1.92	0.351
	5M	11.24 (9.80)	11.26 (9.71)	-1.06	-5.62, 3.50	0.649
KOOS Pain	BL	69.51 (19.18)	69.11 (19.68)			
	2M	80.69 (15.63)	78.96 (15.29)	1.44	-4.09, 6.96	0.610
	5M	81.03 (16.62)	81.87 (16.28)	-0.89	-7.24, 5.46	0.783
KOOS Symptoms	BL	66.92 (20.37)	64.37 (21.18)			
	2M	74.04 (17.98)	72.95 (17.15)	-1.43	-7.40, 4.54	0.638
	5M	75.17 (16.62)	74.91 (19.14)	-1.90	-8.50, 4.70	0.572
KOOS Activities of Daily Living	BL	73.60 (18.84)	75.47 (16.57)	-		
	2M	82.53 (14.86)	81.73 (14.87)	2.56	-2.82, 7.95	0.351
	5M	83.46 (14.41)	83.44 (14.29)	1.56	-5.15, 8.27	0.649
KOOS Sport and Recreation	BL	57.86 (30.43)	53.78 (32.19)			
	2M	62.93 (26.55)	59.75 (32.87)	-1.12	-15.03, 12.78	0.874
	5M	66.34 (27.04)	69.61 (24.45)	-6.82	-20.54, 6.91	0.331
KOOS QoL	BL	53.42 (21.22)	48.02 (26.57)			
	2M	64.63 (20.85)	59.06 (21.92)	0.07	-7.98, 8.12	0.986
	5M	66.62 (21.04)	64.14 (22.12)	-2.45	-10.66, 5.76	0.559
PROMIS Global Mental, T-score	BL	52.78 (8.16)	51.02 (9.50)			
	2M	53.98 (8.10)	49.72 (9.04)	2.37	0.23, 4.51	0.030
	5M	53.58 (9.53)	50.52 (9.39)	1.27	-1.39, 3.94	0.349
PROMIS Global Physical, T-score	BL	45.95 (8.55)	45.65 (7.15)	-		
	2M	49.16 (7.81)	48.14 (7.14)	0.64	-1.97, 3.26	0.630
	5M	49.28 (9.03)	48.94 (8.51)	0.14	-2.69, 2.96	0.924
PROMIS Sleep, T-score	BL	50.05 (8.68)	54.09 (6.59)	-		
	2M	47.10 (9.38)	49.26 (6.69)	1.81	-1.50, 5.11	0.284
	5M	47.90 (8.72)	48.31 (7.21)	3.43	-0.20, 7.07	0.064
PROMIS Mobility, T-score	BL	40.84 (7.03)	40.76 (4.79)	-		
	2M	42.58 (4.49)	43.05 (5.23)	-0.61	-2.62, 1.40	0.554

	5M	43.16 (5.79)	43.42 (5.50)	-0.40	-2.62, 1.81	0.722

BL: Baseline. 2M: 2 months. 5M: 5 months. WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index. KOOS: Knee Injury and Osteoarthritis Outcome Score; PROMIS: Patient-Reported Outcomes Measurement Information System

Intervention Engagement

On average, participants completed 4.8 ± 0.6 calls of the possible 5 calls, with no difference between randomized groups. Average call times for *NEAT2!* participants (13.0 ± 7.2 minutes) were greater than the control group (10.65 ± 4.8 minutes, p <0 .001). Participants in the *NEAT!2* condition used the app for an average of 40.3 ± 13.82 days over the 56-day intervention, with participants receiving an average of 9.7 ± 6.0 notifications per day. Participants responded to *NEAT!2* notifications (movement detected by smartphone) on 9.7 ± 7.8% (range 2-42%) of occasions with an average time between notification and movement of 2.4 ± 0.4 minutes.

Dose Response Relationship Between Intervention Adherence and Changes in Outcomes

The higher percentage of days the *NEAT!2* app was used was associated with greater increases in MVPA (r = 0.335, 95% CI 0.017, 0.585, p= 0.037). There were no other significant relationships between adherence in call completion or response to *NEAT!2* notifications with changes in sedentary time, physical activity, physical function, and pain.

Discussion

This study examined the effects of a multicomponent mHealth sedentary reduction intervention (*NEAT!2*) on sedentary time in adults with recent TKR. Additionally, this study examined the dose-response relationship between adherence to the mHealth program and changes in each outcome. Despite high adherence to the program, the *NEAT!2* intervention did not result in statistically significant changes in any of the study's outcomes including sedentary time, physical activity, physical function, and pain. Although there were no differences in changes between groups in outcomes, there was a positive association

between the adherence to the *NEAT!2* app and MVPA, suggesting that those who used the app more had greater increases in MVPA.

Although some previous interventinos have been effective at reducing sedentary time in non-TKR populations [12–14], the literature is mixed, particularly among older adults [27]. A recent systematic review by Chastin et al. [27] highlights the uncertainties of whether sedentary reduction interventions can effectively reduce sedentary time in older adults. The lack of changes in sedentary time in the current *NEAT!2* mHealth intervention among adults <1 year after TKR is consistent with this review [27], highlighting the challenges of reducing sitting time in an older and clinical population.

The current intervention was guided by the Dual Process Theory [17,18] and targeted both automatic and conscious individual-level behaviors. The behavior change techniques implemented in the current study included strategies such as reminders to interrupt sedentary behavior (targeting automatic processes) and goal setting (targeting conscious processes). Previously, mHealth interventions, including disruptive smartphone apps to interrupt sedentary behavior have shown effectiveness in reducing sedentary time among various populations including individuals with overweight/obesity and diabetes [12,28], however, these strategies may not have been sufficient to change daily sitting time in adults post-TKR within this brief 2 month intervention. Further, many effective sedentary reduction programs have included changes in the environment and included the provision of standing desks, primarily for office workers [29]. While this would work for working adults, nearly half of the participants in the current study were retired or not working; thus, standing desks may not be an effective strategy for this population. Future interventions may need to increase the focus on environmental, as well as cultural and social factors, that could be influencing sedentary behavior more so than individual-level factors [27,30].

Potential post-operative and COVID-19 pandemic barriers faced by the current

participants may have also reinforced sedentary behaviors [31] and prevented the intervention from being effective. Additionally, previous research suggested that adults with TKR and osteoarthritis are unaware of the health benefits of light intensity activity and often think that sedentary time should be replaced with moderate intensity activity [30]. The current intervention promoted primarily light-intensity activity such as standing or light walking, however, the results suggested that the more days the app was used, the greater the increase in MVPA. Despite coaches encouraging the replacement of sedentary time with light intensity activity, participants may still have been focusing on replacing sedentary time with MVPA like a brisk walk. While increasing MVPA would provide substantial health benefits, it is unreasonable to think that all excess sedentary time could be replaced with MVPA. More effort is needed to raise awareness of the health consequences of excess sedentary time and benefits of replacing sedentary time with any intensity of activity in older adults [32].

This study had several strengths. In addition to being one of the first studies to examine a sedentary reduction program after TKR, the use of multiple objective and subjective measurement tools provides further evidence of the challenges and inconsistencies in measuring sedentary time in this population. However, this study has several limitations. The COVID-19 pandemic resulted in necessary changes to recruitment whereby some participants completed baseline testing before surgery and others, post-operatively. While this was accounted for in analyses, the COVID-19 pandemic may have had other effects on participants and outcomes. Further, there is likely error in the determination of responsiveness to the *NEAT!2* notifications as the determination of response was based on movement detected on the smartphone. It is possible that participants may have stood up or walked around, but did not move their phone; thus, the app would not have been able to detect that response. Future studies may need to consider

using more innovative wearables that could detect postural changes.

A multicomponent mHealth sedentary reduction intervention was not effective at reducing sedentary time in adults who had TKR; however, participants who used the app more days throughout the intervention had greater increases in MVPA. This study highlights the challenges of reducing sitting time in this population and presents direction for future studies, which should explore alternative behavior change techniques across different levels of influence (e.g., environmental, social) in future interventions within the first year after TKR.

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Conflicts of Interest

J. Benjamin Jackson III is a consultant for Vilex Inc. All other authors do not have any conflicts to disclose.

Data Availability

The datasets generated or analyzed during this study are available from the corresponding author on reasonable request.

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Supplementary Files

CONSORT (or other) checklists

Consort checklist.
URL: http://asset.jmir.pub/assets/7f036437e512afb09da0a28253cb2b90.pdf