



Reducing sedentary time using an innovative mHealth intervention among patients with total knee replacement: Rationale and study protocol

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ABSTRACT

Introduction: Although knee replacement is effective for improving pain and physical function, subsequent improvements in physical activity typically do not follow. As a result, many patients spend most of their day engaged in sedentary behavior, which may put them at higher risk of experiencing poor function and disability. Intervening on sedentary time, rather than physical activity, may be a more feasible first-step approach for modifying activity-related behaviors in adults who received knee replacement.

Objective: The purpose of this study is to examine the use of a mobile health (mHealth) intervention to reduce sedentary time among adults who received a knee replacement at 3 and 6 months after surgery.

Methods: Patients (n = 92) scheduled for knee replacement will be recruited and at 4 weeks after surgery, they will be randomized to either NEAT!2 or Control. NEAT!2 participants will use the NEAT!2 smartphone app, which provides a vibration and/or audible tone to interrupt prolonged bouts of sitting detected from the smartphone's internal accelerometer, until 3 months after surgery. NEAT!2 participants will receive biweekly coaching calls between 4 and 12 weeks after surgery. Control participants will receive an education control app and receive non-intervention calls to assess general surgery recovery. Both groups will receive 3 retention calls between 3 and 6 months. Data collection will occur pre-operatively and at 3 and 6 months after surgery.

Discussion: The results of this study will help to determine whether an innovative remotely-delivered, mHealth sedentary reduction intervention can decrease sedentary time in adults after knee replacement.

1. Introduction

Knee replacement is rising across all ages [1], and the number of new knee replacements is expected to reach 3.48 million by 2030 [2]. Knee replacement substantially increases lifetime medical costs and accounts for $\geq 50\%$ of osteoarthritis-related medical costs [3]. Hospital-based costs of knee replacements are estimated to be over \$16 billion per year in the United States [4]. Given the extensive economic burden of knee replacement and continued increases in utilization [2], it is critical to identify ways to maximize outcomes following surgery.

Knee replacement is effective at improving health-related quality of life [5], pain [6], and function [7], with $> 75\%$ of adults who received a knee replacement experiencing improvements [6]. Despite improve-

ments after surgery, corresponding changes in physical activity are not common. Post-operative activity levels are similar to pre-operative levels [8,9], suggesting challenges with increasing activity after surgery. Further, less than 5% of adults after knee replacement reach recommended physical activity guidelines 1–2 years after surgery [10,11]. Following surgery, patients face continued barriers to activity, including pain, physical limitations and lack of motivation [12]. The continued low levels of activity following surgery are concerning, as physical inactivity is a leading risk factor for disability [13] and poor function [14].

Sedentary behavior, defined as any waking behavior ≤ 1.5 METs while seated or reclining [15], also does not change after surgery [16]. Adults who received a knee replacement spend nearly two-thirds of the

Abbreviations: Mobile health (mHealth), body mass index (BMI).

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day in sedentary behaviors [16], which is similar to older adults [17], those with knee osteoarthritis [18] and diabetes [19]. Independent of activity, high levels of sedentary behavior are associated with increased risk of all-cause mortality [20], cardiovascular disease [21], and diabetes [22]. Additionally, excess sedentary behavior is linked with functional decline [18,23], physical frailty [24], loss of quality of life [25], and disability [26] in those with knee osteoarthritis. Excess sedentary behavior, regardless of activity levels, may hinder patients' ability to achieve maximal function outcomes following the costly surgical treatment.

Patients receive physical therapy after surgery, but once completed, patients no longer receive any form of rehabilitation or activity intervention. Further intervention in real-world settings may be necessary to overcome barriers to reduce sitting time. Additionally, the surgery may serve as a teachable moment in which it is an optimal opportunity to intervene, motivation may be higher, and behavior changes could be greater [27,28]. Overall, 81% of adults own a smartphone [29] and as smartphone ownership rises, the potential to disseminate effective mobile health (mHealth) interventions across a greater proportion of individuals becomes more feasible. Behavioral mHealth interventions have shown promise across many behaviors, including physical activity [30], sedentary behavior [31], smoking [32], and weight loss [33]. Mobile technology has the ability to intervene just-in-time to promote awareness, increase motivation, and change behaviors in real-world settings at the most optimal time [34].

We aim to examine if an mHealth sedentary reduction intervention can reduce sedentary time in adults who received a knee replacement. Increasing physical activity remains challenging in this population [35,36]; thus, utilizing a novel just-in-time mHealth approach, in which a sedentary behavior is targeted in an individual's natural environment at the right time and context, may be a feasible first step to reduce sedentary behavior and improve overall function. Further, this innovative mHealth intervention has reduced sedentary behavior in adults with diabetes [31] and has the potential to be disseminated widely to a population in great need of increasing activity patterns to improve overall functional levels and prevent or delay disability. As health care systems move towards value-based care, decreasing post-operative sedentary time using an app-based intervention presents an opportunity to add value to the surgery by improving outcomes with minimal increase in cost.

2. Methods

2.1. Study overview

The study is a randomized controlled trial in which 92 participants will be randomized at 4 weeks after knee replacement to one of two groups: (1) *NEAT!2* or (2) Control. Assessments will be completed pre-surgery and 3 months (end of treatment) and 6 months (maintenance) after surgery. All study procedures have been approved by the University of South Carolina's Institutional Review Board and participants will provide written informed consent prior to participation. The trial is registered on [Clinicaltrials.gov](https://clinicaltrials.gov) (NCT04482400).

2.2. Study aims

The primary aim of the study is to examine the effects of the *NEAT!2* (non-exercise activity thermogenesis) mHealth sedentary reduction intervention on sedentary time in adults after knee replacement at the end of treatment (3 months) and following a follow-up period (6 months). We hypothesize that participants randomized to the *NEAT!2* intervention compared to Control will have a greater reduction in objectively-measured sedentary time between pre-surgery and 3 and 6 months after surgery.

The secondary aims of the study include: (1) to evaluate changes in total physical activity time (light, moderate, and vigorous intensity), physical function, and pain in patients after participating in the *NEAT!2* mHealth sedentary reduction intervention at the end of treatment (3 months) and following a follow-up period (6 months); (2) to examine the dose-response relationship between adherence to *NEAT!2* and changes in sedentary time, total physical activity time, physical function, and pain. Measures of adherence include the percentage of calls completed/total possible calls (5 calls), days of app use/total possible days (56 days), and number of activity transitions following *NEAT!2* prompt/total number of *NEAT!2* prompts.

2.3. Study participants

Ninety-two participants will be recruited for this study. Eligible candidates will (1) be 40–79 years of age, (2) plan to have a primary unilateral knee replacement in ≥ 7 days from screening (to allow for activity monitoring; after recruitment started, this criteria was modified from a minimum of 10 days due to a shortened time period between pre-operative testing and surgery), (3) have an Android or iOS smartphone that is accessible and near them the majority of the day, (4) be willing to download the study applications on their smartphone, (5) spend ≥ 7 h/day sitting based on self-report, and (7) be English-speaking. Candidates will be excluded if they (1) have any contraindications to physical activity (e.g., recent myocardial infarction, uncontrolled hypertension), (2) have a mobility limiting comorbidity (e.g., spinal stenosis), or (3) have any scheduled surgery (i.e., knee replacement on contralateral knee) within the next 6 months. Individuals will also not be randomized if they do not have ≥ 4 days of valid accelerometer wear at baseline.

2.4. Recruitment and screening procedures

Participants will be recruited from Columbia, SC area orthopedic centers through multiple avenues. Recruitment flyers will be placed in the pre-operative packets given to every patient who is scheduled for knee replacement. The orthopedic surgeons will also inform the participant of the study and promote participation at the appointment in which the participant schedules the surgery. Study staff may also meet with interested patients at regularly scheduled appointments or make outreach to interested patients following appointments via email, mail, or telephone. Participants will be screened online, via telephone, or in-person to assess them for the study's inclusion and exclusion criteria. Eligible candidates will be invited to meet in-person where study staff will review the full details of the study and answer questions. Interested participants will complete the informed consent process prior to completing the baseline pre-operative assessment. In addition, to ensure compatibility and eliminate the potential of technological issues following randomization after surgery, all participants will download both the MyKneeGuide® and *NEAT!2* apps on their phone. All participants will be able to use MyKneeGuide prior to randomization; however, the *NEAT!2* app will not be turned on. Participants will not receive notifications about sedentary time or see a sedentary reduction goal until after randomization. At that point, only participants randomized to *NEAT!2* will have their app activated which will start to trigger notifications and allow participants to see their sedentary reduction goal.

2.5. Randomization

A staff member will call the participant at 4 weeks after surgery, ensure surgery occurred, and reassess interest in participating in the study. An equipoise induction will be conducted in which the pros and cons of participating in a research study are reviewed, the uncertainty as to which randomized condition will be the most effective, and discuss pros and cons of being randomized to either condition to help prevent differential attrition [37]. Participants who express continued in-

terest in participating will be randomized (stratified by age, <65 years and ≥65 years) on a rolling basis using randomly permuted blocks to one of two conditions: (1) NEAT!2, or (2) Control. Fig. 1 provides an overview of the study design. Intent-to-treat (using all available data) analyses will be performed.

2.6. NEAT!2 sedentary reduction intervention

NEAT!2 is guided by the Dual-Process Theory [38] and targets both automatic and controlled processes [39] to reduce total sedentary time. Fig. 2 describes the theoretical framework for the NEAT!2 sedentary reduction intervention. Participants randomized to NEAT!2 will have their NEAT!2 app turned on at 4 weeks after surgery and will be told they do not need to use the MyKneeGuide app any longer. The NEAT!2 app, designed solely to target automatic processes [39], works by promoting awareness of prolonged sedentary behavior. NEAT!2 uses the internal accelerometer and Android or iOS activity recognition libraries to classify the smartphone's patterns of movement. When 30 min of continuous sedentary time are detected using machine learning algorithms, the NEAT!2 app triggers an audible tone/vibration and places a notification on the phone's

lock/home screen (Fig. 3). A duration of 30 min of continuous sedentary time was chosen based on participant preferences on the frequency of interrupting sedentary behavior [40]. When the app detects movement of a predefined magnitude and threshold (e.g., using the phone while seated would be below the threshold, whereas walking with the phone would be above the threshold), the 30-min timer will restart; thus, the app will only provide notifications when prolonged bouts of minimal to no movement are objectively detected of a different message. Participants will be instructed to engage in any type of activity that is not sitting each time the notification is triggered for at least 2 min. Participants can engage in any activity (i.e., light or moderate intensity activity) that is appropriate or feasible in that moment, given replacing sedentary time with either intensity activity has been shown to be beneficial [41,42]. These experimental studies also informed our decision to recommend a duration of engaging in another activity besides sitting for at least 2 min [41,42].

Participants will be asked to use the app until 3 months after surgery.

NEAT!2 participants will be given an initial goal to reduce total sedentary time by 30 min/day and every 2 weeks, the goal will increase by 30 min until the final goal is reached (90 min reduction in

	Study Week(s) & Events	NEAT!2		Control	
		App	Call	App	Call
Pre-Surgery	ASSESSMENT (Pre-op)				
Post-Surgery	1-3	MyKneeGuide		MyKneeGuide	
	RANDOMIZATION				
	4	NEAT!2	Coaching Call #1	MyKneeGuide	Control Call #1
	5	NEAT!2		MyKneeGuide	
	6	NEAT!2	Coaching Call #2	MyKneeGuide	Control Call #2
	7	NEAT!2		MyKneeGuide	
	8	NEAT!2	Coaching Call #3	MyKneeGuide	Control Call #3
	9	NEAT!2		MyKneeGuide	
	10	NEAT!2	Coaching Call #4	MyKneeGuide	Control Call #4
	11	NEAT!2		MyKneeGuide	
	12	NEAT!2	Coaching Call #5	MyKneeGuide	Control Call #5
	END OF TREATMENT ASSESSMENT (3 Months Post-op)				
Maintenance	13-16	NEAT!2 (optional)		MyKneeGuide (optional)	
	17	NEAT!2 (optional)	Retention #1	MyKneeGuide (optional)	Retention #1
	18-20	NEAT!2 (optional)		MyKneeGuide (optional)	
	21	NEAT!2 (optional)	Retention #2	MyKneeGuide (optional)	Retention #2
	22-25	NEAT!2 (optional)		MyKneeGuide (optional)	
	26	NEAT!2 (optional)	Retention #3	MyKneeGuide (optional)	Retention #3
	MAINTENANCE ASSESSMENT (6 Months Post-op)				

Fig. 1. Study overview.

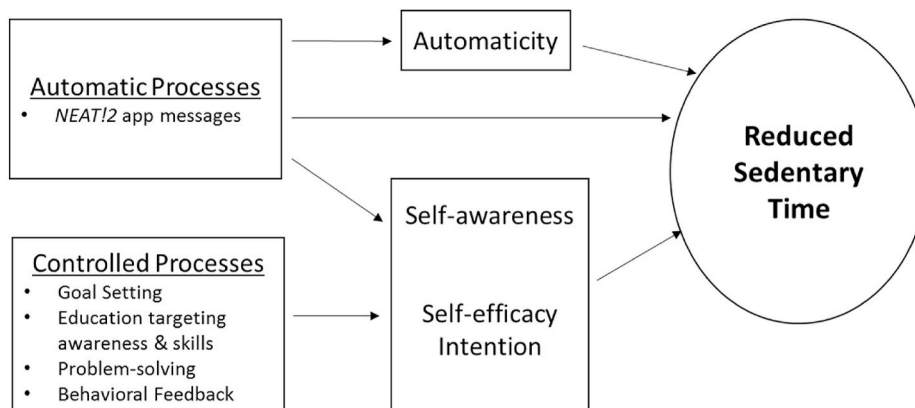


Fig. 2. Theoretical framework for the NEAT!2 Sedentary Reduction Intervention.

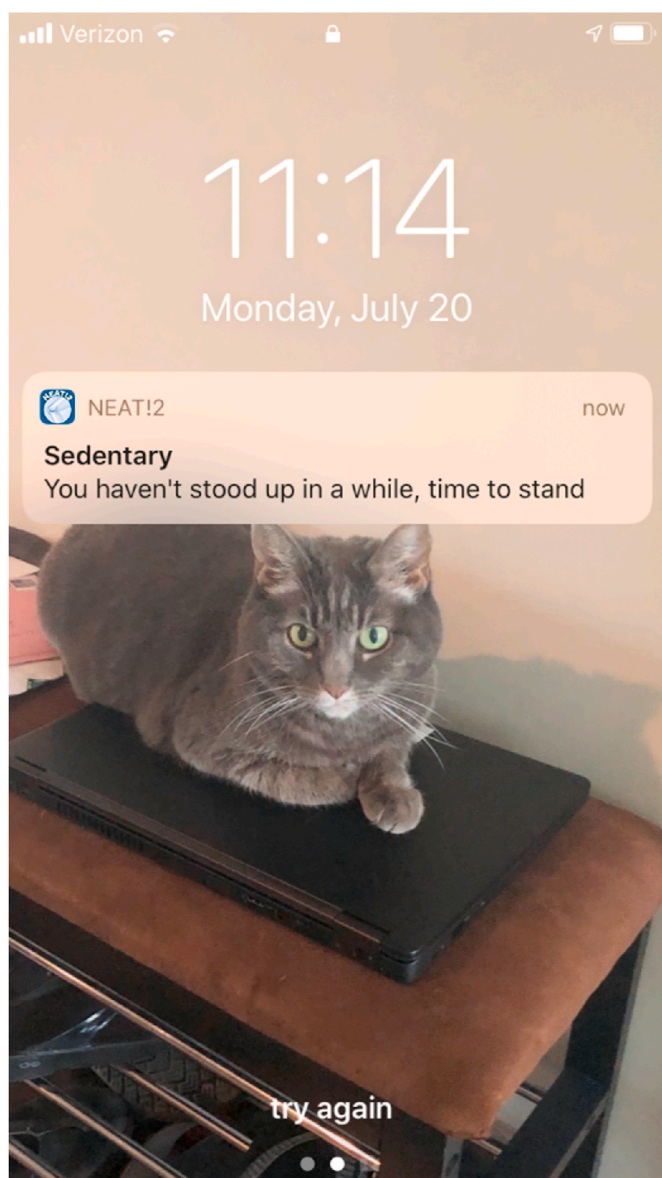


Fig. 3. Screenshot of NEAT!2 notification.

sedentary time each day). This daily sedentary reduction goal will be displayed in the NEAT!2 app. To assist with goal attainment and target controlled processes [39], participants will receive biweekly coaching calls between 4 and 12 weeks after surgery. All coaches will have a bachelors or masters degree in exercise science, psychology, public health or a related field. Coaches will receive study-specific procedural training which includes reviewing the call scripts, motivational interviewing techniques, and role play of calls from each condition to ensure appropriate content is discussed. During calls which will last ~10–15 min, coaches will use motivational interviewing, discuss goal progression and educational handouts, problem solve, and set a SMART (specific, measurable, attainable, realistic/reward, timely) goal related to reducing sedentary time. All calls will be recorded and timed to assess treatment fidelity.

After the 3-month assessment, participants will have the option to continue using the app until after the 6-month assessment. Additionally, participants will receive monthly calls between 3 and 6 months, unrelated to the intervention and focused on surgery recovery, to maintain contact and help with retention during follow-up. The monthly calls will be completed by the research coordinator or other staff member who is not completing coaching calls.

2.7. Attention matched control

Participants randomized to the Control will receive an attention-matched education program. Control participants will be asked to continue using the app (MyKneeGuide®) until 3 months after knee replacement, and the NEAT!2 app will remain inactive. MyKneeGuide® is a commercially available app that provides pre- and post-operative information for knee replacement, tracks appointments, connects to local rehabilitation facilities, and can connect with other patients who have recently had surgery. Control participants also will receive biweekly calls between 4 and 12 weeks after surgery from the same coaches completing the intervention calls. During calls, coaches will discuss surgery recovery and avoid topics related to sedentary behavior and physical activity. All calls will be recorded to evaluate whether any unintended content was discussed (e.g., reducing sedentary time, physical activity). Control participants will receive similar monthly calls between 3 and 6 months from the research coordinator or another staff member not completing coaching calls. Following the 6-month assessment, participants in the Control group will be offered the NEAT!2 app.

2.8. Treatment fidelity

Telephone sessions will be audiotaped, and a 15% sample rated for treatment fidelity on a quarterly basis. If fidelity falls <80%, coaches will be retrained. Fidelity checklists will assess SMART goal setting, intended session content (e.g., sedentary behavior goals for NEAT!2 or antibiotics for Control) and unintended session content (i.e., discussing physical activity or sedentary behavior with Control participants).

2.9. Outcome measures

Outcomes will be assessed pre-operatively and at 3 months (end of treatment) and 6 months (maintenance) after surgery. Participants will receive \$15 for completing the 3- and 6-month assessments (\$30 total). Primary outcomes are the changes in Actigraph assessed sedentary time between baseline and 3 and 6 months. Secondary aims include changes in total physical activity time (light, moderate, and vigorous intensity) from Actigraph, physical function (6 min walk and chair stands), and pain (WOMAC pain subscale) at 3 and 6 months. Exploratory analyses will examine the changes in additional physical function tests, knee symptoms, and in sedentary time and physical activity at 3 and 6 months obtained from the activPAL.

2.10. Sedentary behavior and total physical activity time

Sedentary behavior and total physical activity time will primarily be assessed with the ActiGraph GT9X Link (Pensacola, FL). Participants will be asked to wear the ActiGraph accelerometer on their hip using a waistband for 7 days during waking hours (except water activities). Following best practice recommendations [43–45], at least 4 valid days of the last 7 days will be required to be included in analyses, with a valid day defined as participants wearing the accelerometer for at least 10 h/day [46]. Non-wear time is defined as ≥ 90 min with zero activity counts, allowing for up to 2 min of <100 counts/min [47]. Sedentary time is defined as <100 counts/min and total activity as ≥ 100 counts/min [46]. Average daily sedentary time (minutes/day), percentage of the waking day spent in sedentary time (primary outcome), and weekly total physical activity will be calculated. The Actigraph has been found to be a valid measure of both sedentary [48,49] and physical activity time [50,51]. Data will be processed using ActiLife 6 (Pensacola, FL). Participants will also complete a 7-day log indicating times either device was worn and taken off.

Sedentary time will also be assessed using an ActivPAL™ PAL Technologies Ltd, (Glasgow, UK) which can better distinguish body position (e.g., sitting and standing). At the same time participants are wearing

the Actigraph, participants will be asked to wear the ActivPAL on their thigh (non-surgery leg) using waterproof tape. They will be asked to wear the monitor for 24 h/day. The time spent sitting/lying, standing, and walking, transitions and step counts will be determined using the ActivPAL software. Although the ActivPAL has not been used extensively in adults with knee replacement [52], it has been shown to accurately measure posture [53,54], stepping time [53], and intensity of activity [55] in other populations.

Sedentary behavior will also be assessed at each time point with the SIT-Q [56] to explore changes in domain specific sedentary time. The survey assesses time spent sleeping and sitting time during multiple domains (e.g., meals, transportation, work, leisure).

2.11. Physical function

Physical function measures will include the 6-min walk (secondary outcome), chair stand test (secondary outcome), and timed up and go (exploratory). All physical function tests will be completed following Osteoarthritis Research Society International (OARSI) recommendation procedures [56]. The Six Minute Walk Test evaluates the maximal distance a patient can cover during a 6-min period.

During the chair stand test, participants are asked to complete as many chair stand repetitions as possible during a 30-s period. The Timed Up and Go Test assesses the time in seconds taken to rise from a chair, walk 3-m, turn, walk back to the chair, and sit down.

2.12. Pain and knee symptoms

The Western Ontario and McMaster Universities Arthritis Index (WOMAC) will be used to assess pain, stiffness, and function in adults with osteoarthritis over the last 48 h [57]. The WOMAC consists of 24 items in which participants rate their level of pain, stiffness, and degree of difficulty performing daily activities on a 5-point Likert scale ranging from None (0) to Extreme (4). Scores for each subscale (pain [secondary outcome], stiffness, and function) will be calculated in addition to the total WOMAC scores, which is a sum of all 3 subscale scores. The Knee Injury and Osteoarthritis Outcome Score (KOOS) [58] will also be used to assess general knee symptoms. Specifically, the KOOS assesses knee symptoms and function over the past week using a 5-point Likert scale and consists of five subscales (pain, symptoms, daily function, sport/recreation function, and knee related quality of life). Similar to the WOMAC, the scale ranges from None (0) to Extreme (4). Scores will be normalized (0–100) for each subscale (100 indicating no symptoms and 0 indicating worse or extreme symptoms).

2.13. Adherence to NEAT!2 intervention

Adherence to NEAT!2 intervention will be examined by (a) percentage of coaching calls completed/total calls possible (5 calls), (b) total days the NEAT!2 app was used/total days possible (56 days), and (c) response to NEAT!2 notifications. The response to NEAT!2 notifications will be defined as (1) the percentage of notifications in which a transition from sitting to standing/walking was detected within 5 min of the prompt divided by total number of notifications, and (2) average time from notification to activity transition. All NEAT!2 app data will be obtained and exported from the NEAT!2 coaching interface.

2.14. Demographic, Process, or Additional Exploratory Measures

Weight will be measured at all assessments. Measurements will be taken without shoes, wearing light clothing on a calibrated beam balance scale. Height will also be measured using a stadiometer, and body mass index (BMI) will be calculated as kg/m².

Additional patient-reported outcomes (general health, sleep disturbance, and mobility) will be assessed using Patient-Reported Outcomes

Measurement Information System (PROMIS) [59] via a computer adaptive test via RedCap [60].

Adapted Self-Report Habit Index [47] assesses habit strength related to sitting, stretching, and exercising. Participants answer the questions on a 1–7 Likert scale ranging from “Strongly Disagree” to “Strongly Agree”.

2.15. Adverse events

Potential adverse events will be reported to the principal investigator and project coordinator who will then report the events to the correct personnel (e.g., IRB, study funders, DSMB) based on severity and a course of action will be decided. Risks associated with interrupting sedentary time with brief bouts of light-intensity physical activity such as standing or light ambulation are minimal. Since participants will have recently undergone total knee replacement, we will assess any type of events or adverse events that may occur, such as a fall.

2.16. Sample size considerations

The proposed study's sample size was chosen to allow for 40 subjects to receive NEAT!2 intervention and the same number to serve as the Control (a total of 80). We will recruit 92 subjects into the study, expecting that no more than 15% of these subjects will fail to return at 3- or 6-month post-surgery assessment yielding at least 80 subjects for change from baseline to post-surgery assessments. To estimate power for Aim 1, we used previous data [61] where an average of 70.1% of day was spent in sedentary behavior pre-surgery measured from Actigraph. Based on results from a previous study, we expect to detect an 8.1% reduction (at least 49 min) in sedentary time in participants in NEAT!2 while only modest or no reduction in the Control group [31]. With 40 participants in each group, we have 90% power to detect a difference of 8.1% reduction in sedentary time (i.e. effect size of 0.7) between participants in NEAT!2 and Control from baseline and 3- or 6-month.

2.17. Statistical analysis

The primary analysis will examine changes in Actigraph measured sedentary time (minutes/day, percentage/day) between NEAT!2 and Control. Secondary analysis will examine changes in total physical activity (daily minutes objectively measured from ActiGraph accelerometers), physical function (walking distance from the 6-min walk test), and self-reported pain (WOMAC). Due to multiple statistical testing for each pre-specified hypothesis, we will adjust for errors and keep the overall nominal significance (alpha) level at 0.05. SAS V9.4 (Cary, NC) will be the primary statistical analysis program. Multiple linear regression with generalized estimating equation methodology accounting for follow-up assessments will be used to evaluate whether participants randomized to NEAT!2 sedentary reduction intervention had greater improvements in sedentary time, physical activity, physical function, and pain than Control at 3- and 6- months after surgery. The model will be adjusted for potential covariates (i.e., age, sex, BMI, comorbidities). Regression coefficients and corresponding confidence intervals to compare those in NEAT!2 and Control at 3- and 6-months after surgery will be computed for each outcome (Aims 1 and 2). For Aim 3, multiple linear regression models will be used to evaluate the association between adherence and reduction for baseline differences and adjusted for potential covariates. Regression coefficients and corresponding confidence intervals of adherence will be computed for each outcome. Descriptive analysis of baseline demographic and process data will be conducted.

3. Discussion

The current trial will be one of the first studies to examine the effects of an mHealth sedentary reduction intervention on sedentary time in adults who received a knee replacement. Targeting sedentary behavior instead of physical activity may be a more feasible approach for adults after knee replacement. Knowing the importance of physical activity, some physical activity interventions have been tested in adults after knee replacement; however, the observed increases in activity were modest compared to changes observed in populations who did not have knee replacement, and the interventions were costly [35,36,62]. Adults after knee replacement continue to face barriers to physical activity and may not be ready to active after surgery [12]. Replacing time spent in sedentary behavior with light-intensity physical activity may be more attainable for this population due to continued knee symptoms, physical limitations, and low fitness levels [12]. Facing these barriers may make it more difficult to engage in activity of a moderate/vigorous intensity and obtain 150 min of activity of this intensity each week [63]; however, recommendations to replace sedentary time with short breaks of light intensity activity may be a more achievable goal given their barriers [64]. Replacing sedentary time with light-intensity physical activity is positively associated with increased physical health and well-being [65]. Additionally, adults after knee replacement may find it easier to reduce sedentary time using short breaks of light intensity activity, which may lead to increases in overall self-efficacy [66].

Physical activity interventions typically use behavioral strategies such as counseling [67], goal setting [68], feedback [67,68], and self-monitoring [69–71]; yet these strategies may not be optimal for habitual behaviors. Sedentary behavior is distinct from moderate/vigorous activity in that it is often unplanned and done without intention [39]. Dual process theories [38,72] posit that automatic (unconscious, not intentional) and controlled (conscious, volitional) processes influence behavior. Because of the automatic nature of sedentary behavior, combining coaching with promoting awareness of sedentary time in real-time may be effective intervention strategies [73,74].

We designed a novel smartphone app (*NEAT!2*) using a patient-centered approach to target automatic processes and intervene just-in-time on sedentary behavior in the real world [34]. *NEAT!2* is designed to identify 30 min of continuous sitting time during a user's typical waking hours. Once 30 min is detected, a vibration/audible tone and notification are initiated to intervene just-in-time to interrupt the user's sedentary behavior. Since users are not required to wear their smartphones, there is a chance some false positive prompts will be initiated if the phone is left unattended. Most adults have their phones nearby the majority of the day [75] and look at it several times/hour [75,76], (~85 times/day [77]), often accumulating up to 4 h/day of mobile device use alone [78,79]. Even though the occasional prompt will occur when a user is already standing/moving and may not have their phone nearby, we anticipate that the majority of the prompts will promote awareness and intervene in real-time during users' estimated 12 h of sedentary time/day [80].

Additionally, we chose to use a technology that individuals already own (81% of adults own a smartphone [29]) rather than a commercially available wearable physical activity monitor in which only 21% of adults own [81]. New wearables promote features to interrupt sedentary time, but have not been shown to be accurate [82] or modify sedentary behavior [83,84]. One possible explanation for why other wearables have not been effective is because reminders are set at pre-specified time (e.g., 10 min before the hour). Although our approach may not improve the accuracy of estimating sedentary time as compared to wearables, our just-in-time approach of only using a smartphone minimizes intervention costs and has the greatest potential for scalability.

In addition to being one of the first studies to examine a sedentary reduction program in adults who received a knee replacement, there

are many strengths to this mHealth intervention. First, sedentary behavior and physical activity will be measured using two activity monitors, Actigraph and ActivPAL. Although ActivPAL may be a more accurate assessment of sedentary time due to its ability to determine posture and is recommended in other populations [85], few studies have used them with adults who received a knee replacement [52,86,87]. Another strength of the study is that participants will be enrolled in the study prior to knee replacement and will be randomized shortly after surgery. This allows the examination of sedentary levels before surgery, as well as potentially catch participants during a teachable moment at the start of the intervention, leading to positive behavior changes [27]. Finally, the mHealth intervention does not require additional devices or costs, which may help provide a scalable strategy, if found effective.

4. Conclusion

To our knowledge, no prior studies have examined a sedentary reduction intervention specifically designed for adults after knee replacement. Completion of this trial will help to identify potentially effective and scalable strategies to help adults who received a knee replacement reduce their sedentary time and move more following surgery, which may ultimately lead to improved long-term functional outcomes. With smartphones becoming ubiquitous, the current intervention shows potential to be scaled if proven to be effective for modifying sedentary time.

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Declaration of competing interest

The authors have no conflicts of interest to report.

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