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Feasibility and Acceptability of a Home-Based Sensory Perception Training Game for Patients with Fibromyalgia: A Pilot Study

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Abstract

Objective: The primary aim of this pilot study was to test the feasibility and acceptability of a prototype of a novel digital system enabling somatosensory training at home by means of a gamified mobile application in patients with chronic pain. The secondary aims were to test the effect size of the intervention on clinical outcomes to power a subsequent randomized controlled trial.

Materials and Methods: We conducted a pilot randomized controlled trial in patients with fibromyalgia. This was an 8-week crossover study, which included a 4-week somatosensory training phase (daily use with the novel digital system) and a 4-week control phase (no use of this new system) in a random order. Feasibility was tested by objectively measuring the adherence and retention rates. Acceptability and changes in pain and disability were measured through data from subjective questionnaires.

Results: Thirty-five patients completed the study. The satisfaction questionnaire indicated high training enjoyment, ease of use for daily training and interest to continue to use the intervention after the study. The adherence (93%) and retention (94%) rates were high. The effect sizes were moderate for pain intensity (0.57).

Conclusion: The novel gamified technology for remotely delivered somatosensory training is feasible in a group of patients with fibromyalgia, and results in high engagement, satisfaction, and adherence. A subsequent clinical trial with the final version of the technology platform, including a longer training with more sensory training tasks and a bigger sample size is necessary.

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Introduction

Fibromyalgia syndrome (FMS) is a pain condition that affects an estimated 10 million people in the United States.[1] As a nociplastic pain condition, FMS is characterized by maladaptive nociplastic changes in the central nervous system (CNS).[2] This includes amplification of sensory signals in the CNS,[3] loss of precision in how sensory information is represented in the brain,[4] imprecise valuation of the threat value of somatosensory information,[5] and alterations in the attentional systems that prioritize, select, and filter sensory signals from the body.[6] These nociplastic changes can increase the perceptual intensity of somatosensory signals (i.e., sensations feel stronger than normal), increase aversiveness of sensations (i.e., normal body sensations feel more unpleasant), reduce perceptual resolution (i.e., less accurate sensory discrimination),[7] reduce ability to disengage attention from pain-related sensory information,[8,9] and make it difficult to filter out distracting sensory signals.[10] Pain researchers and scientists have identified these nociplastic changes as key targets for therapeutic intervention.[11]

Among the conservative treatments for nociplastic pain, sensory perception training may be an effective intervention targeting some of these changes in people with chronic pain.[12] Sensory perception training involves applying sensory stimuli to the patient's skin (e.g., pen cap vs. cork, rough vs. smooth texture, two fingers vs. one finger) and querying the patient to identify the sensory features of the stimulus. Training protocols typically involve practicing thousands of sensory perception exercises over a duration of several weeks.[13] Studies have shown promising results in a diverse group of pain conditions, including complex regional pain syndrome, fibromyalgia, phantom limb pain, chronic spinal pain, and postsurgical pain.[14–19] Despite promising initial findings, there have been significant feasibility barriers to real-world application of somatosensory training. Sensory perception exercises are typically delivered by a trained therapist using their hands or tools to manually apply the stimulation.

Home-based sensory training programs have poor adherence due to the need for a second individual to apply the training. For example, in a recent study[13] exploring the effect of a neuroplasticity brain training program (which included sensory exercises) for people with chronic knee pain, 40% of the participants did not complete a single sensory training session due to lack of availability of a partner to assist. To address these feasibility barriers, a prototype of a novel digital system has been developed. It enables somatosensory training in the patient's home. The system uses vibrotactile stimulators wirelessly controlled by a mobile application and delivers the somatosensory perception tasks through a gamified mobile application to engage patients for thousands of repetitions. Additionally, real-time closed-loop algorithms tailor the difficulty of the somatosensory perception tasks to ensure the task difficulty is well matched to patient sensory abilities.

Considering the advantages of this novel digital system, the primary aim of this pilot crossover randomized controlled trial was to test the hypothesis that a technology-delivered sensory training program would be feasible for a population of patients with chronic pain to perform therapy without an assistant, and that the gamification of the sensory training tasks would lead to high engagement and retention. The secondary aims were to test the effect size of the intervention on clinical outcomes in a sample of patients with FMS using common patient-reported outcomes for the purpose of powering a future clinical trial. Lastly, since this study involved new technology and a novel therapeutic

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approach, we performed exploratory analysis on the influence of training dose on clinical changes, and comparative responsiveness of outcome measures for the purpose of protocol development and hypothesis generation for future randomized controlled clinical trials.

Materials and Methods

STUDY DESIGN

A randomized crossover design was used. All subjects were informed of the objective of the project and took part in the study after informed consent had been obtained. The rights of human subjects were protected at all times. This study was approved by the Liege University Hospital Human Ethics Committee.

PARTICIPANTS

Participants with a prior diagnosis of FMS were recruited for this study through advertisements placed in hospitals, health care clinics, and through social media accounts of some fibromyalgia associations.

Inclusion criteria were as follows: (1) diagnosis of FMS from a physician, (2) resting pain >1/10 and/or average pain intensity of at least 4/10 over the past week as measured by 0–10 pain intensity numerical rating scale (NRS), (3) ages 18–65 inclusive, and (4) smartphone available for use during duration of the study. Exclusion criteria included: (1) intellectual deficits, (2) pathologies such as stroke sequelae, epilepsy, or peripheral neuropathy, (3) start of a (new) treatment within 8 weeks before the start of the study.

Participants were not compensated for their participation in the study.

PROCEDURES

Each participant in this 8-week crossover study had a 4-week training phase and a 4-week control phase (Fig. 1). After being included, half of the subjects were randomly allocated (concealed allocation) to start the study with the 4-week training phase (Group A), while the other half were allocated to start with the 4-week control phase consisting of treatment as usual (Group B). During the study, participants were requested not to start any new treatment and/or change anything regarding a potential ongoing treatment related to their FM (drugs, physiotherapy, etc.).

Participants were invited to fill in a battery of questionnaires at baseline and again every 4 weeks through the duration of the study. They are described in the Outcomes paragraph.

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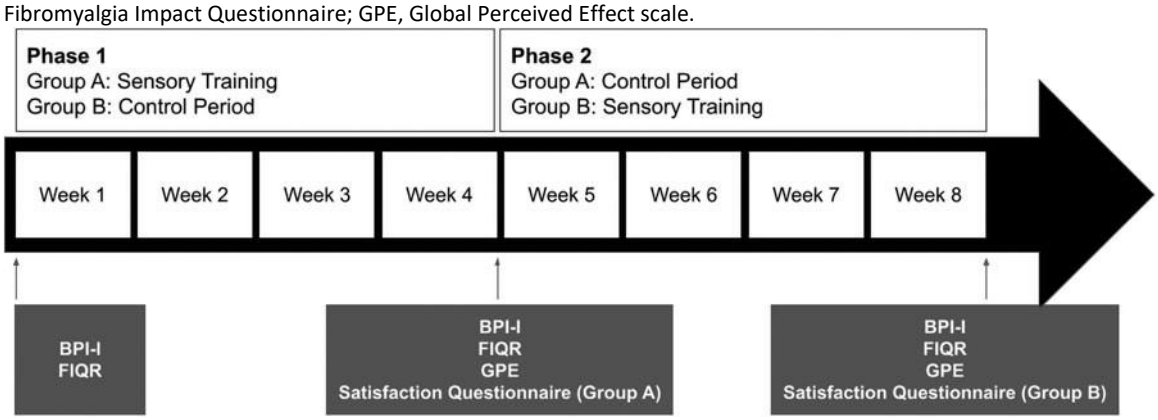
Figure 1. Phases of the experimental protocol. BPI-I, pain Intensity scales of the Brief Pain Inventory; FIQR, revised Fibromyalgia Impact Questionnaire; GPE, Global Perceived Effect scale.



INTERVENTION

The intervention was performed at home for 4 weeks using a sensory perception training system (Fig. 2), which included a gamified smartphone application and a Bluetooth-controlled haptic stimulation device with two stimulators. The battery had the capacity for the one-month training. The haptic stimulation was provided by two 8mm eccentric rotating mass vibration DC motors each with an offset (nonsymmetric) mass attached to the shaft. As the purpose of the intervention was sensory perception training (and not passive stimulation), the parameters of the stimulation pulse were set to the minimum (under 2 seconds per stimulation, one stimulation per task, and 100–150 tasks per session). The intensity of the haptic stimulation was self-selected by the participants according to their comfort in a range of 50%– 100% of the motor's capacity. Participants were instructed to place one tactile stimulator on the most painful region of the body and the other one on the contralateral body location. Participants were requested to perform the somatosensory perception training tasks with the stimulators placed in the same body region each day.

Sensory exercises were delivered through a cued spatial attention task that required the user to attend a cued body part to perform temporal discrimination tasks (i.e., ''what pattern of pulses did you feel?''), while simultaneously ignoring tactile distractors delivered to the noncued body part. The body location of the signal (cued body part) and distractor (noncued body part) were randomly alternated throughout the daily training session. The spatial attention cue was delivered through the smartphone application, and the participant's response was collected through a casual mobile game.

In the gamified interface, the user was instructed to select a bubble with a number on it that represented the stimulation pattern in which they felt on the body from the haptic stimulator, and the participants were given immediate feedback on the accuracy of each answer.

An adaptive psychophysics algorithm was used to adjust the difficulty of the tasks. A series of correct answers in a row would lead to the sensory tasks becoming more difficult by increasing the speed of the pulses and increasing the prominence of tactile distractors on the unattended body region. A series of incorrect answers in a row would lead to the sensory tasks becoming easier by decreasing the speed of the pulses and decreasing the prominence of tactile distractors on the unattended body region.

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The intervention was prescribed to be performed daily for 15 minutes. The application had a built-in timer and only allowed access once a day for the prescribed session duration. Once a day, the technology system sent participants a single short SMS message to their phone containing two to three sentences of pain education. The intervention was completely delivered remotely during the 2020 Coronavirus pandemic. All sensory exercise data and adherence data were streamed to the cloud for analysis.

CONTROL PERIOD

During this period, participants received no new intervention and were invited not to change anything regarding the management of their persistent pain.

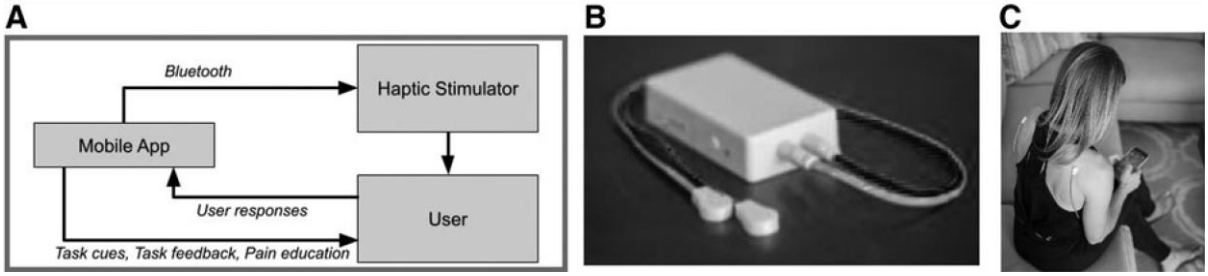
OUTCOME MEASURES

Adherence and retention rates were monitored objectively through the cloud-connected mobile therapy application as indications of the treatment feasibility. Adherence rate was calculated as the percentage of total daily training sessions completed during the intervention. Retention was calculated as the percentage of participants who were still logging in and training with the app in the last 3 days of the month-long study protocol.

The baseline battery of questionnaires included demographic questions. The four (0–10) pain intensity NRS of the Brief Pain Inventory (BPI-I) (to measure the most intense and least intense pain intensity during the last 24 hours, the pain intensity in general and the pain intensity at the moment) resulting in a BPI-I total score ranging from 0 to 40[20] and the revised Fibromyalgia Impact Questionnaire (FIQR) (which investigate three domains i.e., function, overall impact, and symptoms)[21] were submitted to participants at the beginning and the end of each of the two periods (Fig. 1). A satisfaction/ acceptability questionnaire was also used at the end of the training period. It included three items using a 0–10 NRS to assess participant interest in continuing to use the intervention, ease of use, and training enjoyment. A global perceived effect (GPE) scale was also used at the end of both periods.

Once the first battery of questionnaires was completed by a participant, the technology necessary for the study was delivered through courier to the participants' home, and each participant had a 30-minute video conference with the researcher to understand the intervention and learn how to install the App and use the technology system.

Figure 2. (A) Abbreviated system block diagram. (B) Prototype tactile stimulator that enables the sensory training. (C) User during a training session with one stimulator on left side of the body, and other stimulator on right side of the body, and interfacing with a mobile phone for task instructions and gamified response input.



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DATA ANALYSES

All statistical analyses were conducted using SAS version 9.4, with a significance level of 5%. Normality of the outcomes was checked with a histogram, a QQ-plot and the Shapiro–Wilk test. Outcomes are expressed as mean– standard deviation when data follow a normal distribution (median and interquartile otherwise).

Effects sizes (Cohen's *d*) and confidence intervals (CIs) were calculated for the BPI-I and FIQR scores. Interpretation of the effect size was based on the established thresholds where a small effect is observed if Cohen's $d>0.2$, medium effect if Cohen's $d>0.5$, and large effect if Cohen's $d>0.8$.[22]

Linear mixed-effects modeling was used to analyze the time and intervention main effects on the BPI-I and FIQR total scores as well as the time × intervention interaction.

Results

Forty participants with FMS were included in this pilot study. Four participants dropped out before starting the training period (one for personal reasons, two because of lack of time, and one because she no longer agreed to download the application) and one participant participated in 14 sessions but dropped out and did not fill in the questionnaires. Thereby, the results' analyses were conducted on 35 subjects (17 who started with the control period and 18 who started with the training period). Table 1 presents the demographics of the study population.

Table 1. Demographic and Baseline Characteristics of Included Participants

Characteristic	*Value* (n = 35)
Age (years)	Mean ± SD [min–max] 48.2 ± 7.0 [35–61]
Gender (% of females)	91.4%
Time since the FMS diagnosis (years)	Median (IQR 25%–75%) [min–max] 7.5 (4.25–9.75) [1–25]
Most painful body region (body region used for training)	Shoulder 28.6%, upper back 20%, lower back 20%, neck 11.4%, thigh 8.7%, arm 5.7%, forearm 2.8%, hip 2.8%
Pain intensity (BPI-I)	Median (IQR 25%–75%) [min–max]
Most intense last 24 hours (0–10)	8 (6.7–8.5) [3–10]
Least intense last 24 hours (0–10)	4 (3–6) [1–10]
Pain intensity in general (0–10)	6 (5–7) [2–10]
Pain intensity at the moment (0–10)	6 (6–7) [3–10)]
TOTAL score (0–40)	24 (21–28) [13–40]
FIQ-R	Median (IQR 25%–75%) [min–max]
Physical function (/90)	58 (47–70.5) [30–90]
Overall impact (/20)	13 (9–18) [0–20]
Symptom severity (/100)	61 (44–69) [0–94]
TOTAL score (/100)	62 (46–76) [22–93]

BPI-I, Brief Pain Inventory; FIQR, revised Fibromyalgia Impact Questionnaire; FMS, fibromyalgia syndrome; IQR, interquartile range; SD, standard deviation.

ADHERENCE AND RETENTION RATES

The adherence rate for the intervention was very high as described in Table 2.

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Over the 4-week intervention phase, patients completed an average of 3149 sensory perception exercises (min 1.1k–max 4.5k). Regarding the retention, study results indicated 94% of participants were still logging in and training with the app in the last 3 days of the month-long study protocol.

Table 2. Adherence Data

Subjects (n = 35)	*Adherence to daily training for 4 weeks*
27 participants	>90% adherence rate
4 participants	80%–89% adherence rate
2 participants	70%–79% adherence rate
2 participants	<70% adherence

SATISFACTION WITH THE TRAINING

The results of the satisfaction questionnaire related to the training are reported in Table 3.

Table 3. Results of the Satisfaction Questionnaire

	Median (IQR 25–75) [min–max]
Training enjoyment (0 = not at all; 10 = very enjoyable)	9 (7.25–10) [5–10]
Ease of use (0 = not at all; 10 = very easy)	8 (6.5–9) [4–10]
Interest in continuing to use the intervention (0 = not at all; 10 = yes, absolutely)	8 (6.5–10) [0–10]

CLINICAL CHANGES

At the end of the training period, the analysis of the GPE scale indicated that four participants and eight participants reported a strong and slight improvement, respectively (vs. two and two at the end of the control period). In contrast, 12 and 15 participants reported no changes (after the training and control periods). The remaining patients (10 after the training period and 16 after the control period) reported worsening of the symptoms (mostly slight).

The changes in clinical outcomes after the control and the training periods as well as the effect sizes are presented in Table 4.

INFLUENCE OF TRAINING DOSE ON CLINICAL OUTCOMES

Considering that the ''dose'' of training might influence the clinical impact of the intervention and the average number of sensory exercises performed by the entire sample (3149), a subgroup threshold of 3000 sensory exercises was determined post hoc. The effect sizes increased when considering the ''high-dose subgroup'' of 23 participants who performed more than 3000 exercises. They reached 0.88 (95% CI 0.28–1.49) and 0.56 (95% CI -0.03 to 1.15) for the BPI and the FIQR total scores, respectively.

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Table 4. Mean Changes of the Brief Pain Inventory and Revised Fibromyalgia Impact Questionnaire Total Scores, Effect Size Related to the Control, and the Training Periods as Well as Time Effect, Intervention Effect, as Well as Interaction Time × Intervention

	Effect size (Cohen's d*) (95% CI)*	*Control period Mean change*	*Training period Mean change*	*Intervention effect* P	*Time effect* P	*Interaction time × intervention* P
BPI-I total score	0.57 *(95% CI 0.09 to 1.05)*	1.60 ± 5.6	−1.2 ± 7.0	0.18	0.71	**0.040**
FIQR total score	0.46 *(95% CI −0.02 to 0.95)*	1.83 ± 12.7	−4.07 ± 12.8	0.93	0.47	0.12

Significant results ($p < 0.05$) are shown in bold type.
CI, confidence interval.

Discussion

In this study, we tested the feasibility of a novel prototype technology designed to enable patients to perform sensory perception exercises at home. This proof-of-concept research using a crossover design demonstrated the feasibility of the technology for patients with FMS. The training resulted in high adherence and satisfaction rate among patients. The data support further development of the prototype technology and informs protocol development for a subsequent randomized controlled clinical trial.

Traditional approaches for sensory perception training have three main barriers to real-world implementation at scale. First, they require a second trained individual to manually apply many repetitions of the sensory exercises. Second, the training is typically monotonous and not engaging, resulting in high drop off rates. Finally, the stimulus parameters of the sensory tasks cannot be precisely controlled when delivered manually by a human assistant. The prototype technology used in this study was designed to overcome these limitations of traditional training methods in an effort to make this type of neurorehabilitation more accessible to patients with four key features: (1) The technology delivers sensory perception tasks through vibrotactile stimulators to enable patients to perform sensory training tasks independently at home without any assistance from another person. (2) The sensory training exercises are ''gamified'' using principles of serious game design to make the intervention enjoyable and promote adherence. (3) The stimulus parameters of the tasks are precisely controlled by the technology system and adjusted autonomously with dynamic difficulty adjustment algorithms. Finally, (4) the technology system is connected to the internet, allowing adherence to be objectively monitored in real time by the study researchers.

The results of this study confirmed the hypothesis that technology-delivered sensory training at home is feasible in a sample of chronic pain patients. We demonstrated this by the satisfaction questionnaire scores (reporting high training enjoyment, ease of use for daily training, and interest to continue to use the intervention after the study) and the high adherence (93%) and retention (94%) rates. This is particularly notable given that a recent study of assistant-delivered sensory training[13] reported that 40% of the participants did not complete a single sensory training session and no participants completed the full training. Additionally, the engagement levels in this study were significantly higher than 5.5 days, which is the mean patient retention rate reported in prior digital health studies.[23]

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A secondary aim of this study was to measure effect sizes on fibromyalgia-related pain relief to power a future randomized controlled trial. We measured a moderate effect size for pain intensity larger than those reported in some systematic reviews for pharmacological approaches for FMS.[24] Of interest is that we measured larger effect sizes for the subgroup of participants who performed at least 3000 somatosensory tasks. This is in accordance with studies that showed the effects of brain training in chronic pain are influenced by the training dose and can require intensive regimens such as training 60–90 minutes per day.[14,25] We measured a small effect size regarding the FIQR total score. The low impact on FIQR scores may be partly related to the COVID lockdown during the study period as it has been noted that up to 67% of patients with FMS had worsening scores on the FIQR during Covid-related lockdowns.[26,27]

Three main hypotheses related to physiological changes exist to explain the clinical improvements induced: (1) training to improve behavioral discrimination of sensory stimuli may increase precision of neural coding and thereby reduce subjective experience of hypersensibility[7,14]; (2) paying attention to sensory stimuli in the context of rewarding tasks (i.e., *win a game using sensations from the painful body part*) may reduce fear and anxiety related to body sensations and reduce subjective report of sensory amplification[12,28]; (3) repetitively shifting attention toward and away from painful body regions may increase flexible control of alpha rhythms that gate and inhibit pain-related sensory signals.[29–31]

As the present study protocol did not control the amount of tasks performed in each training session, future studies should protocolize the amount of sensory tasks performed, as opposed to controlling the amount of training time, and include at least 3000 tasks. The results of a prior study on sensory training,[14] which included participants with phantom limb pain, showed a significant improvement in pain in all patients following 90 minutes of somatosensory training per day (for 10 days), which is twice the dose of the present study. Unfortunately, studies on sensory discrimination training use very heterogeneous experimental protocols (in terms of techniques used, duration, and frequency of sessions) and no consensus has yet been reached on the optimal training dose.[32]

The potential benefits of the training are also suggested by the results of the GPE scale. Furthermore, the majority of the participants (86%) wanted to continue the sensory training program after the study intervention was complete.

Besides its originality, the present study had several other notable strengths. (1) This is the first study using gamified somatosensory training delivered through an internet-connected mobile application where adherence could be monitored objectively as compared with self-report diaries used in prior trials. (2) The intervention was completely delivered remotely during a Covid lockdown with no patient interaction with a health care professional other than a 30-minute technical onboarding session. As such, there was a minimization of nonspecific factors related to therapeutic alliance. (3) Exclusion criteria were kept narrow to recruit a broad group of participants that would represent a real-world sample. Participants with psychological comorbidities, such as depression and anxiety, which are known risk factors for poor outcome were not excluded from participating in the study. (4) The participants were not financially compensated for their participation in the study, strengthening the fidelity of the results related to retention and adherence, as participants did not have an extrinsic financial motivator to adhere to the study protocol.

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This pilot proof-of-concept study also had several limitations. (1) As a pilot study, the sample size was small and underpowered. Data from this study will be used to adequately power the next clinical trial. The subsequent RCT could include a placebo arm but also a third arm in which patients would benefit from another new promising technology system such as virtual reality.[33] (2) Participants were not blinded resulting in a potential for bias and expectations effects. (3) This study used an early prototype version of the technology. In the subsequent clinical trial, the final version of the platform with an updated commercial grade interface, improved training adjustment algorithms, additional sensory tasks, and feedback for patients will be used to monitor changes in their sensory function over time. (4) The intervention period was shorter than the expected minimum duration for meaningful treatment effects. Future studies will have an intervention protocol of 8– 12 weeks and will ensure a minimum training dose of sensory training tasks. (5) Considering our fear of dropout during this Covid period, there was no washout period at the crossing of the groups to shorten the study period.

Conclusion

This study confirmed the hypothesis that a novel gamified technology for remotely delivered somatosensory training is feasible in a group of patients with fibromyalgia, and results in high engagement, satisfaction, and adherence. The results of this study will be used to power a subsequent randomized controlled trial with the final version of the technology platform.

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Authors' Contributions

C.D., C.L., C.M., M.V., and J.-F. K. conceived and planned the experiments. C.L., C.M., and C.D. carried out the experiments. C.L., C.M., N.D., and C.D. performed the statistical analyses. C.D., C.L., C.M., J.R.M., N.D., M.V., and J.-F. K. contributed to the interpretation of the results. C.D. took the lead in writing the article. All authors provided critical feedback and helped shape the research, analysis, and article.

Author Disclosure Statement

No competing financial interests exist.

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