# Empowering Employees with Musculoskeletal Pain through a Mobile App: Mixed-Methods Pilot Study Evaluating Impact on Pain Perceptions, Pain Intensity, and Physical Activity

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Submitted to: JMIR Formative Research
on: October 24, 2024

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## Abstract

**Background:** Mobile apps present opportunities to empower employees with musculoskeletal pain and reduce long-term absenteeism. However, adoption remains limited due to lack of empirical evidence and challenges in user-friendly design.

**Objective:** This pilot study aimed to evaluate the potential effects of an app-based pain management intervention tailored for employees. Specifically, the study aimed to 1) assess the effect of the intervention on pain perceptions, pain intensity, and physical activity, and 2) identify factors influencing its effectiveness.

**Methods:** Sixty-six employees from a Belgian university hospital, experiencing musculoskeletal pain for at least six weeks, participated in a 24-week intervention. The app-based intervention targeted unhelpful perceptions about pain and taught pain management skills through biopsychosocial education, graded activity, and personal goal-setting. Every six weeks, participants completed a questionnaire measuring pain perceptions (pain catastrophizing and fear-avoidance beliefs). Pain intensity was recorded daily using a visual analogue scale and step count was tracked daily with an activity tracker. Additionally, semi-structured interviews were conducted with 12 participants to explore their experiences with the intervention and its perceived impact.

**Results:** At the 24-week follow-up, a significant improvement was observed in pain catastrophizing ($t = -3.60$, $p < 0.001$, $d = 0.56$). However, results for fear-avoidance beliefs (variance (time) = 1.34, $p = 0.036$) and pain intensity (variance (time) = 17.29, $p = 0.032$) were mixed, and no significant changes were observed in mean daily step count. Qualitative analysis revealed that the effectiveness of the intervention was hindered by content and design choices that did not adequately account for diverse work settings and the busy life of employees. Cognitive biases and non-supportive work environments further complicated the successful implementation of the intervention in the workplace.

**Conclusions:** The app-based pain management intervention showed promise in reducing the threat value of pain and encouraging employees to adopt new coping strategies. To optimize treatment outcomes, future interventions should incorporate a high degree of personalization and strategies to address cognitive biases. Additionally, fostering a supportive work environment is crucial. Future studies should engage workplace stakeholders during the development and implementation of app-based pain management interventions and explore combining mobile apps with real-life support from trusted healthcare providers.

(JMIR Preprints 24/10/2024:67886)
DOI: https://doi.org/10.2196/preprints.67886

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# Original Manuscript

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## Abstract

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**Results:** At the 24-week follow-up, a significant improvement was observed in pain catastrophizing ($t = -3.60$, $p < 0.001$, $d = 0.56$). However, results for fear-avoidance beliefs (variance (time) = 1.34, $p = 0.036$) and pain intensity (variance (time) = 17.29, $p = 0.032$) were mixed, and no significant changes were observed in mean daily step count. Qualitative analysis revealed that the effectiveness of the intervention was hindered by content and design choices that did not adequately account for diverse work settings and the busy life of employees. Cognitive biases and non-supportive work environments further complicated the successful implementation of the intervention in the workplace.
**Conclusions:** The app-based pain management intervention showed promise in reducing the threat value of pain and encouraging employees to adopt new coping strategies. To optimize treatment outcomes, future interventions should incorporate a high degree of personalization and strategies to address cognitive biases. Additionally, fostering a supportive work environment is crucial. Future studies should engage workplace stakeholders during the development and implementation of app-based pain management interventions and explore combining mobile apps with real-life support from trusted healthcare providers.


**Keywords:** mHealth; occupational health; musculoskeletal disorders; mixed methods; pain perceptions; pain behavior; pain management; co-creation; digital health; human-centered design

## Introduction

The European Agency for Safety and Health at Work has highlighted that 58% of the European working population suffers from musculoskeletal pain, which is significantly higher than the global average of 34% [1,2]. Musculoskeletal conditions are a major cause of long-term absenteeism, responsible for up to 60% of cases in Europe [3]. In Belgium, these complaints accounted for 32% of long-term sickness absence in 2022, second only to mental health conditions [4].

Given the biopsychosocial nature of musculoskeletal pain, evidence increasingly supports multidimensional interventions that include physical (e.g., exercise and exposure therapy), psychological (e.g., education and resilience training), and social or work-related components (e.g., workplace ergonomics) [5-8]. For example, a systematic review by Kamper et al. demonstrated that multidisciplinary interventions are more effective than single-component approaches in reducing pain, disability, and sick leave in individuals with chronic low back pain [6]. Similarly, Cullen and colleagues found that return-to-work interventions that integrate health improvement, work relations, and modified working conditions, outperform single-domain interventions [8].

Despite their effectiveness, integrating multidisciplinary interventions into daily life, especially for employees, remains challenging. Geographic distribution of healthcare providers, limited operating hours, and session duration pose significant barriers [9,10]. Additionally, shortages of healthcare professionals and the limited capacity of specialized pain centers contribute to long waiting times, often resulting in extended sick leave and complicating recovery and reintegration [9,11]. In Belgium, waiting times for treatment at a specialized center are estimated between one and three months [12].

Mobile health (mHealth), defined as the use of mobile devices to deliver healthcare services, can provide information, deliver treatments, and support self-monitoring, allowing individuals to manage their conditions more conveniently [13,14]. A systematic review found that mHealth interventions improve therapy adherence and health outcomes, such as better glycemic control in diabetes, improved blood pressure in hypertension, and weight reduction in obesity [15]. The popularity of mHealth has led to the development of numerous pain management apps. By 2014, there were already 279 pain management apps available in major app stores [16]. However, the quality of these apps was not clear; nearly 60% of the apps offered only one functionality, with self-care information being the most common and goal-setting the least. Moreover, 92% lacked involvement from end-users and domain experts during development, and only 0.4% had undergone clinical validation [16]. Other reviews have raised concerns about the appropriateness and effectiveness of commercially available pain management apps [17,18].

Recent efforts to adapt validated pain management interventions into app-based formats have shown promise. A systematic review of clinical trials by Ligero and colleagues highlighted the beneficial effect of pain management apps on pain intensity, quality of life, and disability [19]. Notably, significant improvements in psychosocial risk factors of disability, such as pain catastrophizing and fear-avoidance beliefs, have been reported following app-delivered mindfulness training or education combined with physical exercise [20-22].

Despite these advancements, no pain management apps have been specifically tailored to address the unique challenges faced by employees managing pain in the workplace. A systematic review by Grant and colleagues identified issues with symptom management, work relations, and workplace adjustments as major barriers to return to work for employees with chronic pain [23]. Occupational health models, such as the Job Demand-Control model, highlight how unfavorable working conditions (e.g., high physical demands, high workload, lack of social support, and lack of job autonomy) contribute to musculoskeletal pain and absenteeism [24-30]. Psychobehavioral pain models, such as the Fear-Avoidance model, discuss how maladaptive pain perceptions (e.g., pain catastrophizing and fear-avoidance beliefs) increase the risk of persistent pain [31]. A fearful interpretation of pain has been associated with higher pain intensity, disability, activity avoidance, and absenteeism [31-37]. Moreover, research has shown that pain perceptions and work-related factors interact, altering the risk of pain and related absenteeism [38,39].

To address this gap, we developed an app-based pain management intervention considering the cognitive and affective responses to pain, the work context, and lifestyle of employees. The intervention targeted unhelpful perceptions about pain and taught pain management skills through biopsychosocial education, graded activity, and personal goal-setting [40-46]. This approach is in line with a review of clinical practice guidelines for musculoskeletal pain, stating that self-management programs should include monitoring, education, physical activity, and psychosocial interventions [47]. The app was developed using a human-centered design methodology from December 2019 to October 2021, involving 320 employees with musculoskeletal pain and eight healthcare professionals [48,49]. This process included iterative phases of research, ideation, prototyping, and testing to ensure that the final prototype was user-friendly and met the specific needs of employees with musculoskeletal pain.

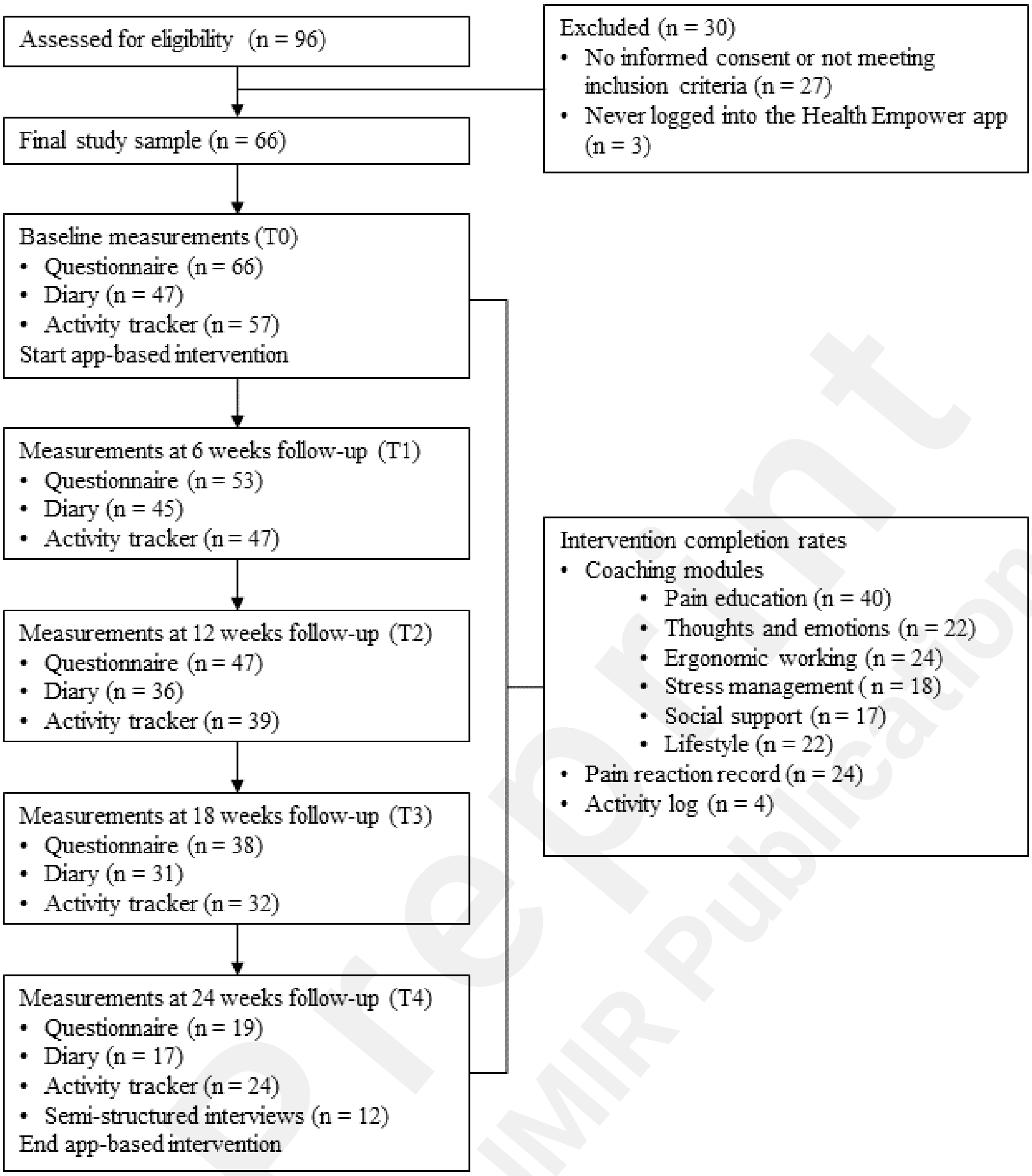
The objectives of this pilot study were to 1) assess the effect of the intervention on pain perceptions, pain intensity, and physical activity, and 2) identify factors influencing its effectiveness.

# Methods

## Study Design

Participants were recruited between August and October 2021. Employees from a Belgian university hospital were informed about the project through various channels, including mailings and brochures. Those interested were asked to contact the researchers for additional information. Eligible participants were at least 18 years old, had been experiencing musculoskeletal pain for at least six weeks, were proficient in Dutch, had access to a smartphone (Android or iOS), and provided written or electronic informed consent. Exclusion criteria included pregnancy or planned retirement between November 2021 and May 2022. An overview of the pilot study is provided in Figure 1.

Figure 1. Flowchart of the study.




In November 2021, the participants received a Fitbit Inspire activity tracker (Fitbit Inc, San Francisco, CA, USA) and were granted access to the pain management app, “Health Empower” (available on the App Store and Play Store). Upon logging in and securing their accounts, participants were asked to complete demographic and background information along with the baseline questionnaire. They were encouraged to use the Health Empower app and Fitbit for 24 weeks and complete a diary and six-weekly follow-up questionnaires.

After 24 weeks, participants were invited to participate in a semi-structured interview. These online interviews, conducted via Microsoft Teams (Microsoft, Redmond, WA, USA), lasted approximately 60 minutes. At the start of the interviews, participants were briefed on the procedure and purpose. The interviews were recorded, transcribed verbatim, and the recordings were subsequently deleted.

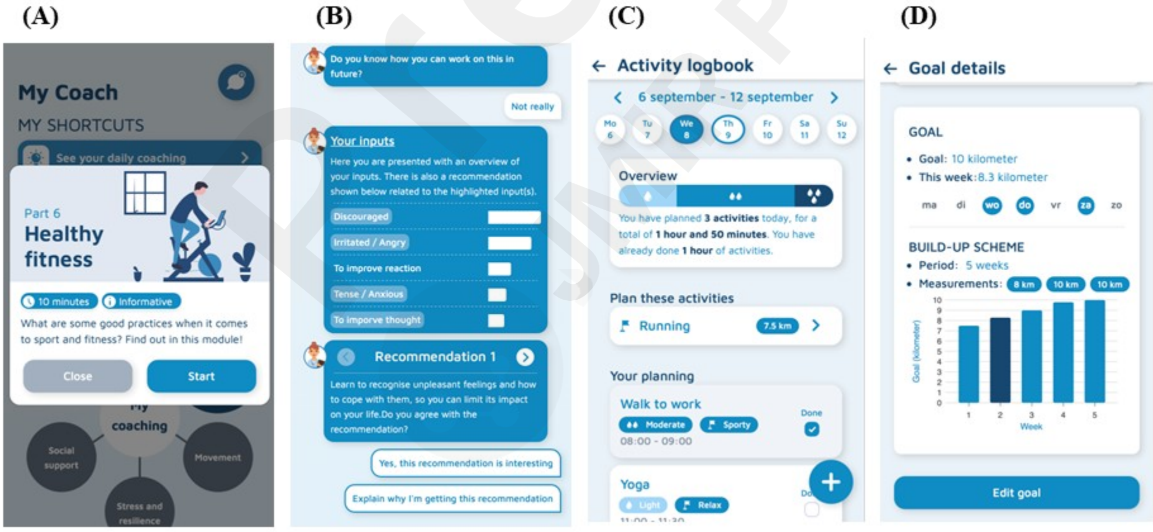
This pilot study was approved by the Ethics Committee Research UZ/KU Leuven (S-65610) and adhered to Belgian and international privacy and ethical regulations.

## Intervention

The app-based intervention targeted unhelpful perceptions about pain and taught pain management skills to employees through biopsychosocial education, graded activity, and personal goal-setting [40-46].

The Health Empower app consisted of six modules, each addressing distinct aspects of pain management through information and exercises (Figure 2). Modules one and two focused on improving cognitive and affective responses to pain. Module one included pain neuroscience education, explaining the neurophysiology of pain and its contributing factors, aiming to reconceptualize pain and reduce its threat value [40,50]. Participants had to complete this module before gaining access to the other modules. The second module expanded on recognizing and addressing unhelpful thoughts and emotions through cognitive behavioral therapy, including mindfulness techniques [46]. Modules three, four, and five focused on the work context. In the third module, participants learned about ergonomics and activity management [43,45]. The information was tailored to sedentary and physically demanding jobs, including guidelines for workstation organization, manual handling of loads, work postures, work-rest cycles, and activity pacing. Ergonomic advice was aligned with pain neuroscience education to avoid conflicting messages [40,42,51]. The fourth module focused on stress management and resilience training, including self-regulation, problem-solving, and goal-setting techniques [46,52,53]. The fifth module promoted social support through empathic communication and conflict resolution skills [52]. The final module encouraged healthy lifestyle habits, offering advice on physical activity, sleep, and nutrition [44,54].

Figure 2. Example screens of the Health Empower app. (A) coaching modules; (B) pain reaction record; (C) activity log; (D) goal-setting.




The app also featured a pain reaction record and an activity log (Figure 2) [40,41]. The pain reaction record allowed users to select statements reflecting their thoughts and coping strategies during pain flare-ups, with tailored recommendations provided by a hierarchical algorithm to improve their response in future situations. The development of the pain reaction record and recommender system is discussed elsewhere [55,56]. The activity log included tools for planning activities, setting personal goals, and monitoring progress (e.g., by connecting the Fitbit activity tracker to synchronize daily step count) [57,58].

## Measurements

### Socio-demographic and background information

Musculoskeletal pain complaints were assessed using the Dutch Musculoskeletal Questionnaire, where participants reported pain or discomfort in specific body regions over the past week (i.e., neck, shoulders, back, elbows, wrists/hands, hips, knees, or ankles/feet) [59]. Multisite pain was considered if participants reported pain in more than one body part. Participants also provided information on the duration of complaints and the frequency of absenteeism due to pain in the previous year. Additional socio-demographic variables collected included age, gender, level of education, profession, work arrangement, and tenure.

### Work-related factors

Work-related factors measured at baseline included physical job demands, workload, job autonomy, and social support. Physical job demands were evaluated using four out of twelve items from the Dutch Musculoskeletal Questionnaire [59]. Participants rated the frequency of engaging in various physical tasks, such as standing, sitting, or handling loads, on a scale from (almost) never to (almost) always. After conducting exploratory factor analysis, a two-factor structure was identified (Multimedia Appendix 1), with the chosen items showing high loadings on the first factor and demonstrating strong reliability (Cronbach's $\alpha = 0.86$). Scores on this scale ranged from 4 to 16, with higher scores reflecting more physically demanding jobs. Workload and social support were evaluated using subscales of the Short Inventory to Monitor Psychosocial Hazards, a validated questionnaire that assesses major psychosocial hazards at work [60]. The workload subscale, consisting of three items (scores ranging from 3 to 15), measures the perceived volume of tasks and associated time pressures. The social support subscale, consisting of four items (scores ranging from 4 to 20), measures the perceived availability and appreciation from colleagues and supervisors. Both the workload (Cronbach's $\alpha = 0.83$) and social support (Cronbach's $\alpha = 0.76$) subscales showed good reliability, with higher scores indicating higher workload and greater social support. Job autonomy was measured using a subscale of the Questionnaire on the Experience and Evaluation of Work (version 2.0), a validated questionnaire measuring psychosocial well-being and work-related stress [61]. The autonomy subscale, consisting of four items (scores ranging from 4 to 20), evaluates the degree of control and discretion individuals have over various aspects of their work environment, including task planning and choice of work methods. This scale demonstrated good reliability (Cronbach's $\alpha = 0.80$), with higher scores indicating higher levels of autonomy.

### Pain perceptions

Pain-related perceptions were assessed through a six-weekly questionnaire. Catastrophizing was measured using the validated Pain Catastrophizing Scale (PCS), which consists of 13 items evaluating rumination, magnification, and helplessness [62]. The scale had excellent reliability (Cronbach's $\alpha = 0.90$) with a total score ranging from 0 to 52, with higher scores indicating greater degrees of catastrophizing. Fear-avoidance beliefs were assessed using the validated Fear-Avoidance Beliefs Questionnaire [63]. This questionnaire includes two subscales: 1) a work subscale (FABQW) of seven items (scores ranging from 0 to 42) that measures attitudes about work and its relationship to musculoskeletal complaints, and 2) a physical activity subscale (FABQA) of four items (scores ranging from 0 to 24) that evaluates the perception towards movement and physical activities. The FABQW demonstrated good reliability (Cronbach's $\alpha = 0.82$), whereas the FABQA demonstrated poor reliability (Cronbach's α = 0.42). Higher scores on each subscale indicated higher levels of fear-avoidance beliefs.

### Pain intensity

Participants indicated their pain intensity on a Visual Analogue Scale (VAS), ranging from 0 ‘no pain’ to 100 ‘worst pain’, daily. The adaption of the VAS to digital platforms, including smartphones, has been validated in previous studies [64].

### Physical activity

Daily step count, measured by the Fitbit Inspire, was used to estimate physical activity. Research has demonstrated the accuracy of Fitbit activity trackers in measuring step count in both laboratory and free-living settings [65]. Previous studies have associated step count with physical activity, indicating individuals with less than 5,000 steps per day as sedentary and those with at least 10,000 steps per day as active [66].

### Personal experience with the intervention and perceived impact on health

After the 24-week intervention, semi-structured interviews were conducted in two parts. In the first part, participants were posed open-ended questions exploring the perceived impact of the intervention on their health. The second part of the interview involved presenting participants with illustrations of various app features. Participants were asked to discuss their experience with each feature. Probing questions were used to elicit more in-depth responses [67].

## Statistical Analysis

### Sample size

An a priori power analysis was conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) to determine the required sample size. Kristjansdottir and colleagues reported a moderate improvement in pain catastrophizing (Cohen’s d = 0.74) after a 5-month intervention using a smartphone app for individuals with pain [68]. To detect a moderate effect size at a 5% significance level with a power of 80%, a minimum group of 28 participants was required. Considering a 50% dropout rate, enrolling at least 56 participants was recommended [69].

### Quantitative analysis

Quantitative data were analyzed using SPSS 28.0 statistical software package (SPSS Inc., Chicago, IL). Univariate descriptive statistics were conducted for the sociodemographic and background variables. To include information from participants with missing data at one or more time points, linear multilevel models with random intercepts and slopes were used to evaluate changes in pain perceptions (PCS, FABQA, and FABQW), pain intensity (VAS), and physical activity (daily step count) [70]. This approach models variability in regression slopes and the covariance between slopes and intercepts. Variability in regression slopes specifies whether changes in scores over time differ significantly across individuals, while the covariance indicates the relationship between baseline scores and score changes over time. Changes in pain perceptions were evaluated across five time points: baseline, and after 6, 12, 18, and 24 weeks. Average pain intensity and daily step count were calculated for each participant across five periods: four periods of five consecutive weeks and one period of four consecutive weeks. Time periods with fewer than five measurements were considered invalid [71]. Additionally, days with less than 500 steps were also considered invalid [71,72].

### Qualitative analysis

Qualitative data from the semi-structured interviews were analyzed using the Qualitative Analysis Guide of Leuven [73]. This 10-step approach included a preparation phase and a coding phase. First, interviews were transcribed and summarized into brief abstracts. Concrete experiences were transformed into concepts, and these were compared across interviews. Common concepts served as initial codes for the coding process and underwent refinement over several iterations. The final codes were integrated into a meaningful conceptual framework in relation to the research questions. Two researchers conducted the analysis, resolving disagreements through consensus or consultation with a third researcher. To ensure anonymity and maintain neutrality, all participant quotes are presented using the pronoun 'he' throughout the paper, regardless of the participant's gender.

### Integration of quantitative and qualitative results

Two researchers evaluated alignment between the quantitative and qualitative results, encompassing confirmation, expansion, or discordance [74]. Disagreements were resolved through consensus or consultation with a third researcher. The meta-inferences derived from this analysis were presented in a side-by-side joint display for each research question.

# Results

## Participant Characteristics

A total of 96 employees expressed interest in participating in the study (Figure 1). Thirty were excluded for not meeting the inclusion criteria or failing to provide informed consent (n = 27) or never logging into the app (n = 3). The remaining 66 employees (86.4% female) were included in this study. An overview of sociodemographic and background information is provided in Table 1. Baseline characteristics were comparable between participants who completed the study (i.e., completed the 24-week follow-up questionnaire) and those who dropped out (Multimedia Appendix 2).

Table 1. Sociodemographic and baseline information of study participants.

| | Variable | Sample (n=66) |
|---|---|---|
| | | |
| **Sociodemographics** | | |
| | Age (years), mean (SD) | 42 (10.8) |
| | Gender (female), n (%) | 57 (86.4) |
| | Degree (bachelor or higher), n (%) | 55 (83.3) |
| | Profession (healthcare), n (%) | 60 (90.9) |
| | Tenure (≥ 10 years), n (%) | 37 (56.1) |
| | Work arrangement (fulltime), n (%) | 35 (53.0) |
| | Multi-site pain (yes), n (%) | 59 (89.4) |
| | Pain duration (≥ 3 months), n (%) | 61 (92.4) |
| | Pain-related sick leave (≥ 1 month), n (%) | 3 (4.5) |
| **Work-related factors** | | |
| | Physical job demands, mean (SD) | 6.2 (2.7) |
| | Workload, mean (SD) | 9.5 (2.5) |
| | Job autonomy, mean (SD) | 12.9 (3.8) |
| | Social support, mean (SD) | 14.2 (3.5) |
| **Outcome variables at baseline** | | |
| | Pain catastrophizing, mean (SD) | 13.3 (7.7) |
| | Fear-avoidance (activities), mean (SD) | 9.3 (4.3) |

| | | |
|---|---|---|
| | Fear-avoidance (work), mean (SD) | 15.2 (7.4) |
| | Pain intensity (VAS), mean (SD) | 33.0 (18.4) |
| | Physical activity (daily step count), mean (SD) | 9564 (2579.3) |

## Effect of the App-based Pain Management Intervention

Meta-inferences of quantitative and qualitative results on the potential effect of the intervention are presented in Table 2. Overall, there was alignment between quantitative and qualitative results, with qualitative insights explaining observations in the quantitative data.

Table 2. Joint display of quantitative and qualitative findings on the intervention effect.

| Theme | Quantitative findings | Qualitative findings | Meta-inferences |
|---|---|---|---|
| | | | |
| Pain perceptions | Significant moderate decrease in pain catastrophizing ($p < 0.001$).<br>Significant variance in slopes for fear-avoidance beliefs ($p = 0.036$). | Participants felt reassured by the information, reducing worries and encouraging them to optimize coping strategies. Perspectives on pain contributors and treatment options varied post intervention, with many emphasizing physical factors. | The reduction in pain catastrophizing aligns with feelings of reassurance. Mixed responses in fear-avoidance beliefs reflect differing views on pain contributors and management strategies. |
| Pain intensity | Significant variance in slopes for pain intensity ($p = 0.032$). | Participants had varied experiences regarding pain evolution, with some noting improvements that they often attributed to other interventions. | Mixed responses in pain intensity reflect diverse participant experiences. The attribution of pain reduction to other factors suggests that the impact of the intervention on pain intensity was not universally acknowledged. |
| Physical activity | No significant effect of the intervention on daily step count. | Participants reported increased awareness of activity levels, motivating some to be more active. However, the majority reported minimal lifestyle changes. | The lack of a significant change in step count is consistent with reports of minimal overall lifestyle changes. Qualitative findings expanded on the effect of the intervention by highlighting increased awareness. |

### *Pain perceptions*

Quantitative data analysis showed a decrease in pain catastrophizing scores ($t = -3.60$, $p < 0.001$, $d = 0.56$), reflecting reduced pain-related fear (Table 3 and Multimedia Appendix 3). The marginally significant variance in pain catastrophizing scores (variance (time) = 1.00, $p = 0.092$) and covariance (covariance (AR) = -0.38, $p = 0.087$) suggest that participants with higher baseline scores experienced a more pronounced decrease in catastrophizing. Furthermore, we observed a significant variance for fear-avoidance beliefs regarding physical activities (variance (time) = 1.34, $p = 0.036$). While some participants experienced increases in fear-avoidance beliefs, others experienced decreases, indicating the varied impact of the intervention.

Table 3. Multilevel analysis of pain perceptions, pain intensity, and physical activity.

| | Variable | Estimate (se) | p-value |
|---|---|---|---|
| | | | |
| **Pain catastrophizing** | | | |
| | Fixed effect (time) | -0.83 (0.23) | < 0.001[a] |
| | Variance (time) | 1.00 (0.59) | 0.092 |
| | Covariance (autoregressive) | -0.38 (0.22) | 0.087 |
| **Fear-avoidance (activities)** | | | |
| | Fixed effect (time) | -0.35 (0.24) | 0.153 |
| | Variance (time) | 1.34 (0.64) | 0.036 |
| | Covariance (autoregressive) | -0.12 (0.29) | 0.668 |
| **Fear-avoidance (work)** | | | |

| | | | |
|---|---|---|---|
| | Fixed effect (time) | -0.25 (0.26) | 0.343 |
| | Variance (time) | 0.81 (0.71) | 0.225 |
| | Covariance (autoregressive) | -0.11 (0.32) | 0.724 |
| **Pain intensity (VAS)** | | | |
| | Fixed effect (time) | -0.37 (0.84) | 0.666 |
| | Variance (time) | 17.29 (8.07) | 0.032 |
| | Covariance (autoregressive) | -0.26 (0.19) | 0.170 |
| **Physical activity (daily step count)** | | | |
| | Fixed effect (time) | 107.50 (87.48) | 0.228 |
| | Variance (time) | 108345.09 (73646.87) | 0.141 |
| | Covariance (autoregressive) | 0.34 (0.33) | 0.300 |

[a]Moderate effect size (Cohen's d = 0.56).

Qualitative data analysis revealed three subthemes regarding the impact of the intervention on pain perceptions: (1) worries and insecurities, (2) contributing factors, and (3) coping strategies. Consistent with the observed decrease in pain catastrophizing scores, many participants found reassurance in the information provided by the intervention, feeling that reducing the impact of pain on their life was possible. This reassurance inspired them to optimize their management strategies. The recognition of their existing coping efforts also provided validation and motivation to continue these strategies. For instance, Participant 2 explained how the intervention confirmed that his current pain management approaches were effective, reinforcing his confidence:

*"When I read the information in the app, I often thought, 'Well, yes, I can actually manage my pain this way too.' Sometimes I was already doing it, but it was nice to have confirmation that I wasn't doing anything wrong and that I should keep going. That information really helped me." [Participant 2]*

The variance for fear-avoidance beliefs scores was reflected in the diverse perspectives on the factors contributing to pain and strategies for coping post-intervention. For example, Participant 3 continued to emphasize physical factors as the primary contributors to his pain. This participant attributed his pain to past injuries or surgeries and viewed his work environment as a significant aggravator:

*"I had surgery for a cartilage injury, and my joints inflame easily. I don't believe my pain is psychological. Stress might affect muscle tension, but it's not as significant as wear and tear (…) My posture isn't great when I'm working at the computer. I think this has caused muscle imbalances that led to my neck pain." [Participant 3]*

This focus on physical contributors led participants like Participant 5 to prioritize strategies aimed at reducing physical strain. For example, this participant adopted avoidance behaviors to prevent further pain:

*"I'm much more conscious of my movements and posture now. I don't lift things by bending over anymore. I bend my knees or get down on one knee to pick something up. I learned that from the app." [Participant 5]*

In contrast, several participants recognized the role of psychosocial factors in their pain, acknowledging that cognitive and emotional processes can significantly influence their pain experience. For instance, Participant 7 reflected on how the intervention shifted his perspective from viewing pain primarily as a physical issue to a biopsychosocial phenomenon, helping him recognize the drawbacks of avoidance and the benefits of staying active. As a result, this participant became less concerned with ergonomics to reduce physical strain:

*"I didn't realize how convinced your brain can be that you'll feel pain during certain activities (...) One of the things I learned was that staying still is actually bad. But what do many people with pain do? They just sit there, and it only gets worse. (...) I found the idea of stopping complaining about the pain and just getting moving really useful. (…) I didn't spend much time on the information about lifting, I don't think it's that important in my situation." [Participant 7]*

## Pain intensity

Quantitative data analysis showed a significant variance for pain intensity scores (variance (time) = 17.29, $p = 0.032$) (Table 3 and Multimedia Appendix 3). While pain intensity increased for some participants, it decreased for others, highlighting the varied and uncertain impact of the intervention on pain intensity.

The qualitative data revealed one subtheme related to pain intensity: (1) severity of complaints. Consistent with quantitative data, participants provided diverse perspectives on the evolution of their pain. Many participants expressed to be disappointed that their pain had not decreased after the intervention. For example, Participant 9 was frustrated with the limited impact of the intervention on his pain, noting it did not provide the actionable tips he had expected:

*"A lot of people ask me, 'Has it helped with the intensity of the pain?' and I have to answer, 'No,' because I was expecting more specific tips that I could try out" [Participant 9]*

Despite not experiencing a general improvement in their pain complaints, some participants recognized that the intervention helped reduce the burden of pain in specific situations. For instance, Participant 12 shared how the intervention helped him communicate his needs more effectively, reducing stress and pain:

*"I've learned to inform others about my pain problem without complaining. Just a brief 'look, I can't do this alone, I need help because of my neck,' and that reduces my stress and pain (...) But it's not gone, of course." [Participant 12]*

Participants who did experience improvements in their pain often viewed the intervention as secondary to other factors. They believed changes might have occurred over time or attributed them to other interventions. Participant 6 conveyed this ambiguity, questioning whether our intervention had any real impact on his pain:

*"I have to say that my pain has decreased (...) But is it because of the app? I don't really feel that way. It might just be coincidental since my pain was already starting to decrease, so it could be a combination of both." [Participant 6]*

## Physical activity

Quantitative data analysis showed no significant effect of the intervention on daily step count (Table 3 and Multimedia Appendix 3).

Two subthemes emerged from the qualitative data regarding the effect of the intervention on physical activity: (1) awareness and (2) physical activity habits. Many participants reported that the intervention heightened their awareness of daily activities, leading them to reflect on their daily routines. For instance, Participant 2 described how the daily questionnaires encouraged him to think critically about his activity level:

*"You had to fill out your questionnaire every evening and reflect on your day (...) I might have sat down too much or walked a lot (...) It made me aware that maybe I had done too little or too much. I found that really useful." [Participant 2]*

This awareness, combined with Fitbit prompts, served as motivators for some participants to move more and rethink their sedentary habits. Participant 1 explained how tracking his activities encouraged him to be more active:

*"Both the Fitbit and the app motivate you to think more about your health and to sit less. Since you have to record how long you've been sitting and walking, it makes you realize. I never really thought about it before (...) Now, I'm more likely to go for a walk or do something else instead of lying on the couch. When you see that you've only taken a few steps today, you make sure to walk more the next day. " [Participant 1]*

However, overall changes in physical activity habits were minimal, which was consistent with quantitative findings. Participants with physically demanding jobs, like Participant 9, reported that the intervention had little impact on their routines:

*"I have a demanding job and my household responsibilities (...) I do stand still a lot at work, but I also move around a lot. By the evening, I just don't feel like doing more. I do check the Fitbit, but it doesn't motivate me to go outside in the evening to reach ten thousand steps. My life hasn't changed because of the Fitbit." [Participant 9]*

## Factors Influencing Effectiveness of the App-based Pain Management Intervention

Analysis of semi-structured interviews identified three themes related to factors influencing effectiveness of the intervention: (1) intervention quality, (2) personal characteristics, and (3) work context. Meta-inferences of quantitative and qualitative results on these factors are presented in Table 4. Overall, there was alignment between quantitative and qualitative results, with qualitative insights explaining observations in the quantitative data.

Table 4. Joint display of quantitative and qualitative findings on factors influencing effectiveness.

| Theme | Quantitative findings | Qualitative findings | Meta-inferences |
|---|---|---|---|
| | | | |
| Intervention quality | High non-usage and drop-out rates: 36% of participants completed each module, 36% used the pain reaction record, and 6% used the activity log. Follow-up questionnaire completion dropped from 71% at 12 weeks to 29% at 24 weeks. | Some participants found the content clear and actionable, while others felt it was too basic or impractical. The design, including interactive elements, was appreciated by many, but a lack of flexibility, triggers, and integration with other tools hindered engagement. | High non-usage and dropout rates align with participant feedback, highlighting a need for improvements in content and design to account for diverse work settings and the busy life of employees. |
| Personal characteristics | Favorable baseline scores for pain perceptions, pain intensity, daily step count, along with low self-reported sick leave. Completion rates were higher for physical-focused modules (35%) compared to psychosocial-focused modules (29%). | Participants described their pain as manageable, leading to casual engagement with the app. Many believed they already had sufficient knowledge of pain management and were skeptical of the cognitive and psychosocial elements of the intervention. | The limited perceived impact of pain on life, as reflected by favorable baseline scores, and perceptions of being well-versed in pain management correspond to low engagement with the app. Preferences for physical over psychosocial approaches to pain management correspond with selective use of the |

| | | | |
|---|---|---|---|
| | | | modules. |
| Work context | Overall favorable baseline scores for physical job demands, workload, social support, and job autonomy. | Participants encountered workplace barriers, including a lack of adjustable ergonomic equipment and resistance from colleagues or supervisors to modify work conditions. Some received accommodations, but many felt that persistent pain was not adequately acknowledged. | While baseline scores indicated limited job demands and adequate job resources, qualitative findings highlight significant workplace challenges, hindering effective application of advice from the app. |

## Intervention quality

Follow-up data showed relatively high non-usage and dropout rates (Figure 1). On average, each module was completed by only 36% of participants. The pain reaction record was used by 36%, while the activity log was used by just 6%. Regarding dropout, 71% of participants completed the 12-week follow-up questionnaire, but only 29% completed the 24-week follow-up.

Two subthemes emerged from the qualitative data regarding quality of the intervention: (1) content, and (2) design. Consistent with the high non-usage and dropout rates, mixed reactions to content and design suggested that the intervention struggled to maintain long-term engagement and meet the diverse needs of its users. Some found the information provided clear, actionable, and accessible. For instance, Participant 7 appreciated the straightforward, non-medical language:

*"I found the content good and accessible for a broad audience (...) not too medical, just very basic but with enough information. And the videos in between were well done." [Participant 7]*

However, some participants felt the advice was too basic or impractical for their specific situation. Participant 1 highlighted the difficulty of applying certain ergonomic tips due to his bifocals:

*"Tips like 'your screen should be at eye level' (...) Sorry, that doesn’t work for me because I have bifocals, so my screen needs to be lower to read properly (...) Also the tips on how to sit properly, I can’t keep that up for two hours.” [Participant 1]*

Additionally, some participants like Participant 9 found that the intervention focused too much on pain, particularly through repetitive questionnaires. This emphasis was counterproductive, making participants more fixated on their pain rather than helping them manage it:

*"I am not someone who is fixated on pain all the time. Reflecting on pain in the questionnaires was a drawback of this study for me. I didn’t want to always think about pain." [Participant 6]*

The design of the app, including its usability and visual appeal, also impacted participant engagement. Many participants appreciated the interactive elements, such as videos and quizzes. Familiar design choices, such as chat-style questionnaires, were particularly well-received, as noted by Participant 12:

*"It wasn’t just text, but also videos and quizzes. I enjoyed testing myself to see if I understood everything (...) The chat-style questionnaire was very intuitive. I buy a lot online so it was recognizable (…) The colors were neutral, which was easy on the eyes." [Participant 12]*

Despite these positives, several design elements did not align well with the busy life of the participants. A lack of flexibility was a common complaint. Participant 9 expressed frustration with not being able to advance through the content when he had time available:

*“It would have been better if there was more flexibility (…) It was disappointing that I couldn’t move on when I had some time. Don’t block people, let them explore further. People have limited time because of work. When they find time, let them continue with the modules.” [Participant 9]*

Time-consuming actions and poor integration with other tools also detracted from the experience. Some participants found the app redundant, particularly if they were already using more comprehensive tools. For example, Participant 5 preferred his own activity tracker, because it featured automated tracking instead of questionnaires:

*"I have another activity tracker with more options. It automatically tracks heart rate and activities, so I always checked that app (...) I mostly used your app to go through the modules, but I didn’t really use the other features because I had something else, and maybe even better." [Participant 5]*

Furthermore, notifications, while helpful, were often insufficient to maintain regular engagement with the app. Participant 11 suggested that more prominent alerts, similar to those used in social media apps, might have encouraged more consistent use:

*"What would help me is something like a red dot or a number, like on social media apps (...) That would remind me that there is something to do. I got the notifications for the questionnaires, but that wasn’t enough to keep me actively engaged." [Participant 11]*

## Personal characteristics

Completions rates varied considerably between coaching modules (Figure 1). While 61% of participants completed the first module on pain education, the modules focusing on physical topics (i.e., modules 3 and 6) had an average completion rate of 35%, and those on psychosocial topics (i.e., modules 2, 4, and 5) had a lower average completion rate of 29%.

Two subthemes emerged from the qualitative data regarding personal characteristics: (1) perceived impact of pain on daily life, and (2) beliefs and attitudes towards pain management. The differences in completion rates of coaching modules highlighted how participants’ beliefs and attitudes influenced their engagement with various aspects of the intervention. For many participants, pain had a manageable impact on their daily life, leading to a more casual engagement with the app. For instance, Participant 11, who described his pain as an inconvenience rather than debilitating, participated out of curiosity:

*"I didn’t have specific expectations about the study. I thought, ‘Well, if it helps, great; if not, no harm done’ (...) I have to say, I didn’t complete or use everything. I often thought, ‘It’s not bad, I’m doing well.’ My back pain is unpleasant, but manageable. I live my life; I don’t stay home just because my back hurts." [Participant 11]*

This mindset aligns with favorable baseline scores on pain perceptions, and pain intensity, as well as the relatively high daily step count at baseline and low self-reported sick leave (Table 1).

Furthermore, many participants felt they were already well-versed in pain management, whether through personal experience, previous treatments, or professional background. This existing knowledge often led to limited engagement with the app, as they did not expect to learn new information. Participant 8 reflected on how much content was a review of what he had already learned:

*"I found it valuable to check if there were things I didn't know or could improve (...) But a lot of it was repetition, as I had already gone through a similar program at a specialized center. So, I skimmed through some parts fairly quickly." [Participant 8]*

Participants also had different perspectives on the biopsychosocial approach of the intervention. For example, Participant 4 appreciated the cognitive approach as it aligned with his ongoing treatment:

*"I found it interesting because I'm seeing a new physiotherapist who also focuses a lot on how thoughts influence pain and how it's processed in the brain (...) So, this aligned with that approach, especially since no clear cause has been found for my pain. I have a muscle condition, but I'm not convinced that it explains all my symptoms." [Participant 4]*

In contrast, others were skeptical of the cognitive and psychosocial elements, linking their pain to biomedical factors. Consequently, these participants favored physical approaches to pain management. Participant 3, for example, expressed doubt about the effectiveness of cognitive strategies for his pain, limiting his engagement with those aspects of the content:

*"With my background and education, I'm skeptical about the cognitive approach to pain (...) I didn't have high expectations for improvement through this method, as I usually know what's causing my pain, muscle imbalance or a damaged joint. I'm more inclined to address pain by exercising (…) I still read everything in the coaching, but I paid more attention to some things than others." [Participant 3]*

## Work context

Overall, participants reported favorable scores for physical job demands, workload, social support, and job autonomy at baseline, indicating a good balance between job demands and job resources (Table 1).

Two subthemes emerged from the qualitative data regarding work context: (1) ergonomic equipment, and (2) social support. Despite the favorable scores on work related factors, several participants encountered barriers when trying to implement advice from the app. Some participants, like Participant 5, were unable to customize their workspaces due to shared workstations and a lack of adjustable equipment , which often resulted in discomfort or exacerbated pain:

*"We have five different workstations, and at stations three and four, the tables are lower, which is harder for me because I have to bend over and lift patients from a lower position. I notice that on those stations, I have more complaints (...) I can't do much about it because those tables have standard heights." [Participant 5]*

Many participants reported that persistent pain often received less recognition compared to more visible health conditions. This lack of understanding and empathy made it difficult for them to openly discuss their pain and request necessary accommodations. Participant 11 expressed frustration with the dismissive attitudes of some colleagues:

*"Most people don't take it seriously when you say you're in pain. They might listen, but they quickly forget. It's the usual 'Just take a pill and keep going.' (…) There's just a lack of understanding, and I've tried to accept it because they don't get it. If you don't have pain yourself, it's hard to*

*understand." [Participant 11]*

Additionally, resistance from colleagues and employers toward modifying work conditions was a recurring issue. This resistance often stemmed from concerns about creating distinctions between employees or fears of reduced productivity. Participant 8 noted the difficulties he faced when returning to work after a long absence due to pain:

*"They don't adjust anything; it's really hard to deal with (...) I was off work for a year, and when I returned, the first thing they said was that I had to do all the work - all kinds of patients, all shifts. (…) I think just an extra ten-minute break would help, but it's really hard to get that. They don't like it because then the other colleagues have to work harder or cover for me." [Participant 8]*

However, efforts made by colleagues and supervisors to optimize the work environment and reduce physical demands were much appreciated by the participants. These efforts often included providing ergonomic equipment or adjusting work schedules and tasks. For instance, Participant 2 highlighted the accommodations made to help manage his chronic pain:

*"I feel like they make an effort to keep people with chronic pain employed (...) They created a schedule for me where I work three half-days, one full day, and have one day off. They've also tried to ensure I have a variety of tasks, so I can't say they aren't taking it into account." [Participant 2]*

# Discussion

## Effect of the App-based Pain Management Intervention

This longitudinal pilot evaluated the potential effect of an innovative app-based pain management intervention for employees. The intervention targeted unhelpful perceptions about pain and taught pain management skills through biopsychosocial education, graded activity, and personal goal-setting [40-46].

### Pain perceptions

Our results demonstrated a significant and moderate improvement in pain catastrophizing. This finding is consistent with previous studies that adapted validated pain treatment strategies into app-based formats [20-22]. Participants reported that the intervention provided reassurance and encouraged them to optimize their coping strategies, suggesting that the intervention effectively reduced the threat value of pain. The emphasis on pain neuroscience education, a key component of our intervention, likely contributed to these outcomes, as this approach has shown to address maladaptive pain perceptions such as catastrophizing and fear of movement [40,75].

However, we observed a mixed effect on fear-avoidance beliefs, with scores increasing for some participants and decreasing for others. This variability may reflect differing beliefs regarding the causes of pain and the appropriate treatment strategies after the intervention. In contrast to our focus on education and graded activity, Sitges and colleagues incorporated a progressive exercise program in their pain management app, which may explain the significant improvement in fear-avoidance beliefs in their study [20]. Exercise programs can provide positive movement experiences, helping reshape fearful cognitive representations of pain [42,76]. In their study, participants completed one-hour sessions of video-assisted physical exercises and pain education twice a week for four weeks, keeping in mind a rest period of one to four days between sessions [20]. While this approach was successful, it may not be suitable for employees managing pain amid busy work schedules. Given that our participants preferred flexible and less time-consuming design choices, multiple short sessions or one longer session a week might be more suitable for this population. Evidence suggests that all exercise programs are effective for chronic pain, providing no consensus on the duration, intensity, and type the program [76]. Therefore, future studies should investigate which exercise programs are most suitable for employees with musculoskeletal pain.

### Pain intensity

Our results showed a mixed impact of the intervention on pain intensity, with scores increasing for some participants and decreasing for others. Our intervention primarily emphasized biopsychosocial education to address maladaptive pain perceptions [40,75]. While modifying cognitive representations of pain can influence pain experiences, research suggests that education alone may not be sufficient to achieve meaningful reductions in pain and disability [42,75-77]. This aligns with our qualitative data, as participants credited improvements in pain intensity to supplementary interventions like physical exercise. A systematic review showed that home-based exercise programs delivered by mHealth can successfully improve pain, disability, and quality of life [19]. Moreover, combining education with exercise therapy appears to be more effective for reducing pain intensity compared to exercise therapy alone [76]. Therefore, broadening our intervention to include a structured exercise program might not only enhance its effect on pain perceptions but also yield more substantial improvements in pain intensity.

### Physical activity

Although our intervention included guidance on graded activity, personal goal-setting, and healthy lifestyle habits, no significant changes in daily step count were observed [42-44,57,58]. While many participants reported increased awareness of their activity levels, particularly through self-monitoring tools like Fitbit, this heightened awareness did not lead to measurable increases in physical activity. This outcome contrasts with prior research, which found that mHealth interventions can promote small to moderate increases in physical activity, even without direct human support [78].

One possible explanation for our findings lies in the methods used to measure physical activity. While daily step count is a common metric, it does not account for activity intensity [66]. Other studies have assessed physical activity through minutes of moderate and vigorous activity or total energy expenditure [78]. For instance, moderate-intensity activities require at least three times the energy expended at rest, whereas vigorous activities require at least six times as much energy [79]. Estimates suggest that a cadence of around 100 steps per minute corresponds to moderate intensity, while approximately 130 steps per minute aligns with vigorous intensity [66]. However, wrist-worn trackers like the Fitbit Inspire may miss activities that don’t involve vertical arm movement, such as cycling [80]. Therefore, future studies should alternative tools to quantify physical activity levels, such as heart rate monitors, which can better estimate moderate and vigorous activity [80]. Moderate intensity typically corresponds to 64% of maximal heart rate, while vigorous intensity is about 77% [79].

Another factor to consider is the role of gamification in mHealth interventions for physical activity, which involves using game elements like points, leaderboards, progress bars, and badges [81]. One study found that social features, in particular, are effective in promoting physical activity [82]. However, research on individuals with chronic musculoskeletal conditions indicates a general aversion to social features in self-management apps, as these individuals often regard their condition as a private matter [83]. Future studies should explore which gamification techniques might be most suitable for employees with musculoskeletal pain, to potentially enhance the effectiveness of app-based interventions on physical activity.

## Factors Influencing Effectiveness of the App-based Pain Management Intervention

Integrating quantitative and qualitative data revealed that intervention quality, personal characteristics, and the work context might also explain the limited effect of the intervention on fear avoidance beliefs, pain intensity, and physical activity.

### *Intervention quality*

Several participants questioned the relevance of the app to their specific work environments, particularly those with physically demanding jobs. Previous studies have shown that such jobs exhibit more variability in workstation design and organization than office-based jobs, complicating the application of ergonomic advice [84]. Given that our app provided generalized ergonomic guidance, it may not have adequately addressed the unique needs of employees in more physically demanding roles [85,86]. Studies suggest that face-to-face ergonomic guidance from healthcare providers tends to be more effective in reducing musculoskeletal symptoms than solely relying on information materials like leaflets [87]. However, a systematic review showed that mHealth interventions can complement face-to-face treatment in improving pain and functional disability [88]. Future app-based interventions could enhance their impact by offering tailored ergonomic advice that reflects the specific work setting, perhaps by integrating real-life support from healthcare providers.

Several participants also reported that self-monitoring increased their vigilance toward pain. Research has shown that hypervigilance may lead to avoidance behavior and heightened pain perception, which may account for the considerable variability observed in fear-avoidance beliefs and pain intensity [31,50]. Since pain reduction is not the primary objective of this app-based intervention, future studies might consider measuring pain less frequently (e.g., only in the six weekly questionnaire). Alternatively, a systematic review has shown significant associations between self-reported pain intensity and physiological parameters, such as heart rate variability, skin conductance, and brain electrical activity [88]. Future research should explore whether symptom severity could be estimated from physiological data automatically collected through wearable devices, reducing the need for frequent self-reporting.

### *Personal characteristics*

Many participants reported a limited impact of pain on their life and focused on maintaining valued activities, which was reflected in the relatively favorable baseline scores for pain perceptions, pain intensity, and step count [62,66,90,91]. This contrasts with studies like Sitges et al., which observed higher baseline levels of fear-avoidance beliefs, potentially explaining the greater improvements reported after app use in those studies [20]. Similarly, Monninghoff et al. found that mHealth interventions aimed at increasing physical activity tend to be more effective in individuals with lower baseline activity levels [78]. Our study focused on employees with persistent musculoskeletal pain who remained in active employment. The significant reduction in pain catastrophizing suggests that our intervention holds promise in preventing sickness absence [35,37]. However, future research should investigate the effect of pain management apps on employees with acute pain or those on sick leave, as these individuals may exhibit more maladaptive pain beliefs [32,37,92,93].

Cognitive biases, such as confirmation bias (the tendency to focus on information that aligns with pre-existing beliefs) and belief perseverance (maintaining an existing belief despite disconfirming information), could explain the mixed effect of our intervention on fear-avoidance beliefs [94,95]. Despite many participants being healthcare professionals, they predominantly held biomedical views of pain management. It is possible that fear-avoidance scores improved among participants with an open and critical mindset, who engaged thoughtfully with the coaching modules. Conversely, maladaptive perceptions about pain and work might have strengthened in those who primarily sought validation of their current beliefs. Previous studies highlighted the persistence of a biomedical approach in healthcare, even with the increasing emphasis on psychosocial aspects in medical education [96-98]. Moreover, cognitive bias is a frequent cause of errors in clinical-decision making among healthcare professionals [99].

Strategies such as counter-explanation, which presents alternative hypotheses supported by evidence, have been shown to help overcome cognitive biases [100]. Raising awareness of cognitive biases, combined with simple, visual, and jargon-free communication, can promote critical thinking and openness to new perspectives [100,101]. Pain neuroscience education, which employs metaphors and alternative explanations, already incorporates some of these strategies [40]. However, many participants considered themselves experts on their health condition, not recognizing the need to change their behavior. According to the Transtheoretical Model, individuals in this precontemplation stage may not benefit from such strategies without additional guidance [102]. Expanding our intervention to include motivational interviewing, which uses empathic communication to elicit motivation to change, could be beneficial for those resistant to change [103,104]. Research suggests that interaction with a healthcare provider is critical for successful pain neuroscience education, as it allows for a personalized approach that takes the individual's story into account [75,76]. Encouraging individuals to share their personal experiences can also raise awareness of the biopsychosocial nature of pain and increase their readiness to change [75]. Future studies could explore the integration of artificial intelligence, as recent advancements have enabled chatbots to demonstrate empathy and tailor recommendations based on user data [105,106]. However, concerns about trustworthiness often arise in mHealth interventions, highlighting the need for professional oversight [105]. Incorporating real-life support from healthcare professionals, through regular check-ins or virtual consultations, could provide the additional guidance needed to clarify misconceptions, enhance engagement, and build trust in the intervention.

### *Work context*

Despite relatively favorable scores on physical job demands, workload, job autonomy, and social support, participants highlighted several workplace challenges, including as lack of ergonomic equipment and resistance from colleagues and supervisors to modifying work conditions. These challenges could also explain the mixed effect of the intervention on fear-avoidance beliefs and pain intensity. Participants who perceived a conflict between the intervention and their work environment may have experienced worsening scores, while those without these barriers saw improvements. Our results align with previous studies suggesting that limited understanding and imbalanced workloads hinder the implementation of supporting measures for employees with musculoskeletal pain [23,85,107,108].

Establishing clear workplace policies and involving stakeholder, such as educating colleagues and supervisors about the challenges of managing pain, is critical for successful implementation of health-related recommendations [85,107,109,110]. Expanding the intervention to include workplace-focused strategies could enhance its effectiveness. For instance, research shows that supervisors who receive tailored advice are more likely to implement health-related interventions [86]. In this context, the data gathered during our intervention could offer valuable insights to supervisors about occupational risks, helping them develop both individual and collective actions to support employees [111]. However, concerns about the potential misuse of employee data, such as discrimination, emphasize the importance of robust privacy protections and legislative safeguards [111,112].

## Strengths and Limitations

This was the first study to evaluate a minimal viable prototype of an app-based pain management intervention tailored to employees. While the one-group pilot design limited our ability to infer causality, the combination of quantitative and qualitative data provided valuable insights into the potential advantages and disadvantages of the intervention [113]. These findings can guide modifications to the intervention and inform the design of a large-scale clinical trial [114]. Special attention should be directed towards the study population and control condition. Focusing on specific job profiles could enhance the ability to tailor interventions, leading to better outcomes [85,86]. Comparing the app with a waiting group receiving no treatment, guideline-conform face-to-face treatment, or a sham version of the app, have been suggested as viable control conditions [21,68,115].

A key strength of this study is the inclusion of multiple outcomes, rather than focusing solely on pain intensity. Pain-perceptions stemming from the Fear-avoidance model, as well as physical activity, were included because these have been linked to disability and sickness absence in individuals with pain [26,30-37,116,117]. However, future studies should include measurements assessing endurance pain responses when evaluating the effectiveness of pain management apps for employees, as many of our participants displayed characteristics of endurance pain responses rather than avoidance responses [118,119]. This involves suppressing and ignoring pain to maintain daily activities, which has been linked to emotional distress, prolonged complaints, and increased sickness absence [118].

High dropout and non-usage attrition rates were a limitation of this study, though multilevel analysis was employed to address missing data [70]. High dropout and non-usage attrition rates are common in mHealth intervention [120,69]. Eysenbach and colleagues stated that compatibility plays an important role in the adoption of new technologies [120]. Despite the overall positive feedback, participants reported several negative experiences with our intervention, including design choices that did not align with their busy life. Both developers and end-users make many assumptions when developing prototypes, underscoring the need for test sessions in real life settings. [49]. Competing interventions and technologies also influences attrition [120]. Due to the rapidly expanding field of mHealth, interventions and tools not following technological advancements will be easily rejected by end-users [16,48,121]. Several participants preferred their current tools and apps with more elaborate and user-friendly features, such as automated activity and heart rate tracking. Future studies using app-based interventions should focus on integrating apps and tools already used by end-users. However, attrition does not necessarily indicate an unsuccessful intervention. It is possible that participants discontinued using the app after optimizing their coping strategies, not expecting to obtain additional benefits [120]. Future studies should evaluate how much exposure to treatment would be necessary to obtain any relevant benefits and use these insights to define criteria for dropout and non-usage attrition.

Finally, the overrepresentation of healthcare workers in our sample limits the generalizability of our findings to other sectors [122]. Future studies should explore the effectiveness of pain management apps in more diverse populations, particularly those with lower digital health literacy, as these individuals may require different educational strategies and additional guidance [100,123,124].

## Conclusion

The app-based pain management intervention, focusing on biopsychosocial education, graded activity, and personal goal-setting, showed promise in reducing the threat value of pain and encouraging employees to adopt new coping strategies. Effectiveness was hindered by content and design choices that did not adequately account for diverse work settings or the busy lives of employees. Cognitive biases and non-supportive work environments further complicated the successful implementation of the intervention in the workplace. Future studies should involve workplace stakeholders, in addition to end-users and healthcare professionals, during the development and implementation of app-based pain management interventions for employees. Moreover, combining mobile apps with follow-up support from trusted healthcare providers may offer additional guidance to employees and their employers, enhancing their effectiveness.

## Author Contribution

SK: concept and design of the study, data collection, quantitative and qualitative analyses, data interpretation, and drafting the manuscript. LD: concept and design of the study, qualitative analysis, data interpretation, critical review of the manuscript. MS: programming the mobile app and recommender system, data interpretation and critical review of the manuscript. LG and VVA: data interpretation and critical review of the manuscript. SK will be responsible for the overall content as a guarantor. All authors have approved the final version of the manuscript to be published.


## Acknowledgements

This pilot study is a part of a broader research project, entitled “Personal Health Empowerment” (PHE), which aimed to develop and evaluate innovative monitoring and coaching solutions for employees with pain complaints. This project is funded by ITEA (grant number 16040), an European financier of innovative projects that have social added value and make use of technological innovations, and the Flemish Agency for Innovation & Entrepreneurship (grant number HBC.2018.2012) who provides grants to companies for the development or strengthening of their research and development activities.


## Conflicts of Interest

LG, LD, and SK are associated with IDEWE, who owns intellectual property of the Health Empower app.

## Abbreviations

FABQA: fear-avoidance beliefs questionnaire (activities subscale)
FABQW: fear-avoidance beliefs questionnaire (work subscale)
mHealth: mobile health
PCS: pain catastrophizing scale
VAS: visual analogue scale

## Multimedia Appendix 1

## Multimedia Appendix 2

## Multimedia Appendix 3

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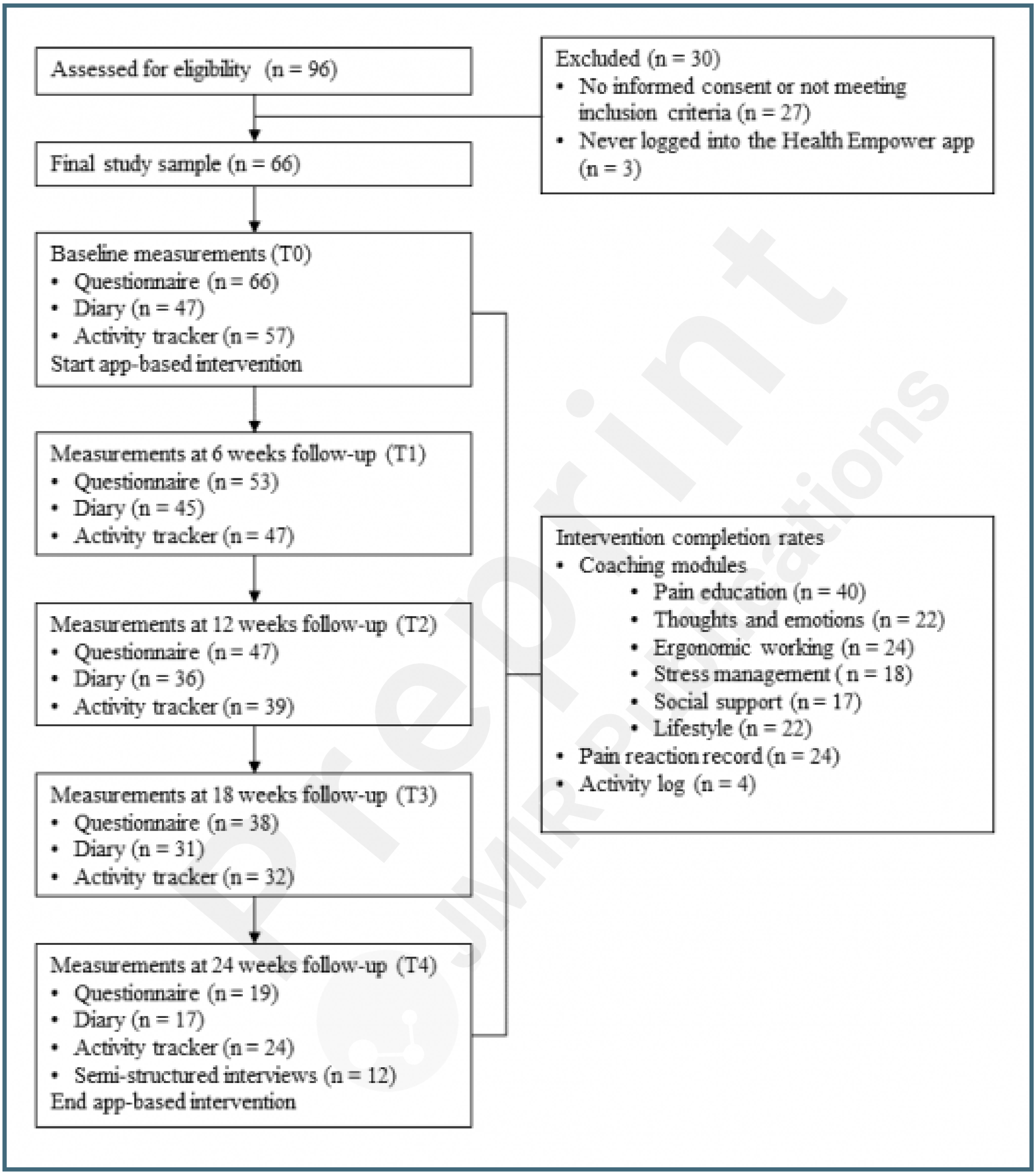
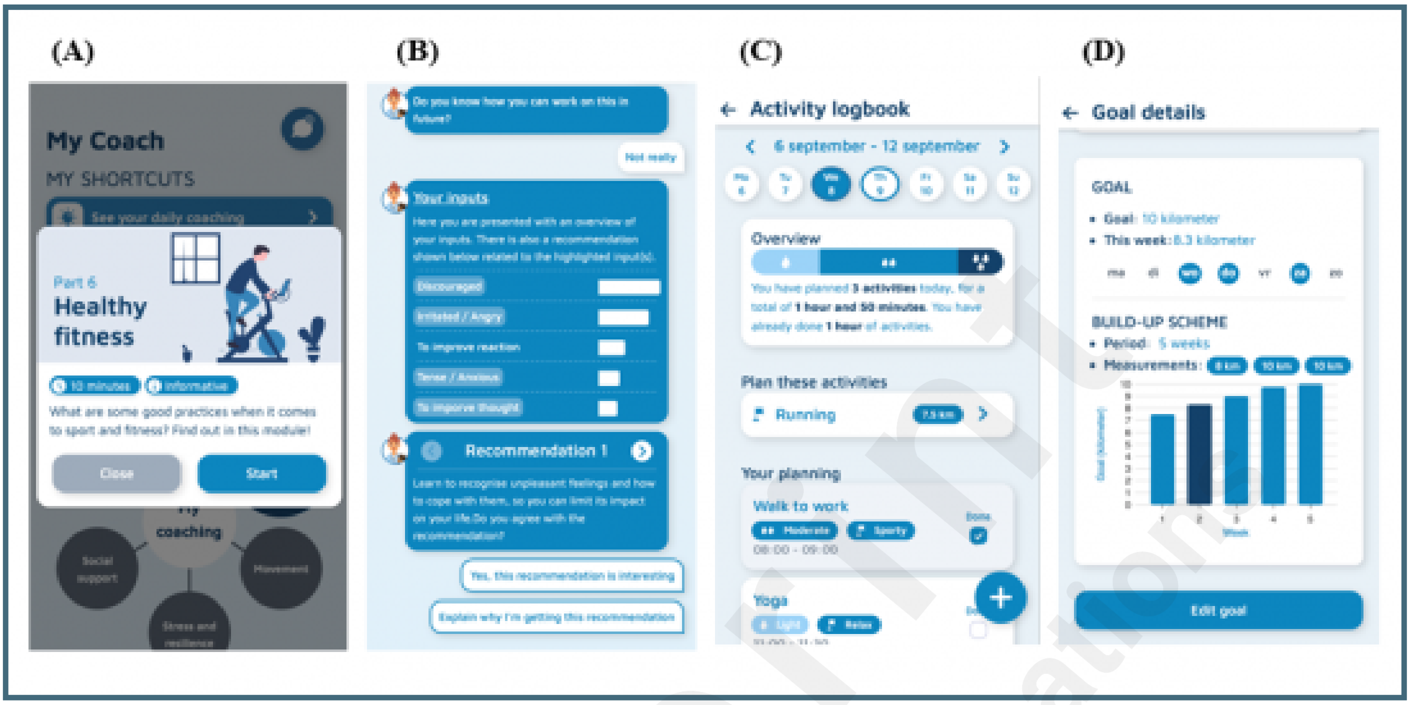
# Supplementary Files

# Figures

Flowchart of the study.



Example screens of the Health Empower app. (A) coaching modules; (B) pain reaction record; (C) activity log; (D) goal-setting.



# Multimedia Appendixes

Exploratory factor analysis for the Dutch Musculoskeletal Questionnaire.
URL: http://asset.jmir.pub/assets/b298c2119fae7772e0cb57e7d0aceea2.docx

Sociodemographic and baseline information of study participants.
URL: http://asset.jmir.pub/assets/b073b63d3355321f6507c70d90f5f9f9.docx

Linear regressions of outcome variables from a randomly selected subset of 20 participants.
URL: http://asset.jmir.pub/assets/dd65e98cbca54f1076ad0679c135c21d.docx