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Exploring the barriers and facilitators for supporting adolescents with knee pains adherence to mobile health apps: A think-aloud study

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Abstract

Background: Mobile health (mHealth) applications have the potential to support adolescents' self-management of knee pain. However, ensuring adherence remains a barrier when designing mHealth concepts for adolescents.

Objective: This study aimed to explore barriers and facilitators for adhering to mHealth interventions to inform design principles.

Methods: Think-aloud tests were conducted with 12 adolescents (aged 12.5 years median) with knee pain, using a low-fidelity prototype. The prototype was informed by the authors previous work, rapid prototyping sessions with seven health professionals, and synthesis via the Behavioral Intervention Technology Model. The think-aloud tests were video recorded and analyzed thematically to identify design principles.

Results: The analysis based on user testing with adolescents with knee pain identified three themes: "user experience and feedback," "contextual challenges," and "new features" and nine subthemes. Adolescents were able to use mHealth behavioral features such as self-tracking, goal setting, education, and data visualization to capture and reflect on their knee pain developments, which facilitated use. However, adolescents struggle with timing interventions, breaking down management behaviors, and biases towards interventions were identified as internal threats to adherence. Competing activities, parental meddling, and privacy concerns were external adherence barriers. Twelve design principles were identified for integrating these insights into mHealth designs.

Conclusion: Participants' motivations for adherence were influenced by internal and external factors. While adolescents were able to use mHealth behavioral features to capture and reflect on knee pain developments, understanding how to accommodate adolescents' cognitive abilities, competing activities, and need for independence is quintessential to enhance adherence in everyday contexts.

Keywords

mHealth, musculoskeletal pain, adolescent health, treatment adherence, knee pain, pain, general practice, low-fidelity prototypes, think aloud, patient education, self-management, digital health information, user-centered design

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Introduction

Background

Musculoskeletal pain affects approximately one in three adolescents (aged 10–19 years).[1] The most common pain site is knee pain related to almost one-third of musculoskeletal complaints in this demography.[1,2] From the age of 10 there is a steep increase in adolescents seeking treatment for knee pain in general practice.[3] Of the adolescents who experience knee pain, between 40% and 50% will see a stagnation in their recovery, leading them to continue to experience pain and symptoms after two to five years.[4,5] This is critical, since life course studies link pain and functional limitation during adolescence to negative health outcomes like obesity, diabetes, cardiovascular conditions, and reduced mental health in adulthood.[6–8] Intervention studies combining physiotherapeutic exercises and patient education via leaflets with self-management advice have proven effective for improving adolescents' prognosis in clinical trials.[9–11] Still, poor self-management habits and treatment adherence remains a barrier to ensuring positive health outcomes in this patient group.[11]

Mobile health applications

Mobile health (mHealth) technologies are hailed as a promising tool for enhancing the treatments of patients with chronic conditions,[12–15] with systematic reviews documenting how the inclusion of mobile apps is associated with potential benefits in treatment adherence, disease understanding, psychosocial adjustment, and self-management in adolescent populations.[16–19] Utilizing the proximal features of smart phones,[20] mHealth applications hold the potential for supporting patients with ongoing self-management needs through the delivery of tailored patient information, text-reminders, quantified self-tracking, sensors, decision-making assistance, and leveraging support via social media.[21] A recent workshop study identified how such an app for adolescents with knee pain should include features like patient education videos, an exercise video library, pain diaries, pain tracking features, reminder prompts, data visualizations, and tailored management suggestions, to support adolescents' self-management at home.[22] While these findings aligned with insights from other user-centered studies with adolescents with musculoskeletal conditions,[22–25] the question of how to tackle issues with sustaining user engagement is not discussed, despite this being a well-known barrier in mHealth research.[26] Understanding how adolescents with knee pain experience, perceive, and interpret digital health information delivered via mHealth apps is important and may reveal design targets for adjusting core-features and functionalities to sustain adolescent's adherence and self-management of their knee pain.

Low-fidelity prototypes

User-centered methods are hailed as the gold standard for integrating patients' challenges, needs, and desires into mHealth designs.[27,28] Albeit, adapting the "putting users first" and "early inclusion" mantra in the design process does not guarantee instant viability in the hands of patients.[29,30] A recent study identified several biases against adolescent participants within use-centered processes, including a lack of recognition of adolescent's abilities to express themselves, failure to make complexity relatable for adolescents, failing to apply design methods that enables adolescents to describe their routines, challenges, perceived benefits, and repurposing designs for adults amongst others.[31] Low-fidelity prototypes have the capacity to act as filters for unlocking the cognitive, tacit, and latent process present within use situations,[32,33] and prototype interventions have proven viable for engaging with adolescent collaborators.[34,35] Conducting think-aloud tests with low-fidelity mHealth prototypes may unlock novel insights into how adolescents with knee pain experience, understand, and act on digital health information delivered via mobile apps in none-healthcare contexts. This knowledge is important, as it informs post-design adjustments of mHealth core features and information flows, to accommodate the information processing and health decision-making capabilities of adolescents with knee pain, and to ensure the sustainability of mHealth concepts prior to implementation.

Objectives

The aim of this study is to explore the barriers and facilitators for adherence to mHealth-delivered health information, core features, and information flows experienced by adolescents with knee pain across different use scenarios.

Methods and design

The study drew upon design-based research as the methodological framework for balancing the project's design and research elements within a shared inquiry process.[36] The study was conceptualized as a research-led, expert-driven usability study with think-aloud testing,[37,38] using a low-fidelity mHealth prototype[32] as an intervention component. We used relevant studies by Rathleff et al.[9] and Johansen et al.[22,39] and rapid prototyping sessions with health professionals and researchers with a special interest in adolescent knee pain to identify requirements and use-scenarios for an mHealth app. The behavioral intervention technology model (BITM)[40] informed the design of a low-fidelity mHealth prototype. The think-aloud tests were conducted with adolescents (age 10–15 years) with knee pain through Microsoft teams to comply with national COVID-19 regulations. Each think-aloud test was video recorded, transcribed, and analyzed via Thematic Text Analysis by Braun and Clarke.[41] All adolescents were given the option of having a parent present during the think-aloud tests, informed about their rights, and written parental consent was obtained for all participants.[42] A study protocol was forwarded to the Regional Committee for Ethical Research Conduct in Northern Jutland, which waivered registration based on Danish national registration guidelines. The study was reported in accordance with the Consolidated Criteria for Reporting Qualitative Research (COREQ) guidelines (Supplemental Appendix 1) for reporting qualitative research.[15]

Participants

The study was conducted with a main and secondary study population. We included adolescents (age 10–15 years) with long-standing or recurring knee pain with a duration of more than three months as the main study population, which would participate in the think-aloud tests of the mHealth prototype. Exclusion criteria were defined as; competing musculoskeletal pains which was unrelated to their knee pain, other non-specific pain conditions, psychological challenges that required medication, and hearing or visual impairments that could impede adolescents' ability to partake in the digital think-aloud tests. Secondly, researchers with clinical experience in treating adolescents with musculoskeletal conditions were included as the secondary study population, to participate in the design of the low-fidelity prototype. Inclusion criteria were clinical experience with treating adolescents with knee pain in primary or secondary care settings, interest in digital patient education tools, or an interest in enhancing the treatment of adolescents in primary care. Adolescent participants were recruited through social media posts, which were distributed to the patient networks of the Center for General Practice in Aalborg. Each social media post contained a questionnaire (Supplemental Appendix 2) with questions related to the inclusion criteria, consent, and contact information. From this, participants were sampled purposely based on their questionnaire responses.[43] Potential participants were contacted via telephone, by the lead researcher (SKJ) who informed participants of the project's background, aim, objective, methods, and the research group's motivation for conducting the study, before being screened verbally. Participants for the expert population were identified within the networks for the Center for General Practice in Aalborg, contacted via email and telephone, screened, and included in the project.

Think-aloud testing

We used think-aloud interventions with low-fidelity prototypes to facilitate our collection of data. While related to qualitative interviews, the method uses simulation to shed light on user cognitions and decision-making when engaging with artifacts.[44] Drawing on the inclusion of prototypes or protocols, think-aloud interventions use observations, probing- and open questions to explore interaction choices, breakdowns, and verbalizations to gain insight into the tacit practices, cognitions, and contextual barriers relating to artifact use. Through this, think-aloud testing uses a leveled approach to enable participants to shift between their immediate experiences of the design, verbalizing their actions and thoughts when engaging with the design, and articulating their predictions of future actions and use-context during interventions.[44] By exploring the different layers of verbalizations, the think-aloud tests aim to deconstruct the user-experience and identify anchor points for modulating designs[37,44] (Table 1).

Table 1. An overview of the levels of observable verbalizations occurring simultaneously during think-aloud tests, ranging from immediate unmodulated experiences spoken out loud to verbal descriptions of the user experience to descriptions of possible and future use based on higher cognition.

Levels of verbalization during think-aloud testing	
Level 1	Immediate, unmodulated thought spoken aloud, for example, "Heart rate is 112."
Level 2	Experience is recoded into verbal descriptions of non-verbal stimuli; no reprocessing is required, for example, "Patient has tachycardia."
Level 3	Experience recodes into predictions of future actions/ anticipatory guidance, for example, "Intravenous fluids are needed to improve fluid balance and return the heart rate to normal range."

Adapted from Burbach et al.[44]

All interventions were conducted with low-fidelity prototypes and followed Rettig[45] guidelines for conducting think-aloud usability testing. To accommodate the context-sensitive nature of mHealth applications[30] and assist participants in transitioning between the different layers of verbalizations, we incorporated open-scope questions and elements of storytelling into our think-aloud protocols.[44] This included, combining the use of case vignettes, low-fidelity prototypes, and use scenarios to encourage a multi-leveled reflection and verbalization of how participants experienced the prototype's core features and design, how adolescents interpreted the contents and encourage additional reflections upon how the proposed core features could support or inhibit adolescents' self-management of knee pain across use contexts.[37,44]

Patient cases

A case vignette (Supplemental Appendix 3) which had been designed for a previous workshop study.[22] was included to act as a primer for our participant's reflections on the influence of contexts during use. The case vignette had been designed iteratively with input from young adults with knee pain, parents, and GPs to illustrate the common and salient features of adolescent patients seeking treatment for their knee pain in primary care, and included relevant and irrelevant information.[44] As the case had already been pilot-tested in three future workshops they were included without changes to the design and narrative presented herein.

Low-fidelity prototypes

To facilitate our exploration into adolescents' experience of engaging with a functional mHealth app, we included a low-fidelity prototype to simulate user-device interactions, guide participants' reflections, and prime articulation during our think-aloud tests.[45] By using a rapidly generated, low-fidelity approach, we aimed to bridge the gap of ensuring that our prototypes acted as manifestations of our understanding of what an mHealth app should include while acting as filters for exploring how to modulate the core-features and information flows of an mHealth prototype to accommodate the everyday management needs of adolescents with knee pain.

Designing the low-fidelity prototype. We included the BITM by Mohr et al.[40] as a framework for guiding our design of the low-fidelity prototype. The BITM framework was included to bridge the gap between concept design and defining architecture when designing behavioral change technologies. The BITM combines behavioral models of Rettig,[45] Fogg,[46] and Oinas-Kukkonen[47] to explore the relationships between user needs, behavioral interventions, and outcomes across experimental domains. By exploring the how-, what-, where-, and why within user situations, the BITM supported the identification and alignment of persuasive elements (features) within a sequence, aimed at informing the conceptualization of behavioral intervention technologies (Bit-Tech's) for delivering behavioral support to target users. Thus, the integration of the framework allowed us to expand our scope, to incorporate contextual and behavioral aspects into our prototype.

Defining objectives. We used the BITM's[40] state change diagram for guiding the design of the low-fidelity prototype (Supplemental Appendix 4). Our point of departure was based on a literature review of our previous studies on supporting adolescents' self-management of knee pain (two qualitative and one quantitative),[9,22,39] describing how adolescents' knee pain emerged in situ, and inhibited their ability to participate in sports and valued activities. By assigning "*maintaining balance*," "*vocabulary development*," and "*acceptance*" as intervention goals, enhancing adolescents "*knowledge on pain mechanisms*," '*health decision-making*," "*pain prevention*," and "*articulation of pain*" were identified as as primary design objectives, while "*supporting ongoing use*" of the app was highlighted as a secondary objective. The five identified design objectives guided the conceptualization and design of the low-fidelity prototype.

Rapid prototyping. The low-fidelity prototype was designed through a rapid prototyping approach,[48] informed by a series of 45-minute interviews with experts with in-depth knowledge on adolescent musculoskeletal pain, using a muck-up of the low-fidelity prototype which experts provide feedback on. Seven experts participated in the rapid prototyping interventions, including two GPs with experience in treating adolescents with musculoskeletal pain, one rheumatologist, one physiotherapist—, two health researchers with a special interest in adolescent musculoskeletal pain, and one anthropologist with a special interest in at-risk youths in primary care. The discussions from user tests were audio recorded, noted into a framework,[49] and informed the remodeling of the mockup. The expert interviews provided us with insights into the clinician side of treating adolescent knee pain, identified use scenarios, and a BITM which informed the low-fidelity prototype for the think-aloud tests.

Core-features, workflows, and scenarios. The design objectives, expert insights, and BITM (Supplemental Appendix 5) informed the conceptualization of core-features, information flows, and relevant use scenarios which were included within the mHealth low-fidelity prototype (Supplemental Appendix 6), which came to act as the foundation of our think-aloud interventions.[44,50] The prototype design consisted of five core features; setup, goal setting, patient education, quantified self-tracking of knee pain, small data feedback, and big data features. Storytelling elements (Supplemental Appendix 7) included scenarios like; visiting the GP, family dinner, school, and getting up in the morning and served the purpose of creating continuity and sparking additional reflections amounts adolescents.

Setup feature. The setup feature was designed to simulate a situation where our participate would have to locate the application in an app store, download the application, receive information on app use, and setting up a password feature for privacy protection (Figure 1).

Goal setting feature. The goalsetting feature was designed to simulate how an mHealth app could promote ownership by asking adolescents with knee pain to note their goals, and test participants' ability to reflect on and break down their efforts to archive their goals into manageable sub-goals. Defined goals and sub-goals informed the prompts and self-tracking feature (Figure 2).

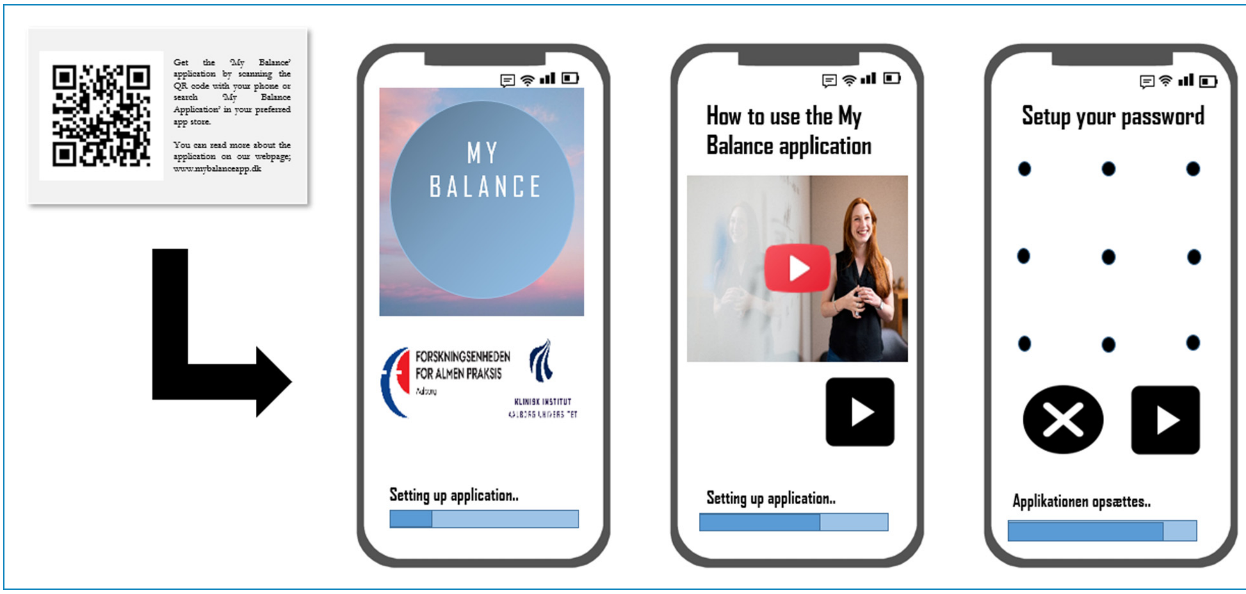

Figure 1. The setup feature consisted of a card with a QR code, a loading screen, an introduction film, and a password feature. Participants were asked to complete the sequence and provide feedback on each step, their choices, and how to improve it.

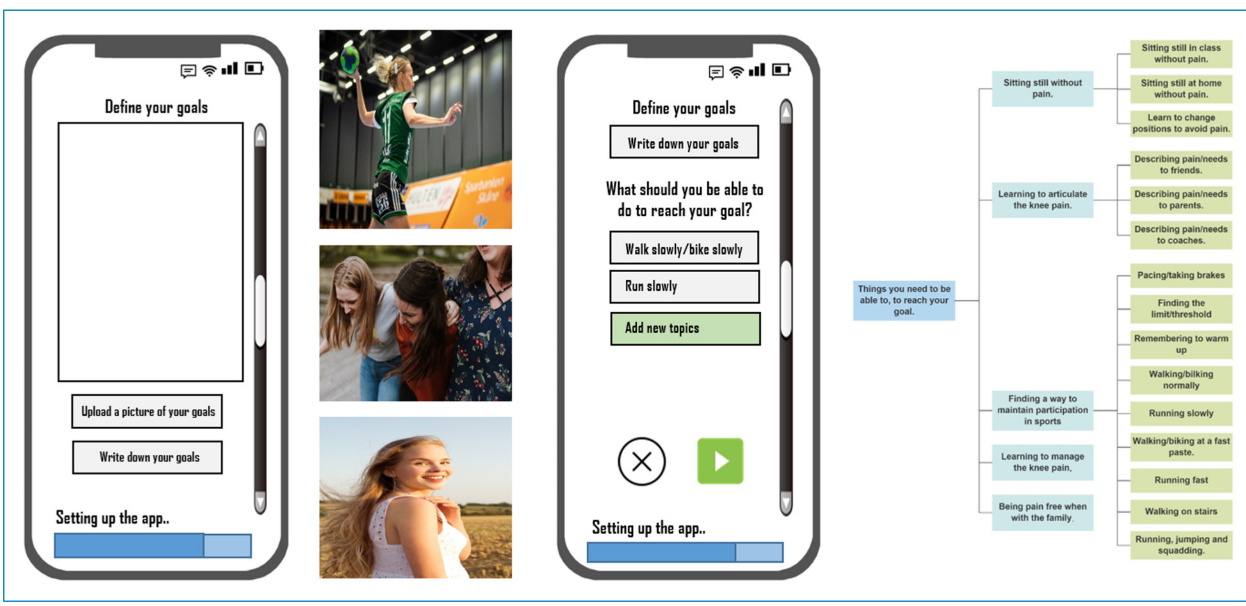

Figure 2. The goal-setting feature used a persuasive strategy which included using the adolescents' own pictures from prior to the injury to remind them of their end goals (left) and build ownership. Secondly, the application used a set of predefined activities (right) and skills to support adolescents in breaking down their goals into sub-goals.

Education feature. The education features design was nested insights on how adolescents with knee pain described feeling like they lacked a proper understanding of the mechanics of their knee pain, possible trajectories, and what actions they could take to manage their pain.[19,36] Using short film clips, the education feature aimed at providing adolescents with general information on the etiology of knee pain, prognosis, and their role in managing the condition, which they could explore at their own paste (Figure 3).

Self-tracking feature. The self-tracking feature simulated using ecological momentary assessments (EMA) to enable adolescents to measure and register their experienced knee pain, current activities, and recent behaviors in everyday situations.[51] The aim of the self-tracking

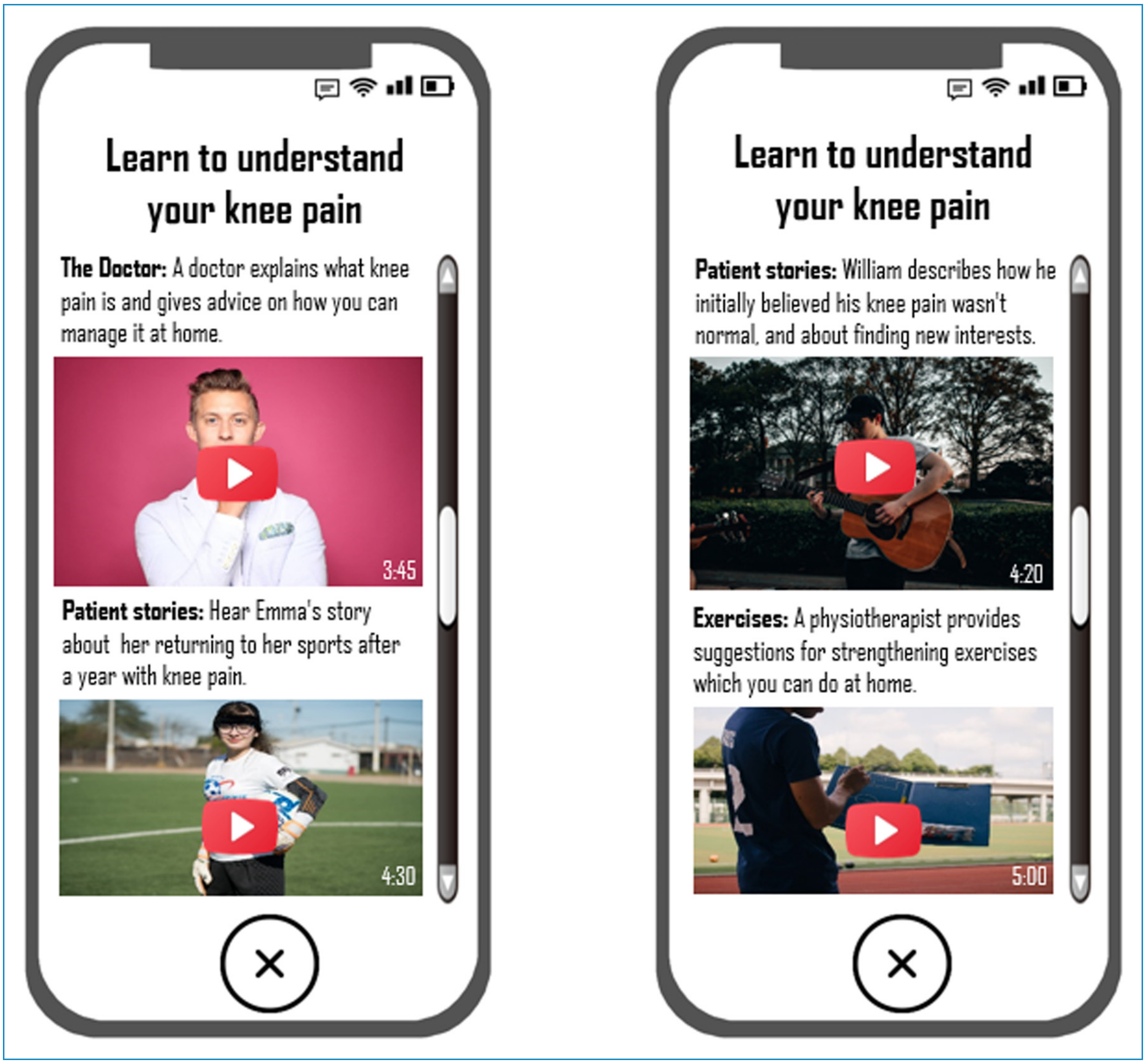

Figure 3. The patient education feature simulated how adolescents could choose between four videos with recognizable characters. The topics of the videos included the etiology of knee pain, returning to sports, acceptance, and finding new hobbies and strengthening exercises. Participants were asked to choose between each video, and describe what they envisioned the video would contain and the motivation behind their choice.

feature was to explore whether adolescents were capable of understanding and using a scale to measure their lived experiences, and if external circumstances would influence their use of this feature (Figure 4).

Data feedback. Two features were included which simulated receiving feedback to allow us to explore how adolescents experience, interpret, draw inferences, and envisage using their self-tracked data in their management of knee pain. Feature one (left) illustrated the connection between adolescents' tracked developments in their knee pain in relation to behavioral choices via small data visualizations.[52] Feature two (right) enabled exploration and articulation of long-term developments in adolescent knee pain via aggregated self-tracked data (Figure 5).

Intervention feature. Upon reviewing the self-tracked data adolescents with knee pain would be asked if they wanted help to balance their knee pain (if entries were yellow or red). The intervention feature simulated how an app could provide just-in-time interventions in the shape of access to short videos with self-management advice (pacing, taking brakes, exercising, and telling others), thus allowing us to explore our participant's ability to reflect on their needs, understand interventions, identify contextual barriers, and define new interventions (Figure 6).

Setting and procedure

All think-aloud tests were facilitated by a male researcher (SKJ), PhD student at the Center for General Practice,

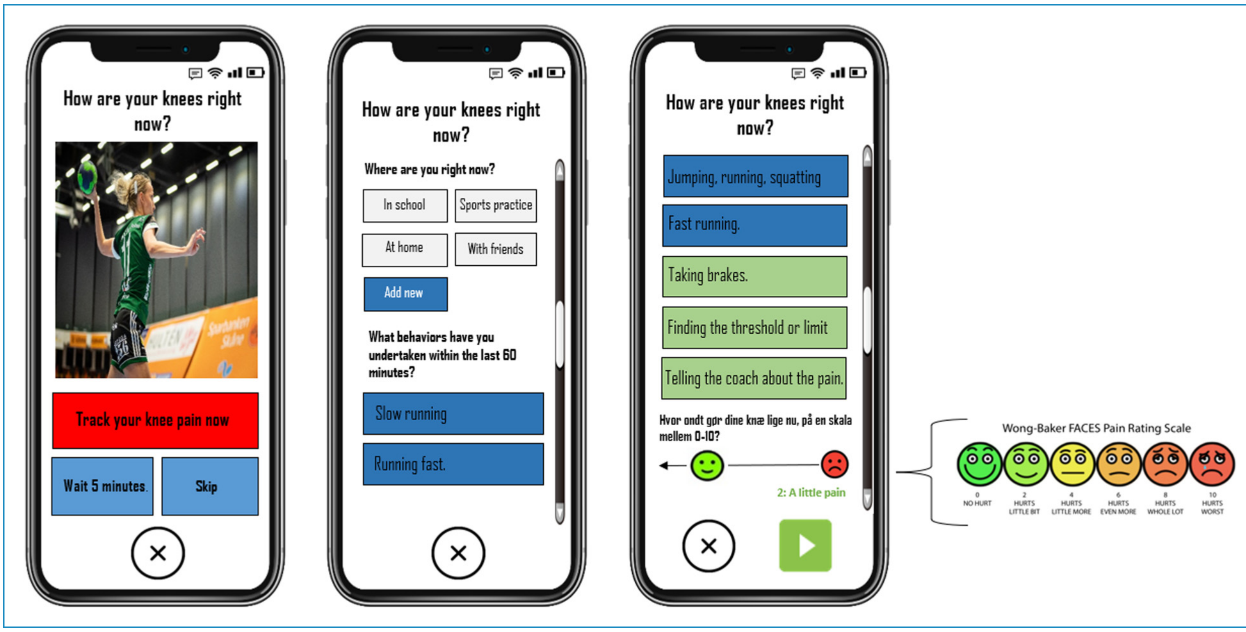

Figure 4. The self-tracking feature consisted of a prompt screen (left) and a tracking screen (middle, right) and was designed to simulate how the app uses information provided during the goalsetting (middle) and a slider based on the Wong-Baker Scale[84] as a proxy for measuring adolescents knee pain in situ.

Aalborg with a background in Information Science, and experience conducting qualitative interviews with adolescents with musculoskeletal conditions.[39] To comply with COVID-19-related restrictions the think-aloud tests were conducted via digitally via Microsoft Teams. Prior to their inclusion, adolescents and their parents or legal guardians had received written information on the project's goals, aims, researchers' background, and motivations for conducting the study. Before the think-aloud tests were initiated, adolescents and parents/legal guardians were briefed on the project's aim, intervention, their rights as participants, and procedures for treatment of data in accordance with the EU General Data Protection Regulation (EUGDPR).[42] Adolescents were then given the choice of having their parents present during the tests. The think-aloud tests were conducted in Danish as this was the native tongue of the participants. Each think-aloud test was scheduled to last between 60 and 75 minutes and was initiated by the facilitator (SKJ) asking participants a set of predefined questions on the clinical characteristics of the adolescent's knee pain (age during onset, symptoms, duration, treatment history, medicine use, and sports participation). After this, the researcher would share his screen with a PowerPoint with the case vignette and the low-fidelity prototype, before going over the case in detail, and asking adolescents to describe how the case related to their experiences with knee pain. This helped the facilitator to establish a baseline for how to proceed with the questioning going forward. During the think-aloud test, the interviewer would go through each scenario outlined within the PowerPoint (Supplemental Appendix 6), describing the situation and narrative before asking the adolescents to describe verbally how the case would complete the predefined tasks like; installing the application, using the tutorial, tracking their knee pain, etc. During the prototype interventions, the facilitator observed the adolescents' choices while remaining vigilant for pauses and verbalization cues.[44,50] If noted, the facilitator would ask the adolescents to articulate their reasoning behind how they envisioned the case would solve the task. After each scenario, the facilitator asked participants a set of predefined questions on the utility of the prototypes core-features, how it could be improved and barriers and facilitators for use. This allowed the researcher to gain additional insights into how contextual circumstances may influence adolescent use decisions. When the test was over, adolescents were asked to provide their feedback on the application and suggestions for improvements, before being debriefed and signing consent forms. All adolescents were given a gift voucher for 200 Danish Kroner (circa 27 Euros) to a national cinema chain for participation.

Data collection

All think-aloud tests were audio and video recorded using the record function of Microsoft teams to capture the participant's descriptions of how they engaged with the prototype. To comply with the EUGDPR and Aalborg University guidelines for data management, all video files were downloaded to a secured one-drive backup folder, licensed by Aalborg University before being copied onto a secure server hosted at Aalborg University for storage. Participants' and parents' names and contact information

Figure 5. The data feedback features simulated how an mHealth app could use adolescents' self-tracked data to provide them with a visual representation of their daily (left) and long-term (right) developments in knee pain. By using the steps from the Wong-Barker scale (*y*-axis), the app outlined the sequence of activities (*x*-axis) and illustrated whether adolescents had reported how this placed them in the green (0–2 pain), yellow (3–7 pain), or red (8–10 pain) bracket.

were noted in a data key file, which was encrypted and stored in a separate folder.

Test interviews

Two test interventions were planned and conducted to test and inform last-minute changes to the interview procedure, setup, and delivery of the low-fidelity prototype. The test interviews were conducted with two adolescents with knee pain, who were included through similar means as test participants (social media posts). As the test interventions were deemed successful by the research group members, the two think-aloud sessions were included in the study as sessions one and two.

Analysis

The data collected during our think-aloud interventions were analyzed using NVivo coding software. Thematic Text Analysis (TTA) by Braun and Clarke[41] was included to guide our analysis of the qualitative data, through the inductive identification of themes and subthemes present within the extracted body of data. The analysis followed Braun and Clarkes the six stepped approach for facilitating qualitative analysis, which included familiarization, generating initial codes, identifying themes, reviewing themes, naming themes, and reporting findings.[41] The analysis was conducted by two researchers (SKJ and MNC) and two student workers, who assisted with the transcription of data. In step one, the data was transcribed for meaning retention as in accordance with the guidelines by Kvale and Brinkmann.[53] Researchers would read through transcribed texts to familiarize themselves with the contents. Step two entailed conducting preliminary coding to identify salient and important semantic features in the transcribed texts. In steps three and four, the researchers (SKJ and MNC) circled between in-depth coding, identifying the semantic themes and subthemes across datasets, and collapsing these themes to reveal the latent themes within the texts.[41] A coding list (Supplemental Appendix 8) was

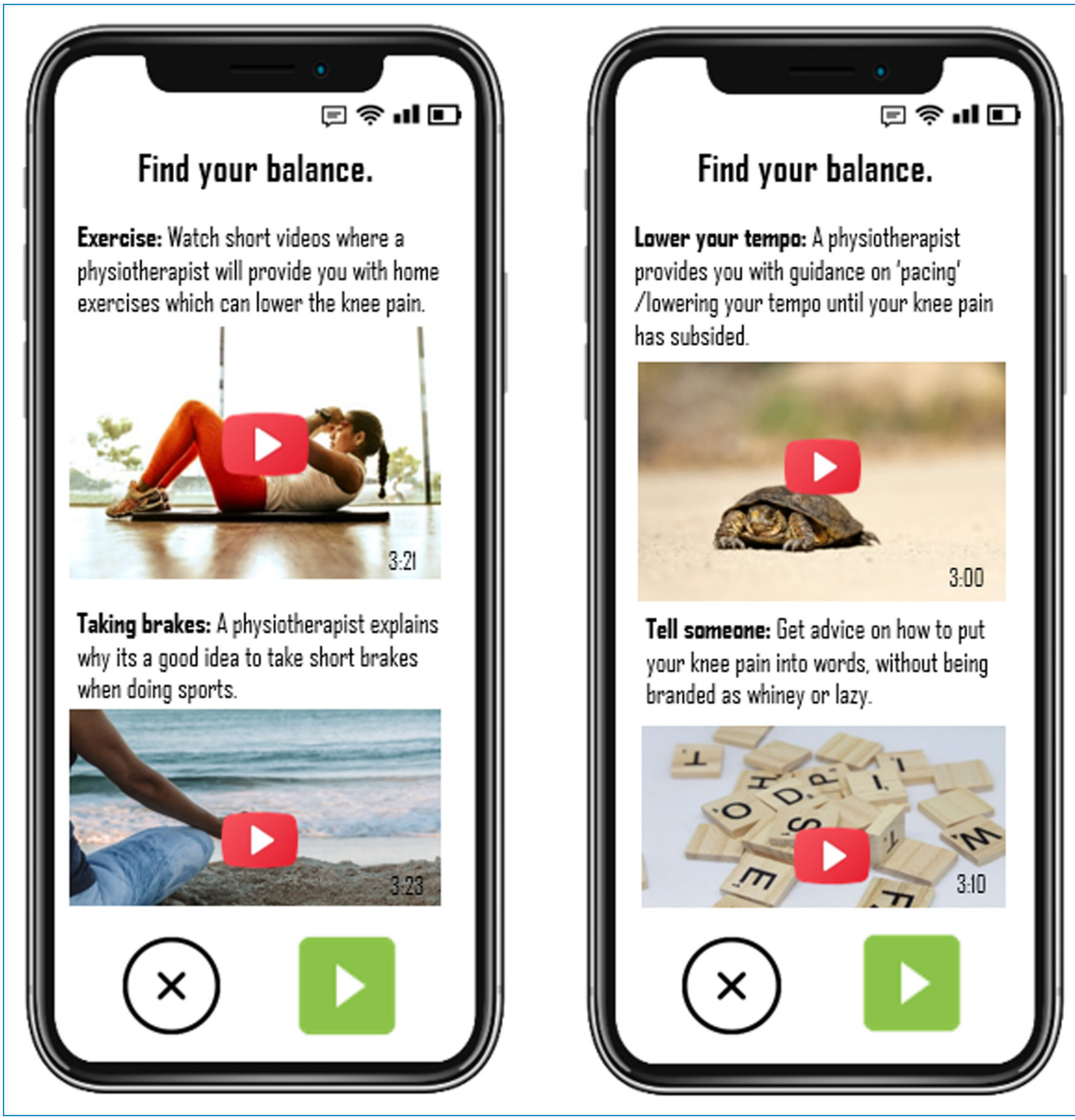

Figure 6. The intervention feature consisted of one screen with four embedded films with self-management advice. During the think-aloud tests participants were asked to choose which videos they felt fitted best with the case vignette, their own challenges with knee pain describe why and how they would use them. Secondly, participants were asked to define new videos and describe the benefits hereof.

created and maintained to ensure an overview and consensus on the identified themes and subthemes. Phase five included selection, clustering, and renaming themes to reflect the meaning behind the thematic structures. The sixth and final phase included opening themes, condensing texts, and reporting the findings within a narrative form to be presented in the "Results" section. The translations of the themes and selected quotes from Danish to English were conducted during the final phase of the analysis, as part of formulating the narrative. The translation was conducted by the two researchers, who read and discussed the final content summary themes to ensure the meaning within the themes was retained.

Results

Inclusion

The inclusion via social media was initiated on the 10th of May and ran until the 20th of June 2021. The social media posts generated 42 individual responses to our inclusion questionnaire. Of the 42 potential participants, 15 failed to meet the inclusion criteria specified within the questionnaire, while six did not provide contact information or consent to contact. From the 21 participants who were contacted for phone screening and inclusion, five could not be reached, one declined participation, and one was eliminated as the screening identified a serious pathology. Of the 14 participants who were included in the think-aloud tests, two participants decided to withdraw before the think-aloud tests with no reason provided. Data saturation was reached during interview 11 as we deemed that no new, significant insights emerged during user tests, and the inclusion was halted after interview 12.

A total of 12 adolescents (nine female) participated in the think-aloud tests. Particpants were aged between 10 and 15 years (12.5 years mean), and had lived with knee pain for 2.8 years on average. From these, a small majority of participants (seven participants; 58.3%) reported their knee pain being mostly limited to one knee. The most common diagnosis was patellofemoral pain (four participants; 33.3%), seconded by Osgood Schlatter (three participants, 25%), and Osteochondritis dissecans (one participant; 8.3%) while four participants and parents could not provide a clear diagnosis (33.3%). General practice was the most common venue for seeking treatments, with 11 participants (91.6%) reported having consulted their GP for treatment, while eight had received physiotherapy (66.6%) and six participants (50%) had sought our specialized care from an orthopedic surgeon or a rheumatologist. Only one participant (8.3%) had not sought any treatment for the knee pain. All included adolescents were currently experiencing some degree of knee pain.

Findings from the analysis

The analysis identified a complex system of codes, sub-themes, and themes that were interconnected within "*adherence barriers and facilitators*" which served as an overarching theme, as well as a starting point for the thematic analysis. The analysis identified 96 individual codes (Supplemental Appendix 8), which were merged into a system comprised of three main themes named "*user experience and feedback*," "*contextual challenges*," and "*suggestions for new features*" each with their individual clusters of related sub-themes. The first theme was connected to five sub-themes including "*installation*," "*goal setting*," "*feedback on information videos*," "*feedback on self-tracking*," and "*feedback on treatment videos*." Two sub-themes named "*parental inclusion*" and "*hiding the knee pain*" were identified in relation to theme two, while the third theme had two subthemes named "*suggestions for features*" and "*suggestions for information materials.*" The emerging theme and subtheme constellations were visualized within a conceptual model to illustrate the complexity within the domain (Figure 7).

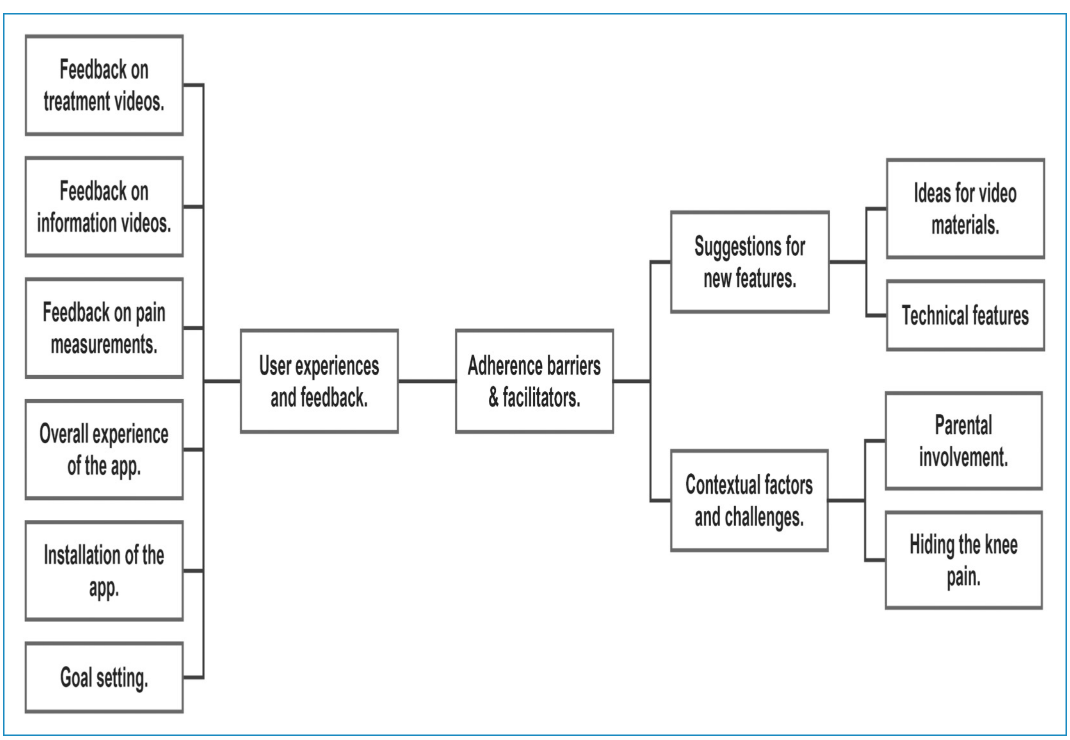

Figure 7. Overview of themes and subthemes. The figure illustrates the system of themes, subthemes, and thematic relationships that emerged during the thematic analysis. By taking point in 'adherence barriers and facilitators' the themes and subthemes were identified inductively through the merger of codes. Thus, each theme and sub-theme should not be viewed as static, but as comprised of several contradictory statements which were explored further during the sixth and final step of the analysis.

Theme 1: User experience and feedback

The majority of the participantst articulated that they were satisfied with the overall design and features presented within the low-fidelity prototype. Furthermore, several participants described how they experienced the prototype, its different features, and the support provided via its features as predominantly positive. Several participants expressed a desire to test the prototype at home, which we interpreted as a validation of our design. Still, the think-aloud tests identified several design challenges that could enhance the usability of the design if resolved.

Installing the application. During the initial exercises with installing and setting up the application, the majority of participants expressed how the information provided on the card was sufficient for enabling them to find, download, and install the application. In relation to the password selection feature, several participants highlighted how it would be easier for them to use a numeric pin code or face identification feature since it was familiar, recognizable, and numbers were easier to remember. Additionally, one participant suggested that the application could be delivered via a text-message, to remind the adolescent to download the application. One adolescent described how recognizability helped her remember her interaction decisions on the application like this:

> I: "Which password system should we have then?" P11: "Well. Either numbers or something like that. Because I think numbers are easy. This way, you can remember the numbers (you selected for the password). Because … if you make dots, I think it could become confusing in some manner. Because when you connect the dots, you might forget that there should be a line here or here…"

Another finding during the installation sequence was how most participants decided to view the "introduction video." This decision was motivated by adolescents' expectation that the "introduction video" could provide them with valuable insights on how to use the app to alleviate their knee pain. Still, several participants highlighted how the "introduction video" didn't meet their expectations, in terms of providing them with tangible information on how to start using the application. Two participants suggested incorporating an additional instruction video, which could be accessed on demand to support adolescents in overcoming challenges related to learning to use the application. One participant suggested using the case to exemplify how to setup the application.

> P3: "So you could actually just pretend to be Frederikke (case) and have a movie showing how she logged in, how she measured (her knee pain) with the scales or how she read the scale at the end. It could be … well … maybe it could be located right after (the introduction video). Because I think the first video was good for telling … what you can use the application for. How the application can be used to describe your day. But a second (introduction) video should show how you actually use the application."

When prompted, several participants provided reasons for skipping the introduction video, including just wanting to get started with using the app, or them believing that their technological skills were sufficient for mastering the application. Furthermore, participants highlighted how it was crucial that instruction movies weren't too long, as adolescents might decide to skip them to avoid boredom.

> P11: "In the beginning I reckoned at most 2.5 minute*s* (..) I believe that it is one minute, because I know that most boys, certainly, if they saw that a video lasted 2.5 minute*s*, they would think that watching it would be boring."

Setup and goal-setting. During the setup process, most adolescents decided to use the goal-setting feature to define their desired outcomes from using the app. This decision was nested in an assumption that this was important to gain the full benefit of using the application. Furthermore, more than half of participates described how uploading a picture of them doing sports was motivating and how seeing this image during prompts reminded them of what their end goal for using the app was. From this, several participants believed that the goal and picture feature could help them become more aware of their pain and motivate exercise adherence and application use.

> I: "How does it affect her, to see a picture of her (case vignette) playing handball." P3: "Hmm … that she becomes motivated to … I must get this knee pain under control, because I don't want them to control my life."

The two participants who abstained from using the goal-setting feature, described how they didn't see a purpose in writing down their goals, and how they wanted to start using the app quickly. In addition, several participants stated that defining goals and uploading pictures could also have an adverse effect, if the adolescent wasn't able to achieve their goals.

> P5: "You can become tired of things, if things are taken away from you … Because you don't know how everything will turn out, or whether there is something you can do within the moment."

While most of the adolescents had no trouble defining their desired goals like becoming pain-free or being able to participate in sports or valued activities, several of the adolescents struggled to break down which actions and sub-goals they needed to undertake or fulfill to achieve their goals.

> I: "Are there certain things, which she (case vignette) should be able to do in order to reach her goals?" P7: "I don't know…" I: "So, would you say, that noting really specific comes to mind?" P7: "No … (laughs) not right now."

Feedback on information videos. All participants selected the "Patient Education Feature" with information videos. From the four options, the case with the girl who was returning to her sports (video 2) was the most popular and selected by all participants. When prompted, several participants highlighted, that they chose video two because the theme was highly relatable and reflected their own wishes and desires. Additionally, several participants envisioned how viewing video 2 could provide adolescents with a sense of hope and motivation, either by illustrating that they were not alone with their knee pain or by providing them with a way forward and a target for recovery.

> P1: "Sometimes you can feel like you're all alone with this (the knee pain), and then it's a comfort to know that … if you have seen the video about … that you're not the only one why is struggling with knee pain."

Additionally, most of the participants decided to view a video with the GP explaining the etiology behind knee pain (video 1). When prompted, participants described envisioning how watching a video with background information on knee pain, could help them understand why the knee pain emerged and provide them with tangible suggestions on how to manage the knee pain. Furthermore, two participants described how they believed, gaining a better understanding of what was occurring inside their knee could help reduce pain-related uncertainty and worrying. In contrast, the two adolescents who declined to view the GP video already felt the possessed sufficient knowledge of the cause of their knee pain and felt additional explanations might cause unnecessary confusion.

> P6: "I don't think that everybody is interested in knowing this, but it's nice enough to know, I reckon. Because then you know what is wrong with your knee instead of you just walking around in uncertainty thinking; oh, what is actually wrong and why am I experiencing pain?"

Video 3 was primarily discarded by the adolescents, with several participants describing how they couldn't relate to the video's main theme and the thought of quitting their sports and finding new hobbies and friends. One a general note, participants stated that it was important that the content of the information videos was easily understandable and relatable to their lived experience with knee pain, with one participant suggesting using graphical illustrations to make the content easier to understand for adolescents. Furthermore, one participant suggested that the gender of the cases presented within the videos should follow the user, since this would increase the case's and contents relatability.

Self-tracking feature. A key insight gained was how the majority of the adolescents were capable of interpreting and using the self-tracking features (Wong-Barker scale), along with reading and understanding the pain visualizations. An example of this was how most participants were able to define a tolerable pain limit, contextualizing the pain visualizations to recent activities and identifying the behaviors or activities that lead to changes in their knee pain. Several participants described how they envisioned the self-tracking feature, and pain graphs could help them to reflect on how and when different activities influenced their knee pain, while enabeling them to remember and articulate their knee pain during GP visits.

> P6: "Because you can go backwards and see; okay, here I was really active and had a lot of pain, and around the time were it wasn't so bad I didn't really do as much', to allow you to get an indication of what it is, that initiates your pain."

All participants understood the intention of the timing feature, but several participants struggled with understanding how to use the timing feature, with participants resorting to trying to track peek pain instances, rather than spreading their measurements out across the day. One participant suggested incorporating a separate tutorial feature, with a video on how to time the application to ensure this didn't become a barrier for adolescents' use.

> P8: "Most of the girls would know how to (time the application). … The boys wouldn't have a clue what to do … maybe only one or two. … Many of them don't even know how to tell the time."

In relation to the prompting feature, several participants stated the importance of ensuring that prompts were polite and could be dismissed or postponed. This was due to several participants describing how their decision to track their pain was context-dependent, with participants describing several instances where they would not be able or willing to interrupt their engagement with activities (e.g. during school hours, during sports, or with friends). One participant exemplified how the self-tracking prompts could be experienced as intrusive if they interrupted participating in valued activities.

> P3: "Well … she (case vignette) is having a good time there. She is preoccupied with playing sports. She can't be bothered to stop, go and say 'oh I just need to track my knee pain'. She can do that afterwards if she wants to."

Feedback on treatment videos. From participants who viewed the video with exercises for alleviating knee pain, several described how their decision was nested in the expectation, that complying with the suggested exercises would either ease the pain, help them to gradually build up strength in the knee, and because this was seen as a more desirable alternative to withdrawing from sports or valued activities. Still, the exercises had to be easy to follow and descrete, so the adolescents would not stand out when performing the exercises in public.

> P11: "Because it would be weird. Firstly, if you are attending practice and people see you while you are making this type of exercises, where you are lying on the ground, they might think that you're odd … even though you're not, because you have knee pain. If you don't want to let your coach or teammates know about it (the knee pain)."

In relation to the second and third videos with suggestions for "pacing" or "taking brakes" about half of the participants stated that they would choose not to view these videos, since they didn't see the relevance behind the suggestions. Contrarily, several of the participants who viewed videos one and two had positive experiences with pacing and taking brakes, and wanted to learn more about distributing their resources throughout the day. Still, the first half of participants viewed pacing or taking brakes as a last resort effort, and highlighted how the video message should be rephrased if they were to follow the advice.

> D7: "Maybe in the same way, but with more details so it's easier to understand. But also, how it's unnecessary to push yourself to the limit during some random practice session, because it's just practice. I mean, there is no reason to give it everything, even though you might want to. Then it's better that you give a little bit extra in the weekends or during matches."

Video four, which focused on telling others about the knee pain was selected by the majority of participants. This was due to most participants having experienced how it was difficult to tell others about their knee pain. Several participants described how learning to articulate their knee pain could help alleviate negative emotions, and make it easier to gain the support, comfort, and understanding from others. Secondly, participants proposed that learning how to articulate their knee pain verbally, could improve their ability to express their pain in a way that their coaches would understand and take seriously.

Theme 2: Contextual barriers

The adolescent participants identified several contextual factors during the think-aloud tests, which resulted in ambivalence and influenced their performance with the application.

Parental inclusion. The question of parental inclusion was highlighted as a source of ambivalence for the participants. While the majority of adolescents described how they would ask parents for help if they encountered difficulties with installing or using the app, participants would generally prefer to solve the issues on their own, and how this was related to wanting to be independent.

> P3: "No, I think more it's a question of having can-do-will-do-it-myself attitude. That I have to show myself that I can do it on my own, and if that doesn't work out, you have to ask (your parents) afterwards."

While several of the adolescents contemplated how allowing parents to view their data could help parents understand their challenges and provide support, this was also associated with several concerns. One major concern raised by several participants, was parents becoming overprotective or worried from viewing their data entries, with some adolescents describing how they would rate their pain lower if their parents were watching. Another concern was privacy and avoiding that parents would see notifications and messages that weren't meant from them.

> P12: "But then if her mother decided to come up and help her (the case) with getting the app up and running … Frederikke (case) wouldn't want that, because what if a message popped up from Carl from her parallel grade … it could contain some information that she (case) didn't want her mother to see."

One solution proposed was having a feature where adolescents could grant temporary access to their data through a QR code.

> D4: "Yes. Maybe you could build it in a way, where you could log on and like … if the daughter has the app then it could be like. My mother could login (via her device) and see my data if I push this button, or you could download a QR code or something. Then you could scan it and enter and see the data."

Hiding the knee pain. A common theme during the interventions was how the adolescents would sometimes decide not to disclose certain aspects regarding their knee pain when engaging with their coaches, parents, or the GP. While most participants had engaged in this behavior, the adolescents described several motivations for this, including fear of being excluded from participating in sports or valued activities, or that their parents would become overprotective if they knew the extent of their pain. Another reason for not disclosing their knee pain was adolescents not wanting to be a burden for their parents or their team, embarrassment, or avoiding being branded by their peers.

> P1: "She can either choose to track her knee pain now, or she can skip this because she thinks that it is embarrassing to do it during school hours. Especially if she hasn't told anyone they might think 'oh does she has a knee injury … then I don't want to be on the same team as her. If she suddenly has a handball match … just for fun … but maybe some of her mates takes things too seriously and will end up thinking … oh, no, no I don't want to do this'."

Furthermore, several participants described how they would transfer this behavior to the application, leading them to underreport their knee pain within the application if they knew that their parents were monitoring them. Finally, several of the adolescents described how they would quickly lose motivation for using the app, if this had negative consequences for their participation in sports.

> D3: "I think I would have entered something different into the application (if others were to see it). Mom … close your ears … I think I would enter something else into the application if I knew my mother could keep track on how my knee pain was progressing. Then I would probably tune down my registrations. If my pain was an eight, I would probably register it at a six."

Theme 3: Suggestions for new features

The adolescents articulated several visions for developing the prototype during the think-aloud interventions, including core features, information flows, and content that could improve the application design.

Technical features. The adolescents articulated several suggestions for how to improve the application design, to accommodate their experienced needs and challenges with managing their knee pain. Several participants suggested adjusting the application information flow, by incorporating an algorithm to ensure that the videos with management advice were delivered based on pain presentations while encouraging adolescents to pace and gradually scale up their activity levels.

> D2: "Well … If you have had a really bad pain in the knee. Then you could take it easier, by have the app suggesting the videos on how to pace and load manage. Or if your knee has been doing better, you could reach a point where you could exercise a little bit more. Maybe it would help because you could gradually be to move it higher and higher up. Until a point where you don't really have pain and you can play sports every day."

Another suggestion related to adolescents learning to use the application, with several participants suggesting incorporating a button with adolescents could press, to get an explanation of how to use a specific core feature. This feature could be incorporated as a supplement to the introduction video, to accommodate those adolescents who just wanted to get started with the application.

> P9: "But also so you could figure out what it (the core feature) is … If you add emojis to them and you don't know what it (a feature) means, you can click on a question mark or something, and it will explain it to you."

Finally, one participant suggested incorporating a reminder feature, to help adolescents to remember to be mindful of their knee pain and doing exercises.

Suggestions for video features. On the content side, participants articulated several visions for improving the education videos to accommodate their self-management needs. While several participants chose to watch the video with advice on how to discuss the knee pain, several participants suggested expanding this with a second video on how saying no, was not a sign of weakness and how having knee pain was okay.

> P3: "I haven't really had any problems with this (saying no) … but I know that there probably is a lot out there, which may struggle with this, because they don't want to appear weak or appear as someone who whines or complains just to complain."

While one participant suggested having a video with suggestions on how to keep in shape with knee pain, several others suggested incorporating a video to teach the adolescents how to find their limit with the pain, and how to prepare for important matches or activities, which could be useful for teaching adolescents to maintain their balance with their knee pain. Finally, one participant suggested how following the rehabilitation of other adolescents with knee pain through a series of video journals, could provide adolescent users insights into what to expect during their own rehabilitation journey.

> P2: "Well … because it would allow you to follow how other people are doing (with their knee pain). This way you'll be able to learn something from them, while it will be entertaining to watch … if you can say so … entertaining

> in a good way. You'll be able to learn something (about knee pain) while being entertained."

Summary and design principles. The analysis uncovered several insights into adolescents with knee pains' perception and interpretation of mHealth information, while identifying several latent and contextual usability barriers which may influenced adolescents' motivation or ability to sustain application use. The insights were summarized into 12 design principles for adjusting mHealth concepts (core features, functionalities, and information flows) towards supporting adherence and self-management of knee pain in everyday use-situations.

1. *Design the application to contain several use-strategies simultaneously.* This includes striking a balance between accommodating users who wants to take a completionism approach, while incorporating a quick-use option for the user who just wants to get started with the application.
2. *Design for familiarity, and gently pushing adolescents to explore new management behaviors.* Adolescents used prior experiences with management when selecting which mHealth core-features to use. Providing adolescents with similar but new suggestions for managing or alleviating knee pain, could help adolescents to acquire new management strategies.
3. *Design for cognitive support, while being mindful of adolescent's cognitive capabilities.* Using mHealth features like education videos, self-tracking features, and data visualizations could help adolescents to recall, examine, and adjust pain beliefs and management decisions. Adolescents should be able to use these features on demand, without having to time, plan, or break down management behaviors.
4. *Tutorials should be stepwise and focus on using individual core-features.* Tutorials should be delivered in a stepwise fashion throughout the app and include short videos with tangible information on how to use individual core-features. Adolescents should have on-demand access to all tutorial videos.
5. *Goal setting should be optional and promote ownership and self-reflection.* A goal-setting feature should be designed to strike a balance between helping adolescents to articulate challenges and personal goals, and building ownership by allowing users to (re) define their own success criteria. The design should consider how failing to meet recovery goals can lead to negative emotions in adolescents.
6. *Patient education videos should be short and accessible for on-demand exploration.* Themes should be recognizable to adolescents, address their lived management challenges (e.g. understanding knee pain and finding the limit), and provide tangible management advice (e.g. exercises and how to articulate knee pain) to reduce uncertainty and give hope. Patient cases were beneficial for enhancing recognition.
7. *Self-tracking prompts should be polite* yet designed to encourage self-reflection on the relationships between momentary pain and behavioral choices. Self-tracking features should use visual scales (e.g. Wong Barker scale) and qualitative ecological momentary assessment to swiftly capture pain and activities. Prompts should be polite and easily postponed or dismissed to avoid contextual breaches.
8. *Data feedback should include big- and small data loops.* Data visualizations should be designed to support adolescents in exploring how different activities influenced short-term developments in knee pain, to identify pain thresholds, and to guide behavioral change. Self-tracked data should be aggregated to allow adolescents to gain a long overview of the progression of their knee pain, which can be shared with patients or GPs.
9. *Feedback should include tangible suggestions for alleviating knee pain*, based on adolescents' self-reported data. Suggestions may include exercises, instructions on pacing, load management tips, warm-up exercises, and guides for talking to peers, coaches, or parents and be delivered to encourage adolescents to explore and develop management skills.
10. *Design for just-in-time delivery of interventions, without requiring the timing of interventions.* Contrary to adolescents' beliefs, several struggled with breaking down management behaviors and timing the intervention. Consider incorporating an easily accessible on/off feature, to limit adolescents' decision-making when timing the intervention.
11. *Design for parental collaboration, but protect adolescents' need for privacy and autonomy.* Adolescents described how parents could help them understand content, solve technical issues, and perform exercises. Contrarily, giving parents access meant risking adverse reactions or revealing private information. Consider including a feature where adolescents can give partial access to data to parents or GP devices.
12. *Design for supporting articulation, without disclosing adolescents' knee pain.* Learning to put their knee pain into words and saying "no" was challenging but important for adolescents' self-management. Still, certain situations may cause adolescents to feel obliged to hide their knee pain or avoid using the application. Consider incorporating videos with "assertive training" and an easily applied silent feature to avoid involuntary disclosure of knee pain.

Discussion

Principal results

The reception of the low-fidelity prototype was positive, with participants expressing an interest in trying it at home. However, our analysis identified several latent usability barriers and facilitators, which may influence participants' motivation or ability to sustain application use. Participants approached individual core-features from the perspective of perceived utility, perception of ability (technical and self-management), and whether adhering to interventions would disrupt competing or valued activities. This aligns with Chan et al.'s[54] observations on how adolescents' motivation for using mHealth was determined by internal and external factors. A key insight was how adolescents adapted different use styles; with some focusing on completionism, while others skipped over features, they deemed redundant. Thus, future apps should accommodate different user profiles from installation and onwards. The think-aloud tests uncovered how participants were able to use the goalsetting, self-tracking, and data-visualization features to capture, identify, and reflect on relationships between activities and knee pain developments, and how personalization of goals, and the ability to track knee pain developments were major facilitators of sustained use. Contrarily, timing interventions, breaking down self-management into measurable sub-activities, and participants favoring education or behavioral change features that aligned with their existing pain beliefs, were identified as latent barriers that inhibited adolescents from experiencing the full benefits of use. Participants envisioned how incorporating patient cases, reminder prompts, and using algorithms to tailor pain relief interventions could enhance the design's persuasive aspects. Finally, contextual factors like competing activities and the desire for privacy and autonomy from parents caused ambivalence and acted as barriers to use. The findings provide us a lateral insight into the potential interaction- and contextual-based barriers present in the use-situation, and how different mHealth core-features could be applied to balance the user interactions to promote self-management of knee pain and sustained use. From this, we present 12 design principles that mHealth researchers can use as a starting point for adjusting current/future mHealth designs to address latent user- and contextual barriers, before transitioning into clinical trials and implementation. Still, additional user-testing with functional mHealth prototypes is needed to develop these principles further and understand how said barriers and facilitators manifest and influence adolescents' reception and integration of mHealth information in everyday situations.

Comparison to previous research

User-centered studies have identified mHealth features and functionalities, which hold the potential to support adolescents' self-management of musculoskeletal conditions and facilitate collaborative care.[22,24,55,56] Still these findings seem to reflect what Papanek[57] describes as the "designers share" of adolescent's lived challenges, for example, managing pain, with little reflection given to adolescent's ability or willingness to adhere to mHealth interventions in everyday situations. Our findings become relevant for bridging what Hunter et al.[26] defines as the research-to-practice gap, when developing mHealth for adolescents with chronic conditions, by identifying latent barriers and facilitators for sustained adherence prior to implementation. Systematic reviews and user studies highlight how features supporting connectivity, access to education materials, goalsetting, self-monitoring and tracking behaviors, sharing experiences, and leveraging social media support can encourage behavioral change in adolescents with musculoskeletal conditions.[22–24,55,56] Our findings expanded upon this notion, by illustrating how adolescents' decisions to engage with core-features were motivated by internal and external factors, as illustrated by Chan et al.[54] Internal factors included whether adolescents envisioned using a core feature enhanced their ability to understand, articulate and exert control of their pain during flair-ups,[58] whereas external factors were predominantly barriers and included competing activities, maintaining privacy, and avoiding causing parents distress.[59] Our think-aloud tests reaffirmed findings from previous studies describing how adolescents were able to understand digital health information[60,61] and relate self-tracked information back to their own experiences with managing musculoskeletal pain.[34] Yet, participants' reliance on preconceived management beliefs when selecting core features, conflicted with qualitative studies highlighting the importance of exploration to identify pain thresholds, maladapting beliefs, and progress adolescents' management of knee pain.[39,62] Understanding how to strike a balance between designing core features that are recognizable, and gradually challenge adolescents' pain beliefs, without causing contextual breaches becomes important to ensure the sustainability of future mHealth designs.

Facilitators for behavioral change

Our think-aloud tests identified mHealth core features with the potential to act as facilitators for behavioral change in adolescents. Heron and Smyth[61] have documented how children down to age 7 successfully used ecological momentary assessments to capture symptoms. Our testing confirmed how adolescents with knee pain viewed the ability to track their knee pain and review tracked data as highly useful, as documented by Lalloo et al.[34] in youth with chronic pain. Our user tests demonstrated how participants were able to read, draw inferences from, and self-reflect on natural developments and behavioral choices related to fluctuations in their knee pain. While this indicated that the self-tracking and data visualization features presented within the prototype could support the self-reflection and construction of knowledge, which facilitates behavioral change,[63] understanding how the data is presented in a way that is actionable, supports an ongoing exploration and flexible negotiation of management tasks between consultations is important and should be explored in future studies.[64] In terms of education materials, Selhorst et al.[65] documented how psychologically informed videos reduced maladaptive beliefs and increased management ability in adolescents with knee pain. Still, our interventions suggested expanding the video features to support adolescents in gaining an understanding of their knee pain, adhering to exercises, and managing their pain by providing them with instructions that can be modeled, which could enhance the app's persuasive elements further. Finally, mHealth studies highlight how personalization and tailoring of interventions were experienced as motivating while promoting ownership and continual use in adolescents with musculoskeletal pain.[66] Our findings corroborated this, as participants described how personalization features like defining goals, adding pictures, timing features, and selecting interventions facilitated sustained use. Still, as our participants adapted different use styles early on, future mHealth designs should explore which use styles exist in adolescents with knee pain and how to integrate these during installation and general application use.

Manifest and latent barriers to use. Our analysis identified several barriers that were either hidden or visible, and inhibited adolescents' ability to benefit and motivation for sustaining their use of the application. A key insight was how adolescents struggled with completing features related to setting timer prompts and breaking down management activities into measurable actions, indicating that adolescents' cognitive capabilities became an obstacle form engaging with these features.[67,68] This also plausibly explains why these barriers were latent, as adolescents would not be able to identify these prior to engaging with related core-features. Contrarily, the manifest barriers were related to the contextual and social aspects of application use, and described as more disruptive, as they caused ambivalence and led adolescents to adapt a use style that aimed at camouflaging the knee pain to maintain performance in valued activities, or avoid alarming parents. Qualitative studies highlighted how competing activities, voluntary and mandatory alike, could lead adolescents to forget or purposely ignore their apps.[22] Our findings corroborated this, while indicating that the introduction of an mHealth app could alter the adolescent-parent dynamic as described by Tarricone et al.,[30] with participants envisioning this leading to non-desirable outcomes like worry, meddling, and overprotective behaviors from parents. Thus, future applications should focus on protecting adolescents' privacy to ensure continual use of the application.

Applying design principles

The insights from the think-aloud tests were summarized in 12 design principles. The identified principles should not be viewed as finite guidelines,[69] but as condensed representations of knowledge, which mHealth researchers and designers may include discretely, combined with HCI or usability principles, to identify domain-specific challenges, usability problems, and dilemmas as opportunities for improving mHealth concepts, as described by Linn et al.[70] and Perez et al.[71] A key feature of the design principles related to their contradictive nature and orientation towards identifying contradictions and formulating strategies for limiting adherence barriers emerging at a user-device-, usability-, activity- and socio-cultural layers of the overall user-expirience[72] prior to subjecting apps to testing.

From design principles to design reflection. By taking point in the premise that adolescents are not small adults,[73] principles 1 to 3 focused on adjusting mHealth features and functionalities to correspond to the identified variations in adolescents' capacities for understanding health information,[67] and how they engaged with the application. By applying principles 1 to 3, we aimed to empower future mHealth designers to reflect on how to balance including- and assertive design strategies, to open up future app designs to accumulate several user-practices, while nudging participants towards adapting more optimal use and management strategies.[74] Principles 4 to 7 focused on enhancing usability features and ensuring buy-in when using mHealth apps, by reflecting on how persuasive elements like customization, goal setting, tutorials, and using features for exploring, tailoring, and visualizing self-management efforts may contribute to sustaining adolescents adherence, as observed by Jeminiwa et al.[75] in adolescents with chronic conditions. Taking the point of how behavioral change literature highlights the importance of ensuring interventions contain the right information, delivered in time, in the right way,[20] design principles 8 to 10 were formulated to empower mHealth researchers to reflect upon, how to identify and leverage teachable moments during interventions,[76] without using timed features to prime interventions. Furthermore, principles 8 to 10 highlighted the importance of ensuring the act of self-tracking data on knee pain (principle 7), enabled participants to reflect on their pain thresholds,[39,62] while exploring how to incorporate several approaches for data aggregation to bridge the gap between providing actionable suggestions for alleviating pain, while allowing for adolescents to explore their over-time developments in their knee pain, as described by Johansen et al.[22] Finally, principles 11 and 12 related to how to balance the dilemma of protecting adolescents sense of autonomy, while empowering their ability to articulate their pain, leverage social support and engage in shared decision-making with parents and GPs. This included reflecting on who should have access to tracked data, how access should be given, and how to empower adolescents with knee pain to seek parental and GP support without risking self-disclosure and loss of privacy or autonomy.[75]

Implications and future research

The analysis uncovered several design implications which may be explored in future research. Participants envisioned how future mHealth designs could include an algorithm to determine which intervention type (e.g. patient education, exercises, pacing, and load-management) would be suitable for alleviating their knee pain, based on self-tracked data. Whilst this feature could be beneficial for persuading adolescents to confront maladaptive pain beliefs, identify pain thresholds, and integrate new self-management strategies,[63] further research is needed to establish optimal intervention times,[46] and failsafe mechanisms to avoid leading adolescents into harm. Adolescents' self-management does not occur in a vacuum.[77] The introduction of mHealth apps could alter the premise for adolescents, parents, and GPs' interaction by introducing a sematic with established behavioral targets, vocabulary, and proxies for self-management, while allowing adolescents' management decisions to be subject to parental and GP scrutiny. Understanding how to balance parents' and GPs' needs for insights, while protecting adolescents' needs for privacy and autonomy becomes quintessential to ensure the sustainability of future designs.

User-centered methods with patient co-design have historically been highlighted as the gold standard for integrating adolescents' and parents' needs into mHealth designs.[27] Still a recent study from Bagge-Petersen et al.[31] identified how user-centered processes are prone to several biases, which may be transported into mHealth designs. As our study alluded to how some barriers were latent and only emerged during use, this places increased importance on identifying said use challenges when transitioning from design to implementation.[31] Qualitative studies with adults with chronic musculoskeletal pain have documented how self-management barriers and facilitators are interlinked on a spectrum[78] and guided how patients responded to management challenges.[79] Based on this, we developed our twelve design principles for adjusting mHealth designs to empower adolescents to navigate emerging barriers and facilitators in their efforts to maintain their balance with their knee pain in their personal ecologies.[22]

Thus, the natural next step should involve user tests with functional, high-fidelity prototypes in everyday settings, to explore the latent, contextual, and social practices emerging from adolescents using apps to self-manage their knee pain via qualitative methods, to develop our design principles and models of implementation. This step is important as it holds the potential for uncovering new use processes and identifying relevant measurements for assessing efficacy,[80] prior to moving to full-scale testing in clinical trials.

Limitations

Several limitations were identified in this study. The study reached saturation at 12 participants, which aligns with Faulkner's[81] observations on how 10 to 15 participants will identify 80% to 90% of usability issues. Still, this means some issues may have gone unnoticed during the think-aloud tests. The design of the low-fidelity prototype was nested in findings from three studies exploring adolescents' experiences with self-managing knee pain conducted by Rathleff et al.[9] and Johansen et al.[22,39] and insights from adult clinicians. Thus, the prototype became a manifestation of how we (authors and experts) envisioned an mHealth app for adolescents with knee pain should look and operate.[32] This approach made our think-aloud tests vulnerable to biases by repurposing clinician-designed solutions for youths.[31] To alleviate these vulnerabilities, we incorporated user-scenarios and used open-ended questions, to ensure adolescents were given a voice during our usability tests. Still, as the low-fidelity prototype was used to prime adolescents' reflections during interventions,[32] we deem this issue a minor one. Another possible limitation relates to how we used a self-designed Redcap questionnaire to support our inclusion, to gather preliminary clinical characteristics, contact information, and consent to contact participants. While the questionnaire was non-validated, the fact that the data collected was only used for inclusion purposes, and how the data on clinical characteristics included in the analysis was collected by the researcher (SKJ) during the think-aloud interventions, we deemed this would not directly influence our findings. The decision to conduct the think-aloud tests digitally, imposed several constraints on the test situation. This included limiting the interviewer's ability to identify non-verbal cues,[82] and restricting adolescents' ability to touch, feel, and engage with the low-fidelity prototype features.[45] To compensate, special attention was given to having adolescents provide stepwise explanations on how they envisioned engaging with the prototype's features, but this remains a limitation. As adolescents were given the option of having a parent present during the think-aloud tests to make them feel safe, this led to several instances of parental interruptions. This was handled by interviewers. but constitutes a limitation as it was difficult to ascertain precisely whether parents' unsolicited opinions influenced the adolescents.

As the tests involved adolescents recalling experiences with knee pain, and envisioning how the prototype would influence participants' management decisions, our think-aloud testing was vulnerable to recall, saliency, and desirability bias.[83] Furthermore, while two researchers were involved in translating the contents of themes and quotes from Danish into English during the formation of the narrative for the results section, no native English speakers were involved in this process, meaning that we cannot guarantee that some insights may have been lost in translation. When combined, these factors may impede the direct transferability of the insights uncovered in this study to future design concepts, and findings should be viewed as indicative at best.

Conclusion

Our think-aloud tests identified how adolescents approached mHealth core features based on perceived utility or whether they believed these would enhance their management capabilities. Features related to supporting adolescents in asserting control of their knee pain like goalsetting, self-tracking, and data visualizations facilitated sustained use. Our analysis uncovered two subsets of use barriers, with one being classified as latent, as these related to adolescents' cognitive capabilities and social dimensions and were difficult to identify during user-centered processes. We identified twelve design principles for integrating the identified barriers and facilitators into future mHealth designs to support self-management and sustain adherence in everyday contexts. Still, additional user tests with functional prototypes are needed to better understand how said barriers and facilitators manifest and how to leverage them to enhance the sustainability of future mHealth designs for youths with knee pain.

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References

1. Rathleff MS, Roos EM, Olesen JL, et al. High prevalence of daily and multi-site pain – a cross-sectional population-based study among 3000 Danish adolescents. *BMC Pediatr* 2013; 13: 191–201. DOI: 10.1186/1471-2431-13-191.
2. Holden S, Kasza J, Winters M, et al. Prognostic factors for adolescent knee pain: an individual participant data meta-analysis of 1281 patients. *Pain* 2021; 162: 1597–1607. DOI: 10.1097/j.pain.0000000000002184.
3. Jensen MB. Muskel-og skelet systemet. In: Hunskår S (ed) *Almen Medicin*. 1st ed. Copenhagen, Denmark: Munksgaard, 2014, pp.351–426.
4. Rathleff MS, Rathleff CR, Olesen JL, et al. Is knee pain during adolescence a self-limiting condition?: Prognosis of patellofemoral pain and other types of knee pain. *Am J Sports Med* 2016; 44: 1165–1171. DOI: 10.1177/0363546515622456.
5. Rathleff MS, Holden S, Straszek CL, et al. Five-year prognosis and impact of adolescent knee pain: a prospective population-based cohort study of 504 adolescents in Denmark. *BMJ Open* 2019; 9: e024113. DOI: 10.1136/bmjopen-2018-024113.
6. de Rezende LFM, Rodrigues Lopes M, Rey-López JP, et al. Sedentary behavior and health outcomes: an overview of systematic reviews. *PLoS One* 2014; 9: e105620. DOI: 10.1371/journal.pone.0105620.
7. von Bonsdorff MB and Rantanen T. Progression of functional limitations in relation to physical activity: a life course approach. *Eur Rev Aging Phys Act* 2011; 8: 30. DOI: 10.1007/s11556-010-0070-9.

8. Hart HF, Barton CJ, Khan KM, et al. Is body mass index associated with patellofemoral pain and patellofemoral osteoarthritis? A systematic review and meta-regression and analysis. *Br J Sports Med* 2017; 51: 781–790. DOI: 10.1136/bjsports-2016-096768.
9. Rathleff MS, Graven-Nielsen T, Hölmich P, et al. Activity modification and load management of adolescents with patellofemoral pain: a prospective intervention study including 151 adolescents. *Am J Sports Med* 2019; 47: 1629–1737. DOI: 10.1177/0363546519843915.
10. Barton CJ and Rathleff MS. 'Managing My Patellofemoral Pain': the creation of an education leaflet for patients. *BMJ Open Sport Exercise Med* 2016; 2: e000086. DOI: 10.1136/bmjsem-2015-000086.
11. Rathleff MS, Roos EM, Olesen JL, et al. Exercise during school hours when added to patient education improves outcome for 2 years in adolescent patellofemoral pain: a cluster randomised trial. *Br J Sports Med* 2015; 49: 406–412. DOI: 10.1136/bjsports-2014-093929.
12. Varshney U. Mobile health: four emerging themes of research. *Decis Support Syst* 2014; 49: 406–412. DOI: 10.1016/j.dss.2014.06.001.
13. Demiris G, Afrin LB, Speedie S, et al. Patient-centered applications: use of information technology to promote disease management and wellness. A white paper by the AMIA knowledge in motion working group. *J Am Med Inform Assoc* 2008; 15: 8–13. DOI: 10.1197/jamia.M2492.
14. Messner E, Probst T, O'Rourke T, et al. mHealth applications: potentials, limitations, current quality and future directions. In: Baumeister H and Montag C (eds) *Digital phenotyping and mobile sensing*. 1st ed., Vol. 1. Cham, Switzerland: Springer, 2019, pp.235–248.
15. Low JK and Manias E. Use of technology-based tools to support adolescents and young adults with chronic disease: systematic review and meta-analysis. *JMIR Mhealth Uhealth* 2019; 7: e12042. DOI: 10.2196/12042.
16. Badawy SM, Barrera L, Sinno MG, et al. Text messaging and mobile phone apps as interventions to improve adherence in adolescents with chronic health conditions: a systematic review. *JMIR Mhealth Uhealth* 2017; 5: e66. DOI: 10.2196/mhealth.7798.
17. Lau N, Waldbaum S, Parigoris R, et al. eHealth and mHealth psychosocial interventions for youths with chronic illnesses: systematic review. *JMIR Pediatrics and Parenting* 2020; 3: e22329. DOI: 10.2196/22329.
18. Hamine S, Gerth-Guyette E, Faulx D, et al. Impact of mHealth chronic disease management on treatment adherence and patient outcomes: a systematic review. *J Med Internet Res* 2015; 17: e52. DOI: 10.2196/jmir.3951.
19. Fedele DA, Cushing CC, Fritz A, et al. Mobile health interventions for improving health outcomes in youth: a meta-analysis. *JAMA Pediatr* 2017; 171: 461–469. DOI: 10.1001/jamapediatrics.2017.0042.
20. Fogg BJ. *Persuasive technology: using computers to change what we think and do*. 1st ed. San Fransisco, California, USA: Morgan Kaufmann Publishers, 2002, p.192.
21. Klasnja P and Pratt W. Healthcare in the pocket: mapping the space of mobile-phone health interventions. *J Biomed Inform* 2012; 45: 184–198. DOI: 10.1016/j.jbi.2011.08.017.
22. Johansen SK, Kanstrup AM, Haseli K, et al. Exploring user visions for modeling mHealth apps toward supporting patient-parent-clinician collaboration and shared decision-making when treating adolescent knee pain in general practice: workshop study. *JMIR Human Factors* 2023; 10: e44462. DOI: 10.2196/44462.
23. Slater H, Campbell JM, Stinson JN, et al. End user and implementer experiences of mHealth technologies for noncommunicable chronic disease management in young adults: systematic review. *J Med Internet Res* 2017; 19: e406. DOI: 10.2196/jmir.8888.
24. Slater H, Jordan JE, Chua J, et al. Young people's experiences of persistent musculoskeletal pain, needs, gaps and perceptions about the role of digital technologies to support their co-care: a qualitative study. *BMJ Open* 2016; 6: e014007. DOI: 10.1136/bmjopen-2016-014007.
25. Slater H, Stinson JN, Jordan JE, et al. Evaluation of digital technologies tailored to support young people's self-management of musculoskeletal pain: mixed methods study. *J Med Internet Res* 2020; 22: e18315. DOI: 10.2196/18315.
26. Hunter JF, Kain ZN and Fortier MA. Pain relief in the palm of your hand: harnessing mobile health to manage pediatric pain. *Paediatr Anaesth* 2019; 29: 120–124. DOI: 10.1111/pan.13547.
27. McCurdie T, Taneva S, Casselman M, et al. mHealth consumer apps: the case for user-centered design. *Biomed Instrum Technol* 2012; 46: 49–56. DOI: 10.2345/0899-8205-46.s2.49.
28. Schnall R, Rojas M, Bakken S, et al. A user-centered model for designing consumer mobile health (mHealth) applications (apps). *J Biomed Inform* 2016; 60: 243–251. DOI: 10.1016/j.jbi.2016.02.002.
29. Cornet VP, Toscos T, Bolchini D, et al. Untold stories in user-centered design of mobile health: practical challenges and strategies learned from the design and evaluation of an app for older adults with heart failure. *JMIR Mhealth Uhealth* 2020; 8: e17703. DOI: 10.2196/17703.
30. Tarricone R, Petracca F, Ciani O, et al. Distinguishing features in the assessment of mHealth apps. *Expert Rev Pharmacoecon Outcomes Res* 2021; 21: 521–526. DOI: 10.1080/14737167.2021.1891883.
31. Bagge-Petersen CM, Langstrup H, Larsen JE, et al. Critical user-configurations in mHealth design: how mHealth-app design practices come to bias design against chronically ill children and young people as mHealth users. *Digit Health* 2022; 8: 1–16. DOI: 10.1177/20552076221109531.
32. Lim Y, Stolterman E and Tenenberg J. The anatomy of prototypes: prototypes as filters, prototypes as manifestations of design ideas. *ACM Trans Comput Hum Interact (TOCHI)* 2008; 15: 1–27. DOI: 10.1145/1375761.1375762.
33. Sanders E. From user-centered to participatory design approaches. In: Frascara J (ed) *Design and the social sciences: Making connections*. London, England: Taylor & Francis, 2002, pp.1–9.
34. Lalloo C, Hundert A, Harris L, et al. Capturing daily disease experiences of adolescents with chronic pain: mHealth-mediated symptom tracking. *JMIR Mhealth Uhealth* 2019; 7: e11838. DOI: 10.2196/11838.
35. Glasemann M, Kanstrup AM and Ryberg T. Design and exploration of a mobile game scenario in a diabetic youth

camp. *Proceedings of the IADIS international conference Mobile Learning 2010,* Porto, Portogal, 19–21 March 2010; 1: 132–140. DOI: 9789728924997.

36. Ejersbo LR, Engelhardt R, Frølunde L, et al. Balancing Product Design and Theoretical Insights. In: Kelly AE, Lesh R and Beak JY (eds) *The handbook of design research in mathematics, science and technology education*. 1st ed. London: Routledge, 2008, pp.11–21.
37. Jaspers MWM, Steen T, Cvd B, et al. The think aloud method: a guide to user interface design. *Int J Med Inf* 2004; 73: 781–795. DOI: 10.1016/j.ijmedinf.2004.08.003.
38. Nielsen J, Clemmensen T and Yssing C. Getting access to what goes on in people's heads? – Reflections on the think-aloud technique. *Nordichi 2002. Proceedings of the second nordic conference on human-computer interaction*, 19–23 October 2002; 1: 101–110. DOI: 10.1145/572020.572033
39. Johansen SK, Holden S, Pourbordbari N, et al. PAINSTORIES–exploring the temporal developments in the challenges, barriers, and self-management needs of adolescents with longstanding knee pain: a qualitative, retrospective interview study with young adults experiencing knee pain since adolescence. *J Pain* 2022; 23: 577–549. DOI: 10.1016/j.jpain.2021.10.006.
40. Mohr DC, Schueller SM, Montague E, et al. The behavioral intervention technology model: an integrated conceptual and technological framework for eHealth and mHealth interventions. *J Med Internet Res* 2014; 16: e3077. https://www.jmir.org/2014/6/e146
41. Braun V and Clarke V. Using thematic analysis in psychology. *Qual Res Psychol* 2006; 3: 77–101. DOI: 10.1191/1478088706qp063oa.
42. Voigt P and Von dem Bussche A. *The EU general data protection regulation (GDPR). A Practical Guide*. 1st ed. Cham, Switzerland: Springer International Publishing, 2017, pp.141–185.
43. Malterud K, Siersma VD and Guassora AD. Sample size in qualitative interview studies: guided by information power. *Qual Health Res* 2016; 40: 795–805. DOI: 10.1177/1049732315617444.
44. Burbach B, Barnason S and Thompson SA. Using "think aloud" to capture clinical reasoning during patient simulation. *Int J Nurs Educ Scholarsh* 2015; 12: 1–7. DOI: 10.1515/ijnes-2014-0044.
45. Rettig M. Prototyping for tiny fingers. *Communications of the ACM* 1994; 37: 21–27. DOI: 10.1145/175276.175288.
46. Fogg BJ. A behavior model for persuasive design. *Proceedings of the 4th international conference on persuasive technology anonymous*, New York, April 26, 2009; 1: 1–7. DOI: 10.1145/1541948.1541999.
47. Oinas-Kukkonen H. A foundation for the study of behavior change support systems. *Pers Ubiquitous Comput* 2013; 17: 1223–1235. DOI: 10.1007/s00779-012-0591-5.
48. Gordon VS and Bieman JM. Rapid prototyping: lessons learned. *IEEE Software* 1995; 12: 85–98. DOI: 10.1109/52.363162.
49. Kanstrup AM and Bertelsen P. *User innovation management: A handbook*. 1st ed. Aalborg, Denmark: Aalborg University Press, 2011, p.45.
50. Lundgrén-Laine H and Salanterä S. Think-aloud technique and protocol analysis in clinical decision-making research. *Qual Health Res* 2010; 20: 565–575. DOI: 10.1177/1049732309354278.
51. Shiffman S, Stone AA and Hufford MR. Ecological momentary assessment. *Annu Rev Clin Psychol* 2008; 4: 1–32. DOI: 10.1146/annurev.clinpsy.3.022806.091415.
52. Kitchin R and Lauriault TP. Small data in the era of big data. *GeoJournal* 2015; 80: 463–475. DOI: 10.1007/s10708-014-9601-7.
53. Kvale S and Brinkmann S. *Interviews: Learning the craft of qualitative research interviewing*. 2nd ed. California: Sage, 2009, pp.97–312.
54. Chan A, Kow R and Cheng JK. Adolescents' perceptions on smartphone applications (apps) for health management. *J Mob Technol Med* 2017; 6: 47–55. DOI: 10.7309/jmtm.6.2.6.
55. Stinson JN, Lalloo C, Harris L, et al. iCanCope with Pain™: user-centred design of a web-and mobile-based self-management program for youth with chronic pain based on identified health care needs. *Pain Res Manag* 2014; 19: 257–265. DOI: 10.1155/2014/935278.
56. Stinson JN, Toomey PC, Stevens BJ, et al. Asking the experts: exploring the self-management needs of adolescents with arthritis. *Arthritis Care Res (Hoboken)* 2014; 1: 72. DOI: 10.1002/art.23244.
57. Papanek V and Lazarus EL. *Design for the Real World: Human Ecology and Social Change*. 2nd ed. Chicago: Academy Chicago Publishers, 2005, p.88.
58. Khanom S, McDonagh JE, Briggs M, et al. Characterizing pain flares in adolescent inflammatory and non-inflammatory musculoskeletal disorders: a qualitative study using an interpretative phenomenological approach. *Eur J Pain* 2020; 24: 1785–1796. DOI: 10.1002/ejp.1626.
59. Leonard BJ, Garwick A and Adwan JZ. Adolescents' perceptions of parental roles and involvement in diabetes management. *J Pediatr Nurs* 2005; 20: 405–414. DOI: 10.1016/j.pedn.2005.03.010.
60. de Oliveira Silva D, Pazzinatto MF, Rathleff MS, et al. Patient education for patellofemoral pain: a systematic review. *J Orth Sports Phys Therapy* 2020; 50: 388–396. DOI: 10.2519/jospt.2020.9400.
61. Heron KE and Smyth JM. Ecological momentary interventions: incorporating mobile technology into psychosocial and health behaviour treatments. *Br J Health Psychol* 2010; 42: 1087–1107. DOI: 10.1348/135910709X466063.
62. Glaviano NR, Holden S, Bazett-Jones DM, et al. Living well (or not) with patellofemoral pain: a qualitative study. *Phys Ther Sport* 2022; 56: 1–7. DOI: 10.1016/j.ptsp.2022.05.011.
63. Rivera-Pelayo V, Zacharias V, Müller L, et al. Applying quantified self-approaches to support reflective learning. *Proceedings of the 2nd international conference on learning analytics and knowledge*, New York, April 29, 2012; 1: 111–114. DOI: 10.1145/2330601.2330631.
64. Mamykina L, Mynatt ED and Kaufman DR. Investigating health management practices of individuals with diabetes. *Proceedings of the SIGCHI conference on human factors in computing systems,* Montréal, Québec, Canada, 2006: 927–936. ACM. DOI: 10.1145/1124772.1124910.
65. Selhorst M, Hoehn J, Degenhart T, et al. Psychologically-informed video reduces maladaptive beliefs in adolescents with patellofemoral pain. *Phys Ther Sport* 2020; 41: 23–28. DOI: 10.1016/j.ptsp.2019.10.009.

66. Radovic A, McCarty CA, Katzman K, et al. Adolescents' perspectives on using technology for health: qualitative study. *JMIR Pediatr Parent* 2018; 1: e2. DOI: 10.2196/pediatrics.8677.
67. Brown SL, Teufel JA and Birch DA. Early adolescents perceptions of health and health literacy. *The Journal of School Health* 2007; 77: 7–15. DOI: 10.1111/j.1746-1561.2007.00156.x.
68. Sawyer SM, Afifi RA, Bearinger LH, et al. Adolescence: a foundation for future health. *Lancet* 2012; 379: 1630–1640. DOI: 10.1016/S0140-6736(12)60072-5.
69. Fu KK, Yang MC and Wood KL. Design principles: the foundation of design. *ASME 2015 international design engineering technical conferences and computers and information in engineering conference,* Boston, 2016, January 19; 1: 11–21. American Society of Mechanical Engineers Digital Collection. DOI: 10.1115/DETC2015-46157.
70. Linn MC, Gerard L, Matuk C, et al. Science education: from separation to integration. *Rev Res Educ* 2016; 40: 529–587. DOI: 10.3102/0091732X16680788.
71. Perez A, Linsey J, Tsenn J, et al. Identifying product scaling principles: a step towards enhancing biomimetic design. *In: ASME international mechanical engineering congress and exposition*, Huston Texas, 2012, August; 1(1): 789–798. DOI: 10.1115/IMECE2011-63975. American Society of Mechanical Engineers Digital Collection.
72. Spinuzzi C. *Tracing genres through organizations: a sociocultural approach to information design*. Cambridge, Massachusetts, USA: Mit Press, 2003, p.30.
73. Sawyer SM and Aroni RA Self-management in adolescents with chronic illness. What does it mean and how can it be achieved?. *Med. J. Aust.* 2005; 183: 405–409. DOI: 10.1016/S0140-6736(12)60072-5.
74. Newell A. Inclusive design or assistive technology. In: Clarkson J, Keates S, Coleman R, et al. (eds) *Inclusive design: Design for the whole population*. 1st ed. London, UK: Springer, 2003, pp.172–181. DOI: 10.1007/978-1-4471-0001-0_11.
75. Jeminiwa RN, Hohmann NS and Fox BI. Developing a theoretical framework for evaluating the quality of mHealth apps for adolescent users: a systematic review. *J Pediatr Pharmacol Ther* 2019; 24: 254–269. DOI: 10.5863/1551-6776-24.4.254.
76. Li LC, Lineker S, Cibere J, et al. Capitalizing on the teachable moment: osteoarthritis physical activity and exercise net for improving physical activity in early knee osteoarthritis. *JMIR Res Protoc* 2013; 2: e17. DOI: 10.2196/resprot.2553.
77. Modi AC, Pai AL, Hommel KA, et al. Pediatric self-management: a framework for research, practice, and policy. *Pediatrics* 2012; 129: 473–485. DOI: 10.1542/peds.2011-1635.
78. Christensen MN, Johansen SK, Sloth SR, et al. Exploring self-management barriers and facilitators experience by people with chronic musculoskeletal pain – a qualitative study. *medRxiv Preprint* 2023: 1–20. DOI: 10.1101/2023.01.18.23284708.
79. Barclay-Goddard R, King J, Dubouloz C, et al. Building on transformative learning and response shift theory to investigate health-related quality of life changes over time in individuals with chronic health conditions and disability. *Arch Phys Med Rehabil* 2012; 93: 214–220. DOI: 10.1016/j.apmr.2011.09.010.
80. Tomlinson M, Rotheram-Borus MJ, Swartz L, et al. Scaling up mHealth: where is the evidence? *PLoS Med* 2013; 10: e1001382. DOI: 10.1371/journal.pmed.1001382.
81. Faulkner L. Beyond the five-user assumption: benefits of increased sample sizes in usability testing. *Behav Res Methods Instrum Comput* 2003; 35: 379–383. DOI: 10.3758/BF03195514.
82. Thunberg S and Arnell L. Pioneering the use of technologies in qualitative research—a research review of the use of digital interviews. *Int J Soc Res Methodol* 2021; 26: 757–768. DOI: 10.1080/13645579.2021.1935565.
83. Gendreau M, Hufford MR and Stone AA. Measuring clinical pain in chronic widespread pain: selected methodological issues. *Best Pract Res Clin Rheumatol* 2003; 14: 575–592. DOI: 10.1016/S1521-6942(03)00031-7.
84. Garra G, Singer AJ, Taira BR, et al. Validation of the Wong-Baker FACES Pain Rating Scale in pediatric emergency department patients. *Acad Emerg Med* 2010; 17: 50–54. DOI: 10.1111/j.1553-2712.2009.00620.x.