

A pain recording system based on mobile health technology for cancer patients in a home setting: A user-centred design

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Abstract— Pain is one of the most common symptoms experienced by patients with cancer at all stages of the disease, many of whom experience poor pain control. Findings from earlier studies suggest that mobile health (mHealth) approaches may have value in the field of pain management. Currently, development is at an early stage and the needs and preferences of users are not yet well understood. The aim of this study is to report the design and development of a mHealth-based pain recording system for this population to support effective pain management. A user-centred design (UCD) approach with multiple stages, including usability testing, was adopted for achieving this and ensure the system's clinical utility. Usability testing was conducted on high-fidelity clickable prototypes developed for the system with eleven representative system users. The system was well-received, and all participants found it well-aligned with their needs and easy to use, with only a few addressable usability issues reported. Captured usability metrics indicated that the under-development system has the potential to be effective, efficient and satisfying for users.

Keywords—mHealth, User-Centred Design, System, Pain Management, Cancer, Reporting, self-Management, Data Collection

I. INTRODUCTION

Pain is one of the most common symptoms experienced by patients with cancer at all stages of the disease [1], many of whom experience poor pain control [2]. While there is evidence of modest improvements in pain management between 2008 and 2014, there is also evidence that one-third of cancer patients who experience pain are under-treated [3, 4]. Poor pain assessment is considered a significant barrier to achieving effective and sufficient pain management [5, 6]; therefore, routine and systematic pain assessment, including documenting a detailed pain history and

medication efficacy, is emphasised by pain management guidelines [6, 7]. Measuring and documenting pain every 4 hours for inpatients, including oncologic surgery patients, for 5 weeks showed improvement in both pain assessment (from 42% to 71%) and pain management (from 59% to 97%) [8]. Routine monitoring of pain in patients with cancer is not currently possible when patients are in the community settings, such as in their home. With limited visits to health professionals in the hospital setting for either follow up appointments or uncontrolled symptoms, there is scope to explore approaches to routine, remote monitoring of pain in patients with cancer.

Endorsing pain self-management in this patient population is an important step that could reduce unexpected hospital visits. Research evidence has shown that pain self-management interventions for cancer patients are effective for better overall pain management [9-13]. One meta-analysis that quantified the benefit of educational interventions for patients showed a decrease in average pain intensity by 1 point on a 0–10 rating scale [10]. Mobile apps are a rapidly emerging mode for delivering health behaviour change and self-management interventions for a variety of conditions including cancer [14]; however, many apps lack theoretical and evidence foundations and patients and health professionals involvement in development stages [14-16].

Pain has a complex nature [17] and can originate for different reasons in cancer patients, causing variations in sensations and descriptions [18]. Collecting pain data is also challenging, especially in a community setting. The majority published work present pain measurement during end-of-life or during active treatment [1]. During these stages, patients are usually in hospital or have frequent clinical contact, facilitating pain data collection. Achieving consistent and frequent recording of pain scores is a well-

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known challenge within pain trials in at-home settings due to low compliance with the completion of pain measures and diaries on paper [19, 20].

To address the mentioned issues at three levels (i.e. patient, healthcare professional [HCP], and researcher), we aimed to design and develop a pain recording system utilising mHealth technology, which is an innovative and timely method for monitoring and promoting cancer pain management in the home setting. Notably, it has shown its effectiveness in various chronic health conditions [21-24], but few mHealth interventions in the field of pain management in cancer patients have been attempted [25-29]. Development of this approach is still at a very early stage and the needs and preferences of users are not well understood. To the best of our knowledge, no previous study has explored the use of a mobile app with the population of adult cancer patient in home settings to both support pain self-management and facilitate routine reporting of pain data to HCPs and researchers, which our system is designed to accomplish.

II. METHODS

The user-centred design (UCD) approach was adopted to design and develop the system through multiple stages as shown in Fig. 1. UCD is an iterative and incremental process that involves users in the early phases of design by implementing design representation and terminology that the user can understand. It utilises prototypes that should be designed and evaluated in a real-life context with the help of real users (HCPs, patients and researchers) [30] and has the potential to shape the system in agreement with their expectations to ensure usability, user satisfaction and adherence [30, 31]. Indeed, poor usability is the main obstacle to health information technology adoption, which can interrupt workflow and cause delays and errors [32].

A. User personas of the system

Based on our existing knowledge of the context and potential users, three user personas were developed to model the needs of users. Personas are detailed description of imaginary people representing target users of a product. They are constructed out of well-understood, highly specified data about real people [33, 34]. The development of user personas aims to focus the design effort effectively towards users' needs and build appealing features [33, 34]. Further refinements of the personas were based on input from professionals in palliative care and research (Table 1).

B. Modelling the system

The system was designed to have three main components: a mobile app for the patients' use, a web-based application (portal) for the HCPs' and researchers' use, and a database hosted on a server connecting the two as the

system architecture illustrates in Fig. 2. The intended app was meant to be used on a regular basis by patients to log pain details, for one or more of the following functionalities: (1) as a stand-alone application to support pain self-management assisting patients to monitor pain and reflect on what could help to ease pain or to avoid triggering pain, (2) as a means to communicate patient self-reported pain scores and attempted pain control strategies to HCPs to support pain assessment and management, (3) as a means to report pain scores to researchers when participating in pain intervention studies, especially longitudinal studies. After patients have submitted data via the app, HCPs and researchers can access and view the patient's data via the system portal. Fig. 3 shows the general data flow diagram for the system. The initial functional requirements were identified and modelled using a use case diagram, as shown in Fig. 4.

TABLE I. THE SYSTEM'S USER PERSONAS

User role	Description
Patient	She is 50 years old and was diagnosed with breast cancer three months ago. She experiences pain due to recent surgery as a part of her treatment and needs to learn how to control her pain. She also needs to assess her pain on a regular basis and keep a log of it to communicate with her doctor at follow-up appointments. She avoids using opioids to minimise negative side effects and instead tries different nonpharmacological pain management strategies. She has a basic knowledge of smart devices, including how to use social media apps and how to read eBooks on an iPad.
HCP ^a	He is an oncologist working in the palliative care unit at a large teaching tertiary hospital. He is 55 years old. Patients with chronic pain are transferred to him to assess their pain, prescribe medications and advise them on appropriate treatments and pain management strategies. He needs to see the pain history of patients to achieve better pain assessment. He uses a computer most of the time as a part of his job to access patients' records and so on.
Researcher	He is a 40-year-old research fellow in the Academic Unit of Palliative Care, at a leading research University. He undertakes research that is aimed at improving pain management for cancer patients. He needs to follow-up with participants in the Randomised Controlled Trials (RCTs) that are undertaken to assess the effectiveness of pain management interventions. He needs to see patients' histories for pain both with and without applying an intervention. He is quite confident in computer use and an excellent internet user.

^a HCP: healthcare professional

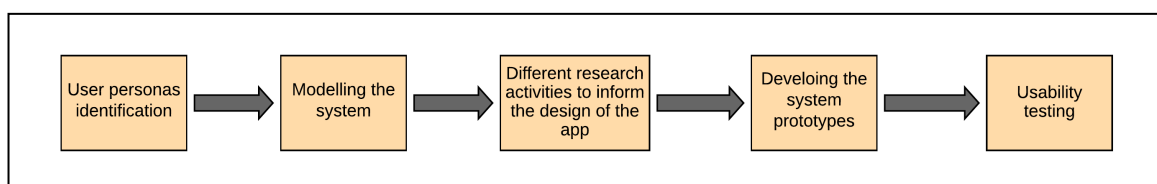


Fig. 1. The system design stages.

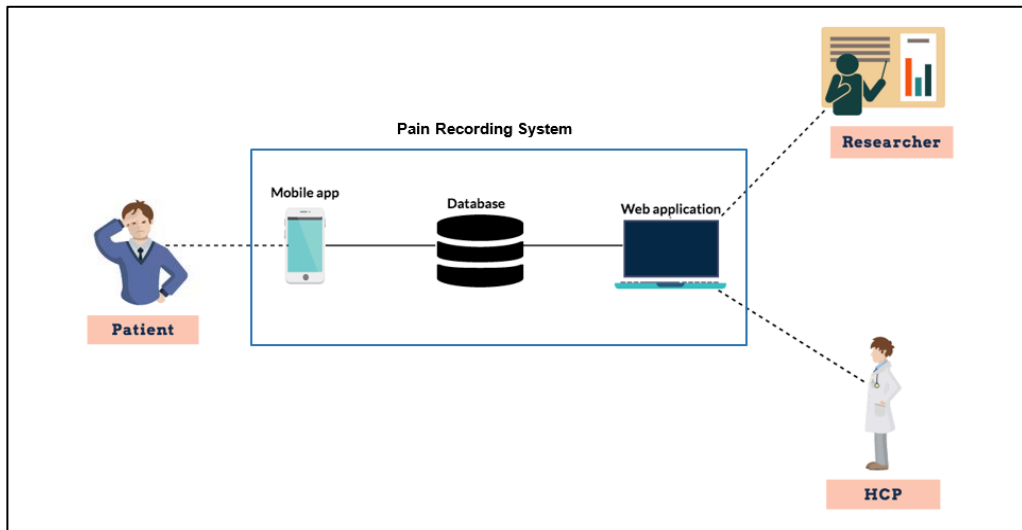


Fig. 2. The architecture of the pain recording system.

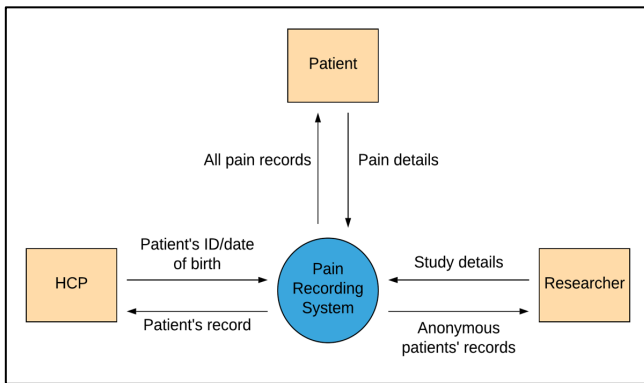


Fig. 3. Data flow diagram for the pain recording system.

HCP: healthcare professional

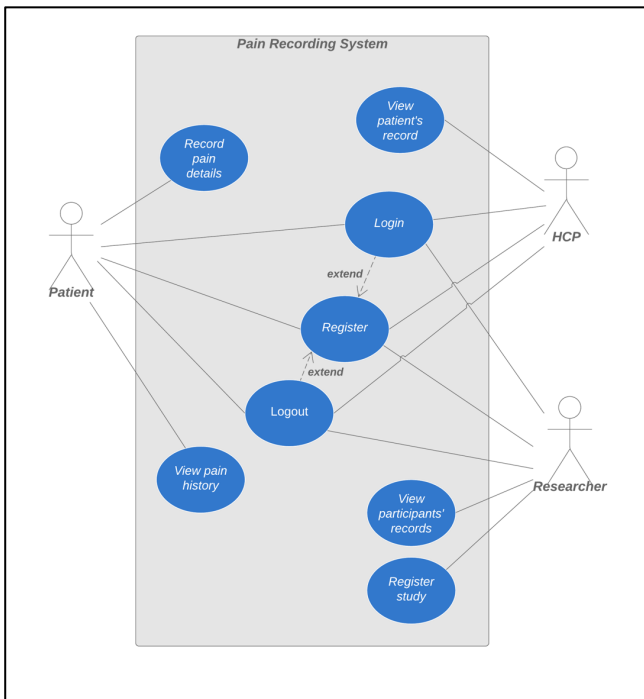


Fig. 4. Use case diagram for the pain recording system.

C. Designing and developing the system's prototypes

Sketch software was used in combination with the InVision platform to design and build high-fidelity clickable prototypes for the app and the portal [35, 36]. The prototypes were developed by A.A. The design was based on the initial investigations mentioned above and different research activities that mainly informed the app's design. This included conducting a systematic review to identify the best validated pain measure to be incorporated into the design of the app [37], applying the Behaviour Change Wheel framework [38] to specify the active contents of the app to support pain self-management [39] and conducting a small-scale review on pain apps that are available in app stores to evaluate their quality and inform the initial workflow of the app [40]. Figs. 5 and 6 show some screenshots of the app and the portal prototypes, respectively.

D. Usability testing

Usability testing, which is an essential process of UCD [41, 42], involves three important components: representative participants, representative tasks, and representative environments. At least one observer is required to monitor participants' interactions with the evaluated software or website [43]. Representative potential participants for the study were sampled purposively and invited to take part via emails. Patients were recruited from the Yorkshire Cancer Community Organisation, a support and advice network for people affected by cancer in the Yorkshire and Humber area, U.K., (<https://yorkshirecancercommunity.co.uk/>) and from patient and public involvement groups affiliated with the School of Medicine at the University of Leeds. Professionals were approached and recruited from the University of Leeds and St James's University Hospital in Leeds. The study was approved by the Ethics Committee of the Faculty of Medicine and Health at the University of Leeds (ref: MREC17-059). Recruitment was halted when data saturation was reached. Specific tasks were identified based on the core system functionalities and the role of potential

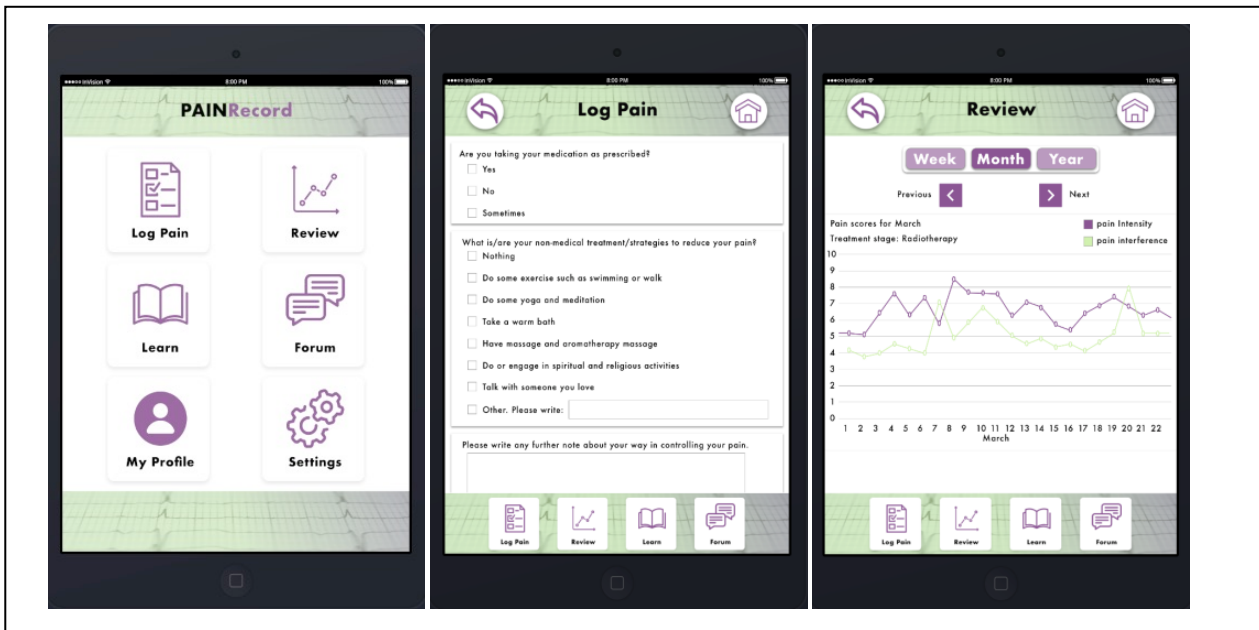


Fig. 5. Screenshots of the app.

users. The tasks were created by A.A. and discussed with D.W. The app and portal prototypes were installed on an iPad and a laptop, which were used by the participants during the test.

1) Usability testing procedure

Participants were interviewed and asked to run the usability test individually after they gave their consent and provided demographic data. They were provided with a brief introduction to the test's purpose and process and given a minimal explanation about the Pain Recording system. A demo¹ of the think aloud protocol was displayed to all participants before starting to ensure full understanding of the process. Participants were asked to

think aloud while using the prototype and to carry out the group of tasks that was appropriate to their role. The tasks were written on separate papers and handed to each participant one at a time. The professional group was given the chance to randomly explore the app prototype before testing the portal prototype to grasp the entire system.

The usability testing sessions were conducted by one researcher (A.A.) in a quiet room at either the University of Leeds or at a HCP's place of work. All audio and touch-screen interactions were recorded for the 60–90 minute duration of the session. These recordings supported the field notes for the think aloud tests. The researcher observed participants' interactions with the system prototypes and documented certain usability metrics, including task completion times and rates, and numbers of user errors. Errors are defined as incidences of unintended actions or omissions [44]. After completion of each task, the participants were asked to rate the task's difficulty using the Single Ease Question (SEQ), a validated 7-point rating scale where 7 is 'very easy' [45]. After finishing the test, the participants were asked to complete the System Usability Scale (SUS) [46]. The usability testing metrics and scales that were used in the study were selected based on recommendations by field experts [44, 47, 48]. Finally, participants were involved in a brief semi-structured interview to capture any requirements and thoughts that had not been articulated during the test.

We combined both quantitative and qualitative methods in our usability testing, which is not common practice in the early stages of developing health apps and systems. Most reported usability studies for such interventions have focused on qualitative usability testing approaches [27, 49–51]. In this study, the qualitative methods were used to identify usability problems and to capture recommendations for improvement; in addition, some usability metrics were collected to support the findings and allow for numerical tracking of design usability for improvement in future testing. This is called the 'quantitative formative approach', which is emphasised by usability testing experts who state

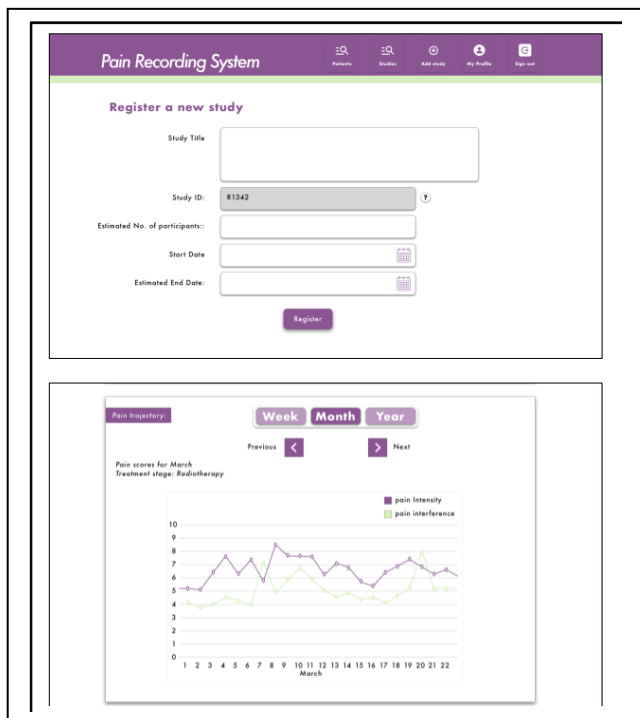


Fig. 6. Screenshots of the portal.

¹ Provided by the Nielsen Norman Group (NN/g) on: <https://www.nngroup.com/articles/thinking-aloud-demo-video/>.

that it statistically supports testers' claims, even with a very small sample size [44].

2) Data analysis

Data analysis began from the first usability testing session to recognise when data saturation was reached. That was the point at which no data were produced that had not already been categorized [27]. Descriptive statistics were used to summarise the demographics and the usability metric data. For calculating the task completion rate, codes for successful and unsuccessful completion were used as one and zero, respectively. To ease the analysis of user errors, a code system was used as follows: one for at least one error committed and zero for no error committed for each task, following [44]'s suggestions. Each usability metric on a task level, including completion rate, number of user errors, SEQ, and time on task, was calculated to obtain the average for each participant separately. Then, the aggregate mean and 95% confidence interval (CI) were calculated for each participant group (i.e. patients and professionals) to draw a conclusion about a metric. The mean and 95% CI were calculated for the SUS scores for each participant group. The transcripts of the semi-structured interviews along with the field notes, were analysed using the thematic content analysis approach [52]. The transcripts were reviewed, and a coding system was created to reflect perceptions, recommendations and usability issues in the system prototypes. The data was coded, and the codes were then grouped into meaningful categories. Finally, similar categories were organised and grouped to represent overarching themes. The research team discussed how the system could be improved to reflect the identified themes (i.e. requirements and usability issues) wherever feasible.

III. RESULTS

Data saturation was reached after testing and interviewing eleven participants as follows: five cancer patients and six palliative care professionals (three of whom had a combined clinical and academic role and three who had a predominantly research role). Table 2 summarises the participant demographics. The captured usability testing metrics suggest participants found the system usable, as outlined in Table 3. Furthermore, task completion rates were 95% and 100% for patient and professional groups respectively.

TABLE II. PARTICIPANT DEMOGRAPHICS

Patients	n = 5
Range of age in years (n, %)	41-65 (2, 40%) >65 (3, 60%)
Gender (n, %)	Female (4, 80%) Male (1, 20%)
Using smart devices (yes %)	100%
Level of confidence in using smart devices (%)	Confident (60%) Very confident (40%)
Tried any pain app before (Yes %)	0%
Using health related apps (Yes %)	60%
Professionals	n = 6
Range of age in years (n, %)	18-40 (6, 100%)
Gender (n, %)	Female (4, 67%)

	Male (2, 33%)
Role (n, %)	Both HCP and researcher (3, 50%) Researcher (3, 50%)
Years of work experience (n, %)	>3 (3, 50%) 1-3 (2, 33%) <1 (1, 17%)
Level of confidence in using computer based applications (%)	Confident (50%) Very confident (50%)
Using health related apps (Yes %)	67%

TABLE III. USABILITY METRICS

Usability metrics	In testing Patients	In testing Professionals
Mean completion rate, (95% CI ^a)	95% (90% , 100%)	100% (100% , 100%)
Mean number of user errors, (95% CI ^a)	0.13 (0.05 , 0.20)	0.04 (0.00 , 0.13)
Mean SEQ, (95% CI ^a)	6 (5 , 7)	7 (6 , 7)
Mean Task time mm:ss, (95% CI ^a)	01:07 (00:57 , 01:21)	00:33 (00:19 , 00:47)
Mean SUS (95% CI ^a)	90 (83 , 97)	85 (76 , 92)

^aBased on 1000 bootstrap samples

Three overarching themes were identified from the qualitative analysis: appreciation of the system; clarifying certain design aspects and functionalities; and enhancing the quality and usage of captured clinical data. Each theme covered several categories, as elaborated below, along with the identified feasible reflection in the design of the functioning system.

Theme 1: Appreciation of the system

- Intuitive layout and navigation: Simplicity of the design was well-liked by participants. All participants found the app and the portal easy to use and understand. There were minimal problems navigating between screens and finding a way to accomplish an aim. For the app prototype, patients said the following:

"I like the fact that it was very simple, the visuals are very simple and there was nothing complicated." (Patient 3)

"I like the simple way to slide out and the explanation for each part that you need to use and was very clear. I liked the whole pages' layouts and the colours used. I do not have anything that I dislike as I find it very easy to use." (Patient 4)

For the portal prototype, one of the professional group members commented the following:

"I think it was very easy and very clear; the layout is very clear, and all the processes are well linked to each other." (Professional 5, Thoracic Surgeon and clinical research fellow)

- Effectiveness of the system's main functions: The participants recognised the usefulness of reporting and reviewing the history of pain for effective pain management.

"We tend to ask patients just to measure outcomes like pain in one quick snapshot of time, and that does not capture their whole experience, so measurements like this

are really helpful and allow you to kind of look over time and look in more detail at how different outcomes fluctuate.” (Professional 2, Cancer Associate Professor)

“If I had it, I would use it. I think it would have helped me if I had kept a diary of how I was every day . . . so having an app like this would be very useful because I used to use a diary, which does not allow much space. With this, you can put in a lot of information about how you are, and I think it’s very good.” (Patient 5)

“It is useful to see the graph and to track things . . . to see what happens when asking a patient to use new medicine because, if I have this information, it is great to incorporate this with the pain scores. As a clinician, I am constantly asking patients after we started if they noticed any benefits. Sometimes, people cannot remember very well because they have been busy recently, so that would be useful from the point of view of tracking things.” (Professional 6, Academic clinical fellow and Palliative medicine)

In addition, the researchers appreciated the ease of collecting pain data through the app and found it a novel approach, with one researcher stating the following:

“For me, as a researcher, I can see that would help me capture pain data easily from patients . . . I could log a couple of different studies on there, and I could make the app work for two or three different studies . . . I think it has really good function and is something not seen before. Normally, you would see a web app designed for a specific study, and it is only used for that study. I like the fact that this is generic, simple and easy to use.” (Professional 3, Cancer research academic fellow)

Theme 2: Clarifying design aspects and functionalities

- Explaining the aim of the app and how it is useful: The participants indicated that it might be useful to provide either some explanation or a video guide for the potential benefits of recording pain using the app for the long term. They thought that people might not see how useful this format is at the beginning of using the app, which raises the risk of early discontinuance.

“I think it probably needs to be shown how it could be helpful. Otherwise, they will not risk inputting their stuff. . . you can have a video guide or a tutorial to show them how to use it.” (Professional 6, Academic clinical fellow and Palliative medicine)

This recommendation was already considered and addressed in the app prototype by two subsections of the ‘Settings’ section: ‘About PainRecord’ and ‘User guide video’. The subsections however were not active in the prototype. This confirmed the need to implement these sections to provide some explanation about the app and the potential benefits of using it as well as to showcase the functionality of the app via a video guide.

- Explaining the reason for having two lines in the pain graph: The participants expected to see one line in the pain graph; there are two lines: one for severity and one for

interference of pain based on the Brief Pain Inventory measure [53].

“Make it clear why there are two lines in the graph because people expect to see one line for pain.” (Patient 3)

This issue was addressed in the ‘Log pain’ section by using some design touches to explain that there are two sub-measures for pain. For example, we matched the colours that were used in the questions for each of the sections to the lines in the graph.

- Data protection and use policy: The participants expressed concern about where the data were stored and who had access to them. They requested clarification of the policy of data use in the app.

“My only other thing is about the GDPR (the General Data Protection Regulation) stuff. I just . . . having a little something somewhere just for people to understand how to log in to this and how your pain diaries are being kept . . . who is doing what whilst it’s there?” (Patient 3)

This concern is appreciated and will be considered when the system is adopted and implemented. It is not feasible however to provide a valid data policy during the developmental stage. The data collection for the development stage is in-line with the GDPR but a data policy would be required for active clinical use to the functional system.

- Simplification of wording and terminologies: The participants noted some terminologies and wording in the app that seemed complicated for the general public.

“I think that’s a bit of a complicated sentence. I think you could restructure that sentence to make it a little easier to understand.” (Patient 5)

All the issues with wording that were mentioned by the participants were noted and simplified. The simplified forms of the wording were based on participants’ suggestions and/or discussions by the research team.

- The forum’s usefulness: The participants questioned the use of an external forum because the app provides a link to the Cancer Research UK online forum. They suggested the provision of explanations about the benefits that they might obtain from using it.

“I think I dislike the forum being linked to me. I think it is unnecessary. It did not tell me what I may gain from it. Maybe an explanation of speaking to other people in similar situations could be helpful and would motivate people to sign up. Again, you have another sign-in page, different logins and different passwords, so I am just not sure that would work for many people.” (Patient 1)

This recommendation was addressed by adding an induction screen before linking to the external forum to highlight the potential benefit from sharing thoughts with others in the same situations and to provide hints for a better user experience. There might have been better impressions of the forum if it had been developed internally. This is currently out of the system’s scope and resources.

Theme 3: Enhancing the quality and usage of captured clinical data

- Capturing used pain-control strategies: Because the app requires users to log pain data once a day, including pain level and strategies used to control their pain, the participants were not sure whether users would be able to recognise the connection between what they do during the day and their pain levels.

“I am not sure how the patients or people always know the strategies that they have taken necessarily . . . they might be quite habitual. . . But I think capturing an overall pattern might be helpful if you’re capturing the different types of things that people are doing. So, if everyone is doing exercise or something, but doing something like taking a warm bath is better, that might be helpful to know.” (Professional 2, Cancer Associate Professor)

“You might find that people will get confused with that . . . people who are religious might pray every day, but whether they feel that this reduces their pain every time, I do not know . . . it doesn’t work in sessions in accurate way. Maybe it could be the same with talking with someone you love—it might be helpful, but it doesn’t really reduce your pain . . . so, I don’t know. It depends on how each person looks at these questions differently.” (Professional 4, Cancer research academic fellow)

In responding to this, the app aims to help patients recognise their practices in relation to their pain levels and to provide hints to trying something different to ease pain. The effectiveness of this and whether patients can recognise the connection will be confirmed by the long-term trial.

- Using notifications: The participants suggested sending a notification to patients when their pain level shows a consistent or increasing layout or when they fail to log pain details for a few days.

“Is it possible to say your pain is consistent? The layout should have your GP or consultant review your medication, so if one has pain every day at a level of 10, the app will alert him to see his consultant.” (Patient 4)

“You want to set times at which your patients are prompted to put in their scores because, if you give the patients the app to use and they barely use it, then you are not collecting enough data as a researcher.” (Professional 6, Academic clinical fellow and Palliative medicine)

These suggestions confirmed the importance of providing users with feedback regarding their interaction with the app. This had already been documented in the requirements list of the app, but it was not feasible to integrate it into the prototype’s design.

- Capturing reliable and updated clinical data: The participants, especially the professionals, raised the concern that patients might struggle to specify the treatment stage or might not provide reliable data for it.

“People get confused between stage and grade . . . I do not think you will necessarily get reliable data for the stage.” (Professional 2, Cancer Associate Professor)

“I think it (treatment stages data) would be valuable, but it would depend on how and what options are provided in the dropdown menu. There are different ways in which you can interpret different stages. In my research, I did not ask this, but I checked for it anyway in the medical records because, for example, some people will say that their diseases are stable, but they are still receiving chemotherapy or immunotherapy. Whether that is considered stable or under treatment depends on how you define it.” (Professional 4, Cancer research academic fellow)

The professionals also indicated that it is quite challenging to find a practical method for capturing accurate and precise data about current prescribed pain medication that could work with patients.

“I think that, potentially, a dropdown box describing different types of medicine could become very big because . . . are you going to summarise for them, for example, opioids . . . the patient may not know what an opioid is.” (Professional 6, Academic clinical fellow and Palliative medicine)

“Patients find it easier to select from an alphabetical list of medications rather than classifying them . . . some do not grasp that they are in the morphine category of drugs, and some do not want to think that they are on this drug!” (Professional 1, Clinical Oncology Consultant and Cancer research academic fellow)

“If you just have a whole list of different medications, that could be quite burdensome for the patient, particularly if they’re not necessarily words that we come across in everyday life . . . if you ask people in an open text box to fill in what they are taking, they would spell it wrong, and they wouldn’t remember. It is really difficult . . . I don’t have a standard way of collecting that information (i.e. medication).” (Professional 2, Cancer Associate Professor)

They suggested integrating a method to instruct patients to review and update their recorded treatment stage and medications.

“I would say the only thing that I dislike about it is some of the information that the patients are being asked to collect and find. I think there has to be a way of ensuring that it’s up-to-date information and there are good prompts and sufficient patient information in order for them to accurately write down what treatment they are receiving or what pain they are having.” (Professional 6, Academic clinical fellow and Palliative medicine)

These issues were addressed by using two dropdown menus with a start typing functionality to refine the list. One menu presents a list of general cancer treatment stages, and the second lists standard categories of pain medications. The list of treatments was specified based on the feedback of HCPs. The medication categories were identified from [54]. To encourage patients to regularly review the data that were provided when they registered, it is displayed at the top of the pain graph with a link for updating the information.

- Providing summaries of the collected data: The professionals asked to see summaries of patients' demographic data and how often they logged pain data.

"You are probably want something to say how often they are completing it so that there is compliance with the instructions of the app." (Professional 6, Academic clinical fellow and Palliative medicine)

"It would be good to have various simple summaries of the data that patients have entered . . . so, number of patients currently active, number of patients completed . . . maybe a pie chart of males and females and a quick graph of the different age ranges. You know, the kind of demographic data that the patient entered on the app." (Professional 3, Cancer research academic fellow)

These recommendations were added to the requirements list in the 'under development' portal.

IV. DISCUSSION

This article reports on the design and development of an innovative mHealth-based pain recording system for adult cancer patients living in home settings. The system has the potential to serve and resolve three issues: (1) facilitating regular pain reporting and remote monitoring; (2) supporting pain self-management; and (3) facilitating the collection of pain data from this population for research purposes. There are a few systems that have been evaluated and are reported in the literature that utilise information communication technology for reporting pain in palliative care cancer patients [55]. Furthermore, despite the increase of pain apps in app stores [56], no studies have reported the use of an app to measure pain in adult cancer patients [37].

By adopting the UCD approach, we involved potential users from the early stages of development. The involvement of end users and HCPs in pain app development is minimal in existing pain apps, which potentially affects their clinical utility [56]. Usability testing sessions were conducted by employing a quantitative formative approach [44], high-fidelity clickable prototypes and eleven representative system users (Table 2). The qualitative results indicated that the system was well-received, and all participants found it easy to use. A few required changes and usability issues with the design were identified by the participants. Unlike other usability testing studies, which have employed two to three iterative cycles for testing and refining a product prototype [27, 50], we conducted one iteration. Due to the small number of changes that emerged from the sole usability testing, it was decided that there was no need for further iterations. Therefore, the changes that are required and the recommendations are being implemented into the functional system directly.

The usability metrics that were identified for the system's prototypes (see Table 3) confirmed the qualitative findings. According to the ISO, the usability of a product is specified by its effectiveness, efficiency and satisfaction [57]. The effectiveness is quantified by the task completion rates and the number of user errors [44, 48]. Both metrics' scores for the system were high and in line with the recommended figures, which are a > 78% completion rate and a < 0.66 average of user errors [44]. The same was

found for the metrics that were used to represent system satisfaction, where the average SEQ and SUS scores showed figures higher than the recommendation of > 4 points and > 68 points, respectively [44, 58]. Efficiency is usually quantified by the task time [44, 48], where the average time to complete a task in the system was only between 33 seconds and 1 minute and 7 seconds (Table 3). The recorded usability metrics for this study indicated that the current system prototype has the potential to be effective, efficient and satisfying for users. They provided a baseline for future usability testing, where system improvements in effectiveness, efficiency and satisfaction can be tracked.

We involved potential users during the early development stages of our system, and have developed a system that is usable and acceptable. There is potential for integration of this mHealth approach into the area of pain management for patients affected by cancer. Further work, however, is required to establish the viability of the approach alongside understanding suitable approaches to implementation in the context of home-based palliative care.

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