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Feel My Pain: Design and Evaluation of Painpad, a Tangible Device for Supporting Inpatient Self-Logging of Pain

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ABSTRACT

Monitoring patients' pain is a critical issue for clinical caregivers, particularly among staff responsible for providing analgesic relief. However, collecting regularly scheduled pain readings from patients can be difficult and time-consuming for clinicians. In this paper we present Painpad, a tangible device that was developed to allow patients to engage in self-logging of their pain. We report findings from two hospital-based field studies in which Painpad was deployed to a total of 78 inpatients recovering from ambulatory surgery. We find that Painpad results in improved frequency and compliance with pain logging, and that self-logged scores may be more faithful to patients' experienced pain than corresponding scores reported to nurses. We also show that older adults may prefer tangible interfaces over tablet-based alternatives for reporting their pain, and we contribute design lessons for pain logging devices intended for use in hospital settings.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Health; Mobile devices; Pain diaries; Pain logging.

INTRODUCTION

Pain logging is useful in a variety of clinical settings. For clinicians, subjective pain data can assist with optimising patient pathways following treatment [23] and in monitoring pain levels to ensure that sufficient analgesia is administered to keep patients pain-free [7]. In the long term, both practices can help to reduce the length of hospital stays. For patients, self-monitoring of pain allows individuals to develop a better understanding of their overall condition [41] and enables patients to become active contributors to their own care [13].

Figure 1. Painpad, a tangible device for inpatient self-logging of pain.

Previous research on pain logging has focused on the use of diaries that allow patients to engage in self-scoring of their experienced pain. Such diaries are intended to be used away from the clinic, as a journal which can later support discussions between patients and clinicians [24, 34]. However, in the context of monitoring patient pain during hospital stays, the standard clinical practice is for nurses to collect subjective pain data from patients [7, 8, 11]. This is typically done by either estimating each patient's pain through observation [5, 32] or by asking patients to verbally rate their pain on a scale ranging from zero to ten, with the nurse noting the provided score on a paper chart in the patient's file [7].

One problem with this practice is that it is labour intensive, placing an undesirable burden on clinical staff who may already be overloaded, and staffing levels may not allow for frequent enough log entries to achieve clinical or research goals. Another problem is that nurse-queried pain records are often incomplete [7] and can be inaccurate because patients sometimes feel inhibited about expressing their pain [12], leading to ineffective treatment [7]. These issues motivate the development of tools that can allow patients to provide their own pain ratings in the context of a hospital.

Recent efforts in HCI have focused on supporting self-logging of pain with lightweight, easy-to-use interfaces (e.g. [1]) but these studies aimed to develop tools that allow patients to self-score their pain away from the hospital. Designing for use in the hospital context brings its own technical and social challenges. In particular, there is a need to ensure that the pain logging technology in question is suitable for use with a variety of patient groups, e.g. those recovering from surgery who may have impaired mobility and dexterity [29]. Furthermore, the physical properties of the device must be designed in light of the hospital environment, minimising disruption to the recovery of patients and the day-to-day workflow of clinicians.

In this paper we present Painpad (see Figure 1), a prototype device designed to support self-logging of pain by hospital inpatients. We report findings from two field studies that establish the efficacy and usability of Painpad by collecting post-operative pain data from inpatients recovering from ambulatory surgery (total hip or knee replacement). Our first study examines user acceptance of Painpad and patients' compliance with bi-hourly logging of pain. We also explore the congruence between patients' pain scores and equivalent ratings collected by a staff nurse. Our second study compares the physical Painpad interface with two tablet-based alternatives to examine preferences among target users.

This paper extends previous HCI research on the use of mobile technologies to enable pain logging [1, 3, 39] by considering the practical and social challenges of enabling self-logging by hospital inpatients. Our specific contributions include:

- The Painpad device, a handheld tool that enables self-logging of pain in a manner that is robust and easy-to-use.

- Evidence of improved rates of compliance, frequency and accuracy of pain scoring from patients using Painpad in a hospital recovery setting.

- Insights into the preferences and needs of older adult patients for self-logging their pain.

- Lessons for the design of in-hospital pain logging devices, taking into account device visibility, customisability, ease of operation, and contextual factors that affect usability.

BACKGROUND & RELATED WORK

Characterising and Measuring Pain
Pain has been characterised as a subjective experience consisting of two dimensions: *intensity* and *disruptiveness* [1]. The former refers to the severity of perceived pain, whereas the latter refers to the way in which pain disrupts an individual's emotional, physical and social wellbeing. Like previous HCI research on pain logging [1], this paper focuses on the scoring of pain *intensity* as it is the primary concern for caregivers tasked with overseeing patient recovery in the hospital [2].

Various approaches have been taken to measuring pain intensity, whether in patients suffering from chronic health conditions or from post-operative pain. Most of these measures are self-report tools in which patients use a rating scale to characterise their pain. A wide range of scales have been developed [15], examples of which include the Pain

Intensity Numeric Rating Scale (PI-NRS) [10], the Visual Analog Scale (VAS) [36, 26, 43] and the Faces Pain Scale-Revised (FPS-R) [16]. Each of these scales provides a different way of translating a patient's pain into a numeric value; for example, the VAS asks patients to mark their pain somewhere along a 10cm line [26], whereas the FPS-R asks patients to select a facial expression that corresponds to their pain experience. These choices are then typically translated into an integer ranging between 0–10, where 0 equates to "no pain" and 10 equates to "worst possible pain" [26].

Subjective pain scales have been found to be easy to use, are appropriate for a range of conditions [26] and have been shown to provide a meaningful indication of changes in wellbeing. Farrar et al. [10] found that a reduction of approximately two points (equivalent to a 30% decrease) in PI-NRS scores represented a clinically important difference, as indicated by improvements in patients' global impression of change. More importantly, self-assessment techniques accommodate the subjective nature of the pain experience [19, 28] and allow clinicians to examine within-patient differences, i.e. how an individual's pain varies over time [38]. However, self-report techniques suffer from a number of drawbacks [26], including that results can suffer from recall bias if the scales are used retrospectively, as when a clinician asks *"how has your pain been lately?"* [38]. This need to avoid bias has led to a drive towards real-time methods for enabling self-logging of pain [1], though there has been little work exploring how such logging could be facilitated among hospital inpatients.

Supporting Self-Logging of Pain with Diaries
One of the most prevalent methods of supporting self-logging has been through pain diaries, which enable thorough documentation by asking patients to record their pain multiple times per day, and while in their natural environment [40]. Such diaries overcome the problem of recall bias by allowing patients to conduct real-time data collection. Studies have shown diary procedures to be low-effort and patients often enjoy the task of logging their pain, provided that the diary is well-designed [40].

Pain diaries were historically administered using paper-based methods, but recent years have seen an interest in electronic techniques for supporting pain logging. Electronic methods have a number of advantages over paper; in particular, electronic diaries have been shown to induce better rates of compliance, with people more likely to record their pain scores when using an electronic diary [6, 13, 18, 24, 30, 38, 40, 41]. Electronic diaries also produce lower rates of data falsification, i.e. retrospective "backfilling" of scores [6, 41] and lead to fewer errors in data collection [3]. Patients also report a preference for electronic methods due to their portability and ease of use [6, 24]. Research has shown that paper and electronic methods produce equivalent scores, meaning that collecting pain scores electronically is a reliable and clinically sound means of data collection [13, 14, 20].

Early examples of electronic pain diaries used web-based desktop interfaces [20] or personal digital assistants (PDAs) [24, 41] to collect data from patients. More recent work has looked at the potential for smartphones and tablet computers

to facilitate pain logging ([1]) and there is now a plethora of commercial apps that allow people to monitor their pain [22, 39]. Several research prototypes based on standardised scales have also been developed, with user feedback indicating positive acceptance of these applications [33]. However, most of these applications have received little or no formative evaluation in the field, with studies instead relying on preliminary user feedback and usability testing to justify their designs (e.g. [20, 21, 33]).

One exception is a recent study by Adams et al. [1], which presented two novel interfaces to support self-logging of pain via smartphones. Their first interface used an adapted version of the Sydney Animated Facial Expressions (SAFE) scale [16], which asks people to rate their pain in accordance with depictions of faces showing different expressions of pain. Their second interface adapted the Visual Analogue Scale for Pain (VAS-P), which is a standard 0–10 measurement scale. They found that both of their interfaces produced high rates of compliance and mapped well to a standardised pain assessment tool. However, their work was geared towards allowing people to score their pain while in their natural environment [37]. Our work focuses on issues that need to be taken into account when designing a pain logging device for clinical settings.

Pain Monitoring in Clinical Environments
The measurement of pain intensity is important for clinicians as information about patients' pain can support optimisation of treatment and continuity of care [4]. The standard approach for assessing pain in hospitals is for clinical staff to collect subjective pain data from patients. This can be achieved through observation, where nurses estimate pain based on their understanding of the patient's condition and current symptoms. However, multiple studies have shown this approach to be inaccurate, with nurses frequently over-estimating [27] or under-estimating [8, 11, 17] the intensity of patients' pain. An alternative method is for nurses to query patients about their pain using standardised scales [7], which can be administered verbally or by asking the patient to mark their pain on a chart [25]. Data collected with this approach is thought to be more reflective of the patient's pain experience and thus overcomes problems associated with estimation by nurses. However, studies have shown that nurses' pain logs remain incomplete and often fail to achieve desired clinical targets [9].

Based on these issues, we suggest that self-logging of pain represents an alternative and practically feasible method for collecting pain data from inpatients. Such an approach could address the problem of incomplete pain records by allowing patients to provide scores over the course of their hospital stay. Using digital technologies would not only lower the workload of clinical staff in data collection but would also allow for pain data to be automatically transmitted to a database, circumventing the need for manual entry of pain scores by staff.

The most immediate solution for permitting inpatient self-logging would appear to be a virtual pain-logging device, e.g. an app on a smartphone or tablet (c.f. [1]). Indeed, the Google Play and Apple App stores have many pain logging apps that could be co-opted for this purpose. Patients could be permitted to install an application on their own device, or could be given a pre-configured computing device for their stay in hospital. However, there are a number of issues that would temper such an approach. Notwithstanding technical and security concerns regarding patient data, there is no guarantee that commercial applications will be able to interface with hospital infrastructure and medical record systems such as those found in the UK's National Health Service. Furthermore, hospitals are busy environments with transient populations, which means device security cannot be guaranteed due to an increased risk of theft [29]. In addition, anything given to patients must be able to be sanitized to prevent patient-to-patient transmission of infection, which may be difficult with commodity smartphones and tablets. Finally, the demographics of the patients who would benefit from pain logging, such as joint replacement surgery or chronic pain patients, tend to be older, have other co-morbidities (such as arthritis which may inhibit touchscreen use [35]), and may not be familiar with smartphones or tablets.

PAINPAD DEVICE DESIGN
Following the considerations outlined above, the HCI and clinical members of our research team created a top-down requirements specification for an inpatient pain logging device. The specification required the device to:

- Be easily cleaned to fit with sanitary practices in hospitals.

- Appear to have limited pecuniary value, so as to avoid making it an attractive prospect for thieves.

- Prompt patients to log their pain at regular intervals, so as to facilitate regular and timely data collection.

- Be able to take input from a variety of inpatients, particularly older adults with limited manual dexterity.

We conducted a series of user-centered design activities [31] to develop a tool that would meet this specification. First, we engaged in direct observations of patients and held discussions with clinicians at our intended study site (Milton Keynes University Hospital, a large public hospital in the United Kingdom). The observations were not recorded but allowed the non-clinical researchers to understand the context of use and establish additional requirements, such as the need for the device to be physically robust in case it is dropped by patients. We then developed an initial conceptual design for Painpad consisting of a palm-sized, physical box-like device with a push-button keypad to enable user entry of pain scores. This was complemented by a loudspeaker and two LEDs to permit auditory and visual feedback. The design was reified into a physical prototype, which underwent four distinct iterations to refine its appearance and technical infrastructure. The first iteration was pilot tested by a specialist pain nurse, three ward nurses, and the lead researchers. This led to several refinements: improved number entry, more batteries, and an on/off switch to give nurses control over the device. Later iterations were given to 15 patients for feedback. This was done informally by clinical staff at the hospital. Comments indicated user acceptance and fed into redesigns of Painpad. Patients requested a smaller device and brighter plastic, both of which were present in our final prototype.

Figure 1 shows the final Painpad prototype. The device is comprised of six off-the-shelf components housed in a custom 3D-printed box.[1] The keypad allows patients to rate their pain on a scale of 0–10. This mirrors the standard PI-NRS [15] in which 0 = "no pain" and 10 = "worst pain imaginable". Scores entered by patients were sent via Wi-Fi to a database that could be monitored by the researchers. We built seven copies of the Painpad for use in our studies.

The final device met the initial brief by using a wipe-clean numeric pad to facilitate cleaning. The use of low-cost (yet robust) components limited the device's value and gave it the veneer of a 'prototype' rather than a high-value computing device. The prompting of pain scores is achieved through scheduled audio and visual reminders to help ensure compliance with pain logging [30, 33]. The device's size (approximately 9.5 x 6.5 x 3cm) allows for it to be held in one hand, facilitating ease of input by older adults.

STUDY ONE: IN-SITU EVALUATION OF PAINPAD

Our first study evaluates Painpad by investigating inpatients' user experience and acceptance of pain logging with the device. It further provides an investigation of compliance and frequency of self-logged pain scoring, as compared to the current clinical practice of collecting pain scores through verbal querying of patients by nurses.

Ethics and Recruitment

We deployed Painpad in collaboration with the R&D Department at Milton Keynes University Hospital. Participant recruitment was done in two phases. In the first phase we obtained approval from the R&D Department to trial versions of Painpad with patients as a method of auditing patient reported pain scores. Our institution did not require ethical approval for this phase since the hospital classified it as an auditing procedure and thus only required R&D Department approval. A clinical member of the research team identified patients from the hospital's elective orthopaedic operating list who met the following inclusion criteria: adults undergoing ambulatory surgery (e.g. hip or knee replacement) with no cognitive impairments (e.g. dementia), no medical conditions unrelated to the individual's surgery (e.g. severe neurological disorder, acute cancer, psychiatric disorder, or acute infections that may affect pain levels or ability to participate) and able to speak and understand conversational English.

A total of 35 patients volunteered for the first phase of this study. Patients were asked if they would be willing to have the Painpad next to their bed after their scheduled surgery. They were told there was no obligation to use the Painpad and that they could ask for it to be removed at any time.

For the second part of the study we sought and obtained ethical approval from our institutional research board to continue to recruit in this manner, and to administer a short questionnaire to gather feedback about Painpad. A total of 31 patients volunteered for this phase. In both phases, nurses continued to manually record pain scores from patients, as is the normal practice at the hospital.

[1] Additional technical details about our implementation of Painpad can be found at: **https://github.com/k64c86/painpad-android**

All data was stored securely. Only the clinical member of the research team had access to data that could identify patients. All other members of the research team had access to each patient's ID number, which was generated for the purposes of the research and bears no link to any other medical databases.

Participants

The data from participants in both phases was pooled since the procedure was the same (see below) and because they all were inpatients recovering in hospital following their scheduled surgery. Initial data screening led us to exclude 12 participants from subsequent analysis either because they did not provide Painpad data (due to device faults etc.) or because we did not receive nurse data about them. This left us with 54 individuals (31 first phase, 23 second phase), all of whom provided data to their Painpad and gave scores verbally to a nurse. Thirteen participants were male, 41 female. These participants' ages ranged from 32–88 (*Mean* = 64.6 years, *Median* = 64.5, *SD* = 12) with hospital stays of 1–7 days (*Mean* = 2.33 days).

Procedure

The procedure for deploying and using Painpad was the same in both phases of the study. Participants were given a consent form upon arrival at the hospital. After undergoing surgery, all participants were given a Painpad at the earliest possible convenience, and were asked to keep the device near their bed while in the recovery ward. The Painpad was programmed to prompt the participant to provide a pain rating at two-hour intervals, beginning at 8:00 and ending at 22:00. This time period was based on the waking hours of the ward in which the study took place. The bi-hourly prompting was based on the hospital's desired clinical target of obtaining a pain reading once every two hours, and was further justified by studies showing that patients are willing to provide scores at scheduled intervals throughout the day [18, 40].

Each time a rating was due, the Painpad's LED lights flashed alternating red and green (for up to 5 minutes or until a button was pressed) and the device emitted an audio notification, which lasted a few seconds. Participants pressed the key corresponding to their pain level (0–10) and the entered value was automatically timestamped and logged into our database. These values were associated with the patient's ID number. In addition to the data obtained through scheduled notifications, participants were allowed to enter additional pain scores whenever they wished. This is standard practice in the use of pain diaries (e.g. [41]) and allows for more granular pain data to be entered at the patient's discretion.

In addition to the Painpad data, nurses collected pain scores from each patient as part of their standard work practice. These scores were collected during nurses' rounds, where each patient is verbally asked to rate the severity of their current pain. The nurse then records the score on a paper chart in the patient's file with a number ranging from 0–10. The hospital's clinical target means that the nurses' scores should ideally meet a bi-hourly recording rota. However, we did not specifically instruct them to do this and thus their scores are reflective of their normal working pattern. Nurses' scores were

later transcribed into a database by a senior staff nurse and were provided to us for comparison with the Painpad data.

Participants had the opportunity to use their Painpad until they were discharged from hospital. When patients were ready to leave, those in the second part of the study were given a paper-based questionnaire about their experiences with Painpad. The questionnaire asked whether participants felt the scores they entered into Painpad were similar to those they gave to the nurse; whether Painpad was easy to use, easy to *remember* to use, and how often they made errors. Participants were also asked whether they were able to notice the notifications (beeping and flashing lights) on their Painpad. Finally, the questionnaire asked how satisfied participants were with Painpad, and how they would rate the appearance of the device. All responses to these questions were scored on 1–5 Likert-type scales. A free text field allowed participants to leave other comments and suggestions about Painpad.[2]

ANALYSIS AND RESULTS

We first consider participants' experiences and feedback about Painpad through analysis of questionnaire data. We then consider participants' compliance with bi-hourly entry of pain scores, as evidenced by the completeness of their pain logging record, and compare this to nurses' compliance. Finally we report the congruence in ratings between a sample of Painpad and nurse data to explore potential differences in pain scores obtained using the two methods.

Patient Experiences with Painpad

We received 19 fully completed usability questionnaires from participants in the second phase of the study (82% response rate). These responses indicate that painpad was received positively. Patients felt that Painpad was easy to use (*Mean*= 4.63) and that it was easy to remember to use Painpad to enter pain scores (*M*= 4.36). Sixteen participants stated that they "never" made an error when entering a value, with three estimating that they made an error "once or twice" (*M*= 4.72, where 1 = many errors and 5 = no errors). The aesthetics and appearance of Painpad were rated as "good" (*M*= 4.26) and participants were "mostly satisfied" with Painpad (*M*= 4.05).

Regarding the notifications delivered by Painpad, participants felt that the flashing LED lights were somewhat effective at drawing their attention to the device (*M*= 3.8). However, it is worth noting that some participants were polarised about this feature; 13 reported noticing the lights "most of the time", but three people noticed them "only a few times" and two "did not notice them at all".[3] The effectiveness of the audio notification was rated with an average of 2.73, equating roughly to the midpoint of the scale ("just right"). However, three participants found the bleeping "too loud or annoying" whereas three others found it "too quiet to notice". This suggests that the volume of the audio notification should be adjustable to suit the needs of different patients and ward settings.

Thirteen of the questionnaires contained a free-text response. These responses were analysed inductively in search of underlying themes [42] and specific statements that would support our evaluation of Painpad. Seven participants characterised Painpad positively, identifying it as something that *"works well and ought to be a great help in the future"* (P50), *"a very good idea"* (P52) or a *"very good way to moneter* [sic] *pain"* (P43). Participants recognised that the device would help them to keep track of fluctuating pain levels, e.g. *"I think it's useful for monitoring the pattern of pain over the day which can be changeable"* (P49), and expressed an interest in monitoring their pain over time to support reflection, e.g. *"A day-to-day chart may be helpful"* (P52).

Other responses provide insight into the challenges experienced by patients with physical or sensory impairments when using Painpad. One participant with limited manual dexterity found the device hard to use: *"I have severe arthritis in my hands so pressing button was difficult... need easy press button for arthritic people"* (P47). Another person explained that the audio notifications were not suitable for her: *"I am hard of hearing and have trouble turning my head so when Painpad was to my side I would forget it was there"* (P39).

Finally, two responses suggested that Painpad could benefit from refinement to make it more applicable to the context of a recovery ward, where multiple people are likely to be resting in close proximity. These individuals reported the audio notifications were problematic in this setting: *"The tone is rather like an annoying wake up alarm... Other patients not under* [clinician] *have a little tut when alarm goes off."* (P37). *"I think this an excellent idea, however with a few glitches! You run this till 10pm, well 9pm was an event as everybody in the ward heard it, I must say I felt little awkward. I am worried about the next one before 10pm... Maybe the option of a quiet button, just the lights maybe a set time on the hour. Maybe when the patient feels more pain just enter a number (the pain or lack of being a prompt/reminder)."* (P40).

Overall, participants' responses indicate positive experiences with Painpad, yet also point towards a need to make the device more suitable to patients' individual needs and preferences [1], as well as to the context of the hospital itself.

Frequency and Compliance with Pain Logging

We next explored patients' frequency of pain scoring and compliance with bi-hourly pain logging in comparison to equivalent nurse data. The pain scores from our 54 participants were first cleaned by inspecting the logs to remove nonsense responses, e.g. from testing and setup of Painpads (such instances were timestamped with a specific identifying number). We also eliminated duplicate values from legitimate responses, i.e. when it was apparent that a patient had entered the same value multiple times at a particular time interval. The nurse data did not require cleaning. This left us with 824 self-logged Painpad readings and 645 nurse scores. Broadly, this indicates that Painpad produced a larger quantity of pain data than the equivalent practice of gathering scores via nurses.

To check patients' compliance with pain logging, we first defined compliance as a patient having entered a pain score

	Painpad			Nurse		
	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
30-min Window Compliance	50.4%	45.8%	55.5%	30.4%	26.6%	34.2%
90-min Window Compliance	65.9%	62.01%	69.8%	38.5%	33.7%	43.2%

Table 1. Compliance rates for bi-hourly pain measurement collected through Painpad or Nurse scoring.

Window	N pairs	Correlation coefficient (r)	t value
2 minutes	20	0.28*	2.249*
5 minutes	26	0.43*	2.890**
15 minutes	57	0.56**	4.704**

Table 2. Correlation coefficients and t test outcomes between self-logged scores using Painpad and nurse queried pain scores. * indicates the test is significant at the level p< 0.05. ** indicates the test is significant at the level p< 0.01.

within a defined window of time around each of the designated two-hour intervals at which Painpad was programmed to issue notifications. Following a previous study of patient compliance with electronic diaries [41], we defined two windows of acceptability: an initial definition of ± 15 minutes and a secondary definition of ± 45 minutes. A pain score logged within each of these windows was defined as compliance. As an example, if a pain score is scheduled for 10:00a.m., a score should be entered between 9:45a.m. and 10:15a.m. to count as compliance under the ± 15 minute window. The secondary definition of ± 45 then expands this window from 9:15a.m. through to 10:45a.m.

To define maximum compliance, we set a threshold of eight possible pain readings for each day, beginning from 8:00a.m. and running until the final possible pain score, which should be entered at or around 22:00. (These times are based on the scheduled notifications of Painpad, which is itself based on the waking hours of the recovery ward in which our study took place.) Thus, for a given day, if a patient entered a pain score within the window of acceptability for 6 of the 8 possible assessments, the compliance score would be 6/8 (75%). The same procedure was adopted for analysis of the nurse's scores. In cases where windows had multiple possible scores, e.g. three Painpad readings at or around 10:00a.m., we took the reading that was closest to the scheduled notification.[4]

Table 1 shows the average compliance for bi-hourly logging of pain from Painpad and the ward nurses. Under the 30-minute window, patient compliance with self-logging using Painpad was 50.4%. This compares favourably to the nurse compliance, which was 30.4% under the same window. Using the more liberal 90-minute window, patients' compliance with bi-hourly Painpad data entry was 65.9% compared to nurses' compliance of 38.5%. These comparisons suggest that self-logging with Painpad produces a more complete account of a patient's pain, as compared to the standard approach of collecting scores through verbal reports to nurses.

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[4]The nature of hospital admission means that there were often days for which we had partial data, e.g. only three pain scores for the first day of use. Rather than ignore such days, we elected to treat them as partial days in which the compliance score is calculated based on the window to which the earliest data point is anchored. For example, if a patient's first pain score is logged at 16:10 with subsequent scores at 20:10 and 22:10, we assume the person received their Painpad from clinical staff at around 16:00 and score the day as 3/4 (75% compliance). This is important because our compliance measures are reflective of the duration of each patient's stay, rather than only reflecting occasions on which patients were known to be present on the recovery ward for an entire day. We adopted the same procedure when considering the nurse data to ensure consistency.

Congruence Between Painpad and Nurse Scores

This part of our analysis explores potential differences between pain scores reported to the nurse and to Painpad. Since pain levels vary over time, exploring this issue requires us to have pain ratings from patients and nurses that have been recorded within close proximity to one another.

Previous studies of congruence between nurse and patient pain logging use scores that are collected simultaneously, i.e. the nurse asks the patient about their pain and the patient records their own private rating [5, 8, 11]. In our study, nurses would have ideally taken readings at or around the same time Painpad notifications were delivered; however, this did not always happen due to the nurses' busy working schedule. Therefore, we compared the timestamps of patient's self-logged scores to those recorded by the nurses to identify any scores that had been taken within close proximity, and which might therefore reasonably be paired. We defined three *a priori* windows of 2, 5 and 15 minutes for matching scores as pairs. (E.g. if a pain score is given to Painpad at 8:00 a.m., a paired nurse score would need to fall between 7:58 and 8:02 to qualify for the 2 minute window.) The 2 minute window represents a short time frame in which pain levels are unlikely to have changed. The 15 minute window is based on the type of analgesic relief (a non-opioid painkiller with a 20-minute onset of action) available to patients in our study. The 5 minute window represents a point of comparison between the two.

Table 2 shows the number of paired scores that fell within each matching window, alongside the outcome of statistical comparisons between the Painpad and Nurse scores. Pearson correlations (Table 2) between the Painpad and Nurse-queried scores indicate weak to modest positive correlations between ratings. Paired t-tests were used to compare the difference in means between the Painpad scores and the Nurse's readings. The tests showed that Painpad scores were significantly different to their corresponding nurse scores within all three windows. In the 2 minute window, Painpad scores were higher (*Mean*= 4.15) than corresponding nurse scores (*M*= 2.50), t = 2.249, p < 0.05. In the 5 minute window, Painpad scores were higher (*M*= 4.69) than corresponding nurse scores (*M*= 2.96), t = 2.89, p < 0.01. In the 15 minute window, Painpad scores were higher (*M*= 4.79) than corresponding nurse scores (*M*= 2.96), t = 4.704, p < 0.01.

Further analysis of the pain scores was carried out to determine the frequency with which scores given to Painpad were higher or lower than those reported to the nurse. Based on previous analyses of congruence [5, 7], patient and nurse scores were considered to be tied if their difference was ± 1. Table 3

Window	N pairs	Lower to nurse n (%)	Higher to nurse n (%)	Equal (± 1) n (%)
2 minutes	20	10 (50%)	2 (10%)	8 (40%)
5 minutes	26	13 (50%)	3 (11.5%)	10 (38.5%)
15 minutes	57	26 (45.6%)	5 (8.8%)	26 (45.6%)

Table 3. Frequency of agreement between patients' self-logged pain scores using Painpad and nurse queried pain scores.

displays the results of this analysis for each of the three time windows. It can be seen that scores were equal between 38.5 to 45.6% of the time (fifth column), depending on the window under consideration. Columns three and four further reveal that, in cases where scores were different, patients reported their pain as lower to the nurse more frequently than they reported it as higher.

To probe participants' awareness of these differences, we looked at participants' questionnaire responses to explore whether they believed there were differences between the scores they provided to nurses and Painpad. Of the 19 responses we had available, the average score for this question was 3, equating to "about the same". Only one participant thought his scores were significantly lower to the nurse.

STUDY TWO: COMPARISON OF PHYSICAL PAINPAD AND TABLET-BASED INTERFACES

Study 1 revealed that self-logging with Painpad led to improved rates of compliance compared to equivalent nurse-queried scoring, and further indicated that patients may report their pain differently to the device than to the nurse. Importantly, the study also suggested that patients found Painpad to be generally easy to use. However, some individuals in the study found it difficult to enter Painpad scores due to impairments that hampered their ability to manipulate the Painpad interface.

Recent work by Adams et al. [1] indicates that mobile touch-screen interfaces like those of cellphones and tablets offer a convenient and potentially easier alternative to physical buttons when collecting pain readings. We therefore designed a second study to explore potential user acceptance and preference for two touch-screen tablet-based alternatives to the physical Painpad. The first design was a 'Tablet Buttons' interface, which represents a straightforward mapping of Painpad to a tablet (see Figure 2). The second is a 'Tablet Slider' interface modelled after the VAS-P scale [15, 36, 43] used by Adams et al. in their study of mobile pain logging [1]. This interface offers a different and potentially easier method of data entry by allowing patients to move a slider to register their pain. Moving the slider to the top of the scale equates to extreme pain (10) and the bottom of the scale signifies little to no pain (0). We compared these two alternatives to the Painpad prototype to determine whether a digital interface might be preferred to a tangible self-logging device.

Both of the tablet-based interfaces were implemented as native Android applications[5], presented to patients using an Acer Iconia B1-A71 tablet measuring 197.4 x 128.5 x 11.3

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[5]Code for the app for both interfaces can be found at:
`https://github.com/k64c86/painpad-android`
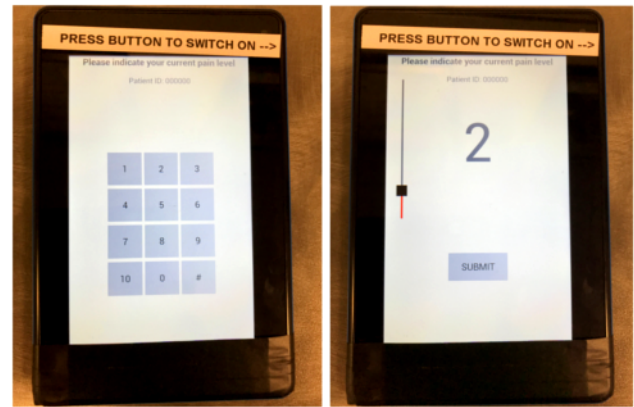
Figure 2. The Tablet Buttons (left) and Tablet Slider (right) pain logging interface designs tested with patients in Study 2.

mm, weighing 320g and running Android 4.1.2. The tablet prompted the user by flashing the screen red and green for 5 minutes and playing a sound for 5 seconds to attract attention. We put a pointer to the "screen on" hardware button so that participants would know how to switch the screen on to enter an unprompted value while the screen was off (see Figure 2).

The design of this study was similar to that of Study 1, with the exception that we used a within-subjects design to collect comparative feedback about the different self-logging interfaces. This was based on early pilot testing, which indicated that patients would not always have time to make good use of all three devices during their hospital stay. We therefore employed a comparative method in which all participants were exposed to Painpad and at least one of the two tablet interfaces. Then, if patients happened to remain in hospital for longer, we allowed them to use the additional tablet interface in order to collect further feedback. (Seventeen of our participants received all three interfaces, and the remaining seven saw only two.) We set a minimum use time of seven hours for each device to ensure that patients were exposed to their assigned interfaces for an amount of time sufficient to enable feedback. We employed counterbalancing to prevent order effects, resulting in four conditions: Painpad followed by Tablet Buttons (PP-TB), Painpad followed by Tablet Slider (PP-TS), Tablet Buttons followed by Painpad (TB-PP), and Tablet Slider followed by Painpad (TS-PP).

An additional difference to Study 1 is that we set the schedule for self-logging of pain scores to an hourly rota instead of bi-hourly. This is because participants were asked to use several devices and we wanted them to make good use of them for self-logging of pain in the time that they had available. No patients reported finding the hourly rota to be burdensome. We do not report compliance comparisons for this study since the nurses were not instructed to shift to an hourly rota.

Ethics and Recruitment
The three interfaces were again deployed in collaboration with the R&D Department and clinicians at the same hospital as Study 1. The study was conducted in a single phase, and all procedures and materials received ethics approval from our

institution's human research ethics committee as well as the hospital R&D Department. Recruitment was again handled by the clinical member of our research team. Inclusion and exclusion criteria were identical to those used in Study 1.

Participants

Twenty-four participants (8 male, 16 female) volunteered for this study, equating to six per condition. Participants' ages ranged from 55–83 (*Mean* = 66.75 years, *Median* = 65, *SD* = 8). Participants were inpatients recovering from ambulatory surgery on the hip or knee, remaining in hospital for between 1–4 days (*Mean* = 1.6 days). None of these individuals had taken part in Study 1.

Procedure

Participants enrolled in the study via the consulting clinician and were given an information sheet explaining the research before providing informed consent. Instructions were worded carefully to avoid encouraging participants to favour any particular interface over another. Participants were then randomly assigned to condition after undergoing their scheduled surgery. A member of the research team provided the patient with a Painpad or Android tablet, depending on the condition to which the individual had been assigned. Participants kept the device near their bed and had access to it for at least seven hours. Notifications were delivered on an hourly basis, beginning at 8:00 and ending at 22:00. A member of the research team then visited the patient and swapped devices from the Painpad to a Tablet interface, or vice versa. The device the patient was no longer using was removed from their rest area. Participants used their second interface for a further seven hours. If the patient was still in hospital after this time then we provided them with the tablet interface they had not yet used for additional feedback.

As in Study 1, nurses continued to collect pain scores verbally by asking each patient about the severity of their current pain. This meant that patients were able to provide an opinion about the Painpad and Tablet interfaces in comparison with the existing practice of being queried verbally by a nurse.

When patients were ready to leave hospital, they were each given a paper-based questionnaire that asked them to rank the input methods they had used based on the perceived ease of providing a pain score, where 1 = 'easiest' and 4 = 'hardest'. They were also asked to consider the nurse method in this ranking, and had the opportunity to write comments to explain their rankings if they wished. The questionnaire then asked which method for pain logging the participant was most satisfied with (and why), and which of the three digital input methods had the best aesthetics. Finally, we provided a free text field that allowed participants to leave other comments and suggestions about the study.

ANALYSIS AND RESULTS

Input Method Preferences

We first consider whether participants preferred the physical Painpad, Tablet Buttons, Tablet Slider, or the nurse-queried method for reporting their pain. We do this by considering the rankings for ease of use and preference provided by each

Logging Method	Rank and N Times Assigned			
	1	2	3	4
Painpad	17	2	4	1
Tablet Buttons	7	6	4	0
Tablet Slider	4	7	5	1
Nurse	10	0	1	5

Table 4. Patient rankings of pain logging methods based on perceived ease of use.

participant. These were analysed by summing the number of times a given logging method was assigned with a particular rank. When calculating these rankings, we found that seven participants had provided tied ranks for ease of use, i.e. they thought that several or all of the methods were equally easy to use. In these cases we assigned both (or all) of the selected methods with the appropriate rank, and any remaining non-tied ranks were adjusted downwards.

Table 4 shows frequency counts of rankings for the perceived ease of each pain logging method. It can be seen that Painpad was rated easiest to use 17 times. By comparison, Tablet Buttons was chosen 7 times, Tablet Slider 4 times, and scoring via nurses 10 times.[6] In terms of overall satisfaction, Painpad was chosen 18 times, Tablet Buttons 5 times, and Tablet Slider 4 times. Nurse scoring was chosen 4 times. These outcomes suggest an overall preference for self-logging with Painpad.

Participants were asked to select which of the three self-logging input methods had the best aesthetic appearance. Interestingly, Painpad was selected only 6 times. In contrast, Tablet Buttons was selected 15 times and Tablet Slider was chosen 14 times. This indicates that people preferred the appearance of the tablet-based interfaces but preferred to use Painpad when it came to entering their pain.

Further analysis of the ranking data suggested an age-related difference in preferences among participants. Twelve (50%) of our participants were aged 66 or older, and eleven of these people described Painpad as easiest to use. In contrast, the preferences of participants below the age of 66 were more evenly spread: five selected Painpad as easiest to use, six selected a tablet-based interface, and seven opted for the nurse scoring. The preference for Painpad by those over 66 may be related to declining motor capability within this group, but could also be explained by their relative unfamiliarity with tablet computing devices (see below).

Patient Experiences with Painpad and Tablet Interfaces

Fifteen of our 24 participants left at least one free-text response. These responses were analysed inductively in search of common themes about the interfaces and explanations for participants' device rankings [42].

Participants' statements provide additional context to their rankings of each pain logging method. For those who cited Painpad as easiest to use, reasons given included that it was *"easier* [to operate] *with one hand"* (P1) and that *"as elderly box easier to handle. Also box was louder so as I am slightly deaf*

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[6]These counts do not sum to 24 because of the presence of tied ranks.

could hear it" (P4). Others found that the physical properties of Painpad were better for the hospital context: *"Could place it on the bed and know where it was owing to its weight. Tablet button—worried about having it on the bed and dropping it"* (P13). However, P8 described Painpad as *"too noisy"*, echoing the sentiments of some participants in Study 1.

For the two tablet-based interfaces, P3 described Tablet Slider as *"easy to use and submit, easy to provide additional inputs, easy to alter if you make a mistake"*. However, preferences for the tablet-based methods appear to have been affected by participants' general familiarity with tablet computing devices. Some found them easy to use; P17, for example, liked Tablet Buttons and stated that *"if you are used to using a tablet it becomes no problem at all! I'm used to using a tablet, it's quick, simple, and confirms that the information you are sending has been received"*.

In contrast, some other patients struggled with the tablets. Early in the study we noticed that participants would make errors by unwittingly pressing the hidden 'back' button on the Android device itself (this button could not be disabled in Android 4.1.2), causing the customised app to close, e.g. *"Tablet buttons screen kept going off"* (P11). This led us to create the workaround of covering the bottom of the device with electrical tape to prevent closures, as shown in Figure 2. Aside from this problem, one participant was concerned about the safety of the Android tablet while it was at their bedside: *"Scared of dropping [Android tablet], too much on table. Avoided use.* [Painpad] *was robust with so much on table"*. This person also stated that it was *"easy to see painpad. Smaller and neat"* (P12).

Finally, two participants left comments about the method of providing scores to nurses. One felt that *"obviously the easiest is the 'nurse asking me' as you don't have to do anything at all. However it is probably not the most accurate. When a question is fired at you you have to make a quick decision and not much time to think about it. With the other methods you have more time to consider your answer"* (P2). A second patient rated the nurse as joint easiest with Painpad, but described the nurse as a more *"conversational method"* (P22). This suggests that patients may gain some benefit from the social interactions involved in being queried by a nurse, even if the scores are not as reliable as those collected using Painpad.

DISCUSSION

Our aim in designing Painpad was to provide a user-friendly method for self-logging of pain that could improve on the current approach of assessing pain through verbal querying by nurses. Painpad was additionally intended to meet a set of design constraints that are important for the hospital context, particularly when the anticipated user group was comprised largely of older adults.

Improving Compliance Through Self-Logging

Our first study showed that allowing patients to self-log their pain with Painpad produced a more complete pain record. Patient compliance with bi-hourly pain scoring was 50.4% under a 30-minute qualifying window, representing a 20 percentage-point improvement over equivalent data collected by nurses. Our work demonstrates the potential for self-logging with Painpad to produce data that is closer to desired clinical targets (in our case, one score every two hours) while also providing workload and cost savings by alleviating burdens from nursing staff.

Although Painpad led to improvements in pain scoring, it is worth noting that compliance in our study was relatively low compared to some previous studies. Examples in the literature include over 90% compliance when using electronic PDA diaries [41] and between 88–95% compliance using tailored mobile applications [1, 39]. However, those studies were focused on diaries that are intended to be used in the patient's own time, i.e. to sample everyday experience away from the hospital. Our compliance figures arose as a result of inpatient stay, in which an individual's daily routine might be disrupted by periods of prolonged sleep, sickness, visits from family, or incidental diagnostic activities that require patients to leave the recovery ward. In addition, other studies have typically assessed compliance with lower thresholds, e.g. three readings per day [41]. Ensuring strict compliance throughout the day may in fact be very difficult in a hospital setting, but Painpad offers a route towards this while representing a clear improvement over nurse scoring.

Accuracy of Pain Scoring: Painpad or Nurse?

Study 1 also suggested that there may be a discrepancy between nurse-queried pain scores and equivalent data recorded privately by patients using Painpad. This finding is important given that the average difference between scores was approximately two PI-NRS scale points, which may equate to a clinically significant difference in pain [10].

While we cannot specify which of the two methods produces a 'ground truth' assessment of pain, related literature leads us to suggest that a patient's self-logged score may be more indicative of their actual pain. For example, patients may be too proud or embarrassed to admit to a nurse that they require pain relief, or may choose to 'suffer in silence' because they do not want to bother nurses who they believe to be busy [5, 12]. This may explain why a greater percentage of scores in Study 1 were lower when reported to the nurse (see Table 3). However, this does not explain why some scores were lower when given to Painpad.

An alternative explanation that can account for both effects is that patients may not wish to waste what they believe to be valuable staff time, and may report their pain to a nurse without thinking about their feelings in detail (a participant in our second study hinted at such an explanation). Self-logging might overcome this problem by allowing patients to reflect carefully on their pain level before submitting a score, in turn producing more accurate data. This is important because inaccurate estimation of pain may hamper clinicians' ability to administer analgesics effectively [32]. Future work on self-logging of inpatient pain should therefore compare pain scores provided by patients to those given to nurses in more detail. Relatedly, substituting a nurse's observation with Painpad has the potential to lose valuable human input to the pain monitoring process. Future work should explore appropriate ways to integrate patient self-logging with nursing practice.

User Experiences of Pain Logging with Painpad

Both of our studies found favourable user experiences with Painpad and with self-logging in general. Participants in Study 1 reported finding Painpad easy to use and felt satisfied by their experience with the device. This suggests that the Painpad prototype fulfilled our initial design goals of enabling regular self-logging in an easy-to-use manner, without requiring high-cost equipment that would be at risk of damage or theft.

In Study 2, the majority of participants reported preferring Painpad to the virtual tablet-based interfaces, with near universal preference for Painpad by participants aged 66 years or older. One explanation for this finding could be that many of the older patients were simply not familiar with tablet or touch-screen technologies. This means that their preference for Painpad might disappear, given sufficient opportunities to become accustomed to tablet-based interaction. However, it is worth considering that capacitive touch-screens can appear less responsive to older adults because skin conductance lowers with age due to the skin becoming more dry and less conductive [35]. A tangible, push-button interface like that of Painpad may therefore be most applicable when data needs to be collected from an older adult population.

Participants also shared a number of specific comments about potential improvements to Painpad, and these can be seen as lessons for future designs. First, designers should ensure that the features of a self-logging device can be adjusted based on a patient's individual needs, especially as inpatients are more likely to be older and possibly have a co-morbidity. Some individuals in our studies were hard of hearing, making it difficult for them to notice the audio reminders, whereas others found the device too noisy and felt embarrassed by its alarms. Future devices for inpatient pain logging should offer user control over these features to provide an experience that can be tailored suited to each patient's condition and personal circumstances. Permitting user control would also allow for the device to be more appropriate for a mixed recovery ward. Some patients in our first study reported that the notifications created a disturbance for their co-inhabitants.

Additionally, designers should ensure that the pain logging device is easily identifiable against the backdrop of patients' recovery environment, which is frequently messy and cluttered. One participant suggested making the painpad a brighter colour, like red or green, so that it would be easy for them to see. Participants in our second study valued Painpad for its visual clarity and for its physical nature, which allowed the device to be easily found while at rest on their bed. This also made it easy for the device to be easily grasped and held, which may help to minimise errors from mis-keying.

Limitations

Our study involved patients undergoing ambulatory surgery for total hip or knee replacement. This means that we inevitably encountered some bias in our patient sample, simply because patients requiring ambulatory surgery tend to be older adults. The reported preferences for Painpad may not ring true if the device was deployed to younger individuals. Studying the preferences of different user groups represents an important area for future research on inpatient painlogging preferences.

Additionally, the increased rates of compliance acquired with Painpad may be due to a novelty effect. The idea of trying a 'new' technology may appeal to some participants, particularly if they are motivated by a desire to be helpful to clinicians (to whom they may feel indebted). Similarly, studies of pain diaries report that participants sometimes feel motivated to complete them because they initially feel as though the researchers are interested in their condition [6]. The implication is that such effects might lead to a drop in compliance with self-logging over time. However, this may be less of a concern for Painpad given that it is intended to support logging of short-term, post-operative pain while in hospital. Moreover, a year-long study of electronic diaries found that compliance rates remained steady over time [18], suggesting that novelty alone cannot account for people's engagement with self-logging through digital technologies.

A limitation of our second study is that the period of use for each interface was relatively short. Longer use in a between-subjects design might have revealed other UX issues unique to each interface and might have allowed older adults to become more accustomed to the tablet interfaces. However, a between-subjects design would need to control for variability in pain levels, which is very difficult when real-time pain monitoring is one of the main issues under study.

CONCLUSION AND FUTURE WORK

In this paper we presented Painpad, a device that enables self-logging of pain by hospitalised patients. Painpad was well-received by participants, and was shown to facilitate improved compliance compared to equivalent nurse scoring. Allowing patients to self-score their pain circumvents the need for nurses to engage in burdensome data collection, and lowers the data management and processing time for clinicians [6, 13] by auto-populating each patient's data into a secure database for use in research and service improvement.

In future work, we plan to explore other input techniques for inpatient pain logging. The present work compared a device with physical buttons and two tablet alternatives, but one could conceivably create a device that incorporates a physical slider and compare this to a keypad alternative. Likewise, unlock journaling [44] represents an alternative, low-effort method for collecting pain scores on mobile phones and tablets. Beyond this, it is worth noting that the pain data collected in our study did not factor into clinical decision-making, yet could easily do so in future. We plan to allow nurses to monitor the pain curve of multiple patients from the convenience of the nurse's station, combining self-logged data with live pain monitoring interfaces to support decision making. Similarly, logging pain scores alongside analgesic dosing times might allow clinicians to identify correlations and make better decisions based on real-time data collected about their patients.

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