



Motivating People with Chronic Pain to do Physical Activity: Opportunities for Technology Design

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ABSTRACT

Physical activity is important for improving quality of life in people with chronic pain. However, actual or anticipated pain exacerbation, and lack of confidence when doing physical activity, make it difficult to maintain and build towards long-term activity goals. Research guiding the design of interactive technology to motivate and support physical activity in people with chronic pain is lacking. We conducted studies with: (1) people with chronic pain, to understand how they maintained and increased physical activity in daily life and what factors deterred them; and (2) pain-specialist physiotherapists, to understand how they supported people with chronic pain. Building on this understanding, we investigated the use of auditory feedback to address some of the psychological barriers and needs identified and to increase self-efficacy, motivation and confidence in physical activity. We conclude by discussing further design opportunities based on the overall findings.

Author Keywords

Interactive Systems Design; Chronic pain; Physical Activity; Auditory Feedback

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors; Design;

INTRODUCTION

Technology is increasingly used to promote physical activity and reduce sedentary behaviour in the general population, but using it to support physical activity in chronic pain is still in its infancy. Applications from rehabilitation in stroke, diabetes, and cardiovascular disease [26] may transfer to chronic pain, but do not address pain-specific physical, psychological and emotional needs [32].

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Chronic (persistent) pain (CP) is a global health concern affecting an estimated one in ten adults [22]. It is defined as pain that persists past healing (around 3 months) after injury or with no identified lesion or pathology [33]. Acute pain usually resolves as injury heals; CP can continue indefinitely through central nervous system changes [15,22]. For people with CP, maintaining physical activity despite ongoing pain is a challenge, and clinical services cannot meet demand [22]. Technology offers a practical way to support self-managed physical activity, but to achieve behaviour change, factors facilitating or undermining adherence need to be examined.

Here we investigate the possibility of using technology to increase physical activity in people with CP from two perspectives: (i) the practical challenges faced by people with CP in maintaining physical activity, and strategies they use to build activity, and (ii) how physiotherapists, specialised in pain rehabilitation, support and motivate people with CP to build physical activity. These complementary perspectives enable us to identify technology opportunities. Whereas people with CP can provide an account of their needs, of barriers and strategies used to meet them, they lack a formulation of their rehabilitation needs; physiotherapists with an understanding of CP can judge what type of activity is beneficial and achievable and link it to valued goals.

These studies make three contributions to HCI. First, a detailed analysis of data from people with CP and physiotherapists identifies factors to be incorporated into technology that promotes adherence to physical activity targets despite pain. Second, we rethink the role of technology in improving uptake of physical activity despite pain. Finally, using this understanding, we experimented with auditory feedback to address the identified needs and barriers that emerged as specific to CP. The paper concludes with lessons learned and suggests a rethinking of design solutions for physical rehabilitation technology in CP and more widely.

BACKGROUND AND RELATED WORK

Before discussing available technologies for people with CP, we describe CP-relevant psychological and emotional issues.

Living with chronic pain (CP)

CP involves changes in the central and peripheral nervous system resulting in amplification of pain signals: overactivity in pain pathways at multiple levels from the periphery to the brain, and underactivity in descending pathways that inhibit pain signals [31]. These changes are closely linked with distress and affect behaviour [5]. CP affects work, relationships and everyday function, risking depression, anxiety and social isolation.

CP self-management shares with other chronic conditions techniques and moderating factors that affect adoption and adherence [21]. However, it differs in that the experience of pain conveys threat [4], generating fear of and catastrophic thinking about movement and activity, and undermining adherence to an activity programme. Yet being active protects against weakening and stiffness; inhibits the neurophysiological mechanisms underlying the spread of pain; increases confidence in physical capacity and underpins achieving valued goals [5]. With effective self-management, patients can make cognitive, behavioural and emotional changes to improve quality of life [38].

Through multicomponent pain management, physiotherapists (and other healthcare staff) educate, advise on activity, and provide psychological support, aiming towards patients' self-management. But with insufficient support, gains diminish and quality of life suffers [32]. In order to cope with anxiety about movement, people with CP consciously and unconsciously adopt protective behaviours (e.g., guarding, using support) which become habitual [19]. Unfortunately, these reduce the benefits of physical activity and may impair motor control (e.g., lack of balance) where there is proprioceptive dysfunction [37].

Technology for physical activity in CP

Technology to support self-management and motivate physical activity shows encouraging results for some chronic diseases [21], but falls short of addressing CP issues (e.g., fear of movement, altered proprioception, low self-efficacy). Existing technology (including information on the Web and treatment by Internet or telephone) does not provide the detailed clinical help valued by people with pain [25].

Smartphone apps for CP self-management generally contain information about pain and pain reduction by physical methods (e.g., Habit Changer: Pain Reduction, www.habitchanger.com/programdetail/painreduction.php), but apply better to acute pain than CP. Some (e.g., Pocket Therapy, www.scavomed.com) include strengthening exercise demonstrations and relaxation/meditation. Others (e.g., Chronic Pain Tracker, www.chronicpaintracker.com) log data on variables such as mood and pain for monitoring, and provide pragmatic reminders such as for medication. An authoritative review [24] found that apps did not address CP-relevant psychological and behavioural issues.

Some recent apps (e.g., WebMD PainCoach, www.webmd.com/webmdpaincoachapp), developed with healthcare professionals, enable the user to monitor pain and set and track activity goals, generating related messages. Other self-monitoring apps (e.g., Google PACO www.pacoapp.com) allow personalised monitoring for specific activities (e.g., exercise) and query user data to identify relevant factors. These apps are promising for monitoring physical and psychological states but offer little psychological support and do not engage with counterproductive behaviour present in CP (e.g., guarding).

Serious games for CP using motion capture technology and multimodal input introduce fun, and monitor and correct movement using sensing technology for automatic tracking [28]. Although useful, these functions do not address activity avoidance through misconceptions or anxiety, and are based on a rehabilitation model where correction of movement and increasing fitness are the goal, rather than increasing overall engagement in life. Some people with CP report that pleasant experiences help with pain and pain-related anxiety and tension, while others cannot engage because of pain interrupting and demanding attention [15]. This suggests potential for enjoyable experience in pain management but needs a better understanding of engagement and maintenance. Additionally, efficacy for meditation and biofeedback using virtual reality is still much stronger for acute pain than for CP [18,39] with a few exceptions in CP proposing the use of biofeedback [8].

Other technologies for physical activity

Rehabilitation in other areas like stroke therapy uses commercially available consoles (e.g., Nintendo Wii). The Microsoft Kinect has been used to prototype games to promote physical activity in older adults [6]. These movement games provide multimodal feedback and are cheap, ubiquitous and accessible. Geurts et al. [7] designed and developed mini-games for people with motor disabilities illustrating the feasibility of commercially available input devices as game controllers, and emphasising the importance of adjusting game parameters to individuals' skills and development goals for optimum gains. Riablo (www.corehab.com), a commercial rehabilitation system, allows clinicians to remotely monitor patients' physical activity with accelerometer data sent over the Internet.

These technologies show the potential for providing engagement and monitoring of a particular activity [28], but are not designed to address the psychological factors associated with CP problems [32]. They rely on the presence (co-located or at distance) of a physiotherapist to address possible psychological needs and calibration. Physiotherapist presence is appropriate for clinical rehabilitation but needs modification for self-management in CP, where experience of activity exacerbating pain and even leading to serious setbacks [9] generates overcautiousness, and concern to establish a 'safe' amount

of activity. Feedback on progress needs to handle slow pace and discouraging, though temporary, setbacks [9].

Motivational technologies like Ubifit [3] and Fish'n'steps [16] for increasing activity in healthy people use goal setting, and monitoring and tracking progress towards goals. They reward progress by feedback designed to provide a sense of pleasure and accomplishment. Rewards maintain motivation [3], but it is unclear what rewards work well in CP given anxiety about pain and strain with activity.

The capacity of emerging technology to automatically detect protective/avoidance behaviour [1], pain [12,20], and other emotional expressions during physical activity and exergames [13,27] is reaching levels comparable with naïve observers and even clinicians. This suggests that it is time to explore its potential. However, technology that adapts to people's emotions is underdeveloped [1] and not yet used in physical rehabilitation contexts.

In summary, most technologies for people with CP either borrow from acute pain or from fitness for healthy people, or provide only information and monitoring. Few address the particular problems of CP, and none grounds the design on an understanding of physical activity needs and barriers in CP [35]. Our study aims to build this understanding and to identify the design requirements for technology to help people with CP to maintain and increase physical activity.

| Studies | Participants |
|------------------|---|
| 1. Role-plays | 2 physiotherapists (PT) |
| 2. Interviews | 14 people with CP, 3 physiotherapists |
| 3. Focus groups | 2 focus groups, with PT and people with CP |
| 4. Blogs, forums | 25 people with CP |
| 5. Observations | 3 PT-led groups or gym exercise sessions with 12 patients; 2 pain management introduction sessions with 15 patients |
| 6. PT-Interviews | 4 PT after observing their classes |

Table 1: Details of studies. 1 physiotherapist (PT) and 2 people with CP were the same between interviews and focus groups. 2 PTs were the same between the interviews and PT-interviews.

METHODS

A series of studies were designed to explore the needs and barriers that emerge during physical rehabilitation in CP. Diverse methods and contexts were used (see below and Table 1):

1. *Role-play with physiotherapists*: To understand the problems that patients highlight regarding physical activity, 2 senior pain management physiotherapists with cognitive behaviour therapy (CBT) training and over 10 years of experience with CP role-played a consultation.
2. *Interviews with people with CP and physiotherapists*: We interviewed people with CP on their needs in returning to activities. Semi-structured interviews of

30-45 minutes with 14 individuals with CP and 3 physiotherapists with extensive experience in treating CP were recorded and analysed.

3. *Focus groups*: Two focus groups of 30 people with CP and a physiotherapist, discussed themes from the interviews and critically evaluated existing technologies and their suitability for CP.
4. *CP blogs and forums*: We analysed seven publicly available blogs and 18 forum entries on physical activity by people with CP, on websites and social groups for CP support.
5. *Observations of physiotherapist-led group sessions*: We observed and recorded three physiotherapist-directed group-exercise sessions for people with CP to understand how physiotherapists support and motivate activity despite pain and related concerns: a 30-minute drop-in session for patients who had previously attended pain management; two gym sessions where each patient follows an individual programme under physiotherapist supervision; and pain management explanation in a programme run by physiotherapists and psychologists. All physiotherapists had worked in CP for 6-10 years; three had CBT training.
6. *Interviews with physiotherapists from the observed group sessions*: The physiotherapists running the observed group sessions were interviewed, using videos of the sessions, to elaborate on how they intentionally motivate and support patients.

Our studies had local Ethics Committee approval and all participants interviewed or observed provided written consent. All interviews were audiotaped. Focus groups and role-plays were audio- and video-recorded. All data were transcribed for further analysis. The data set was analysed using grounded theory methods from Strauss and Corbin [29] to develop concepts from data; to interpret data; and to identify key concepts and relationships between them. Transcripts were analysed iteratively until no new concepts emerged (saturation). Emergent themes are described in the next two sections: the first focuses on barriers to activity and needs for reactivation; the second on physiotherapists' behaviours when addressing those needs and barriers.

FINDINGS: NEEDS AND BARRIERS

Studies revealed various psychosocial barriers that people faced in relation to physical activity in the presence of pain. Interviewees generally described more than one barrier, importantly fear of damage or injury, fear of increasing the pain, worry about getting stranded far from help if pain increased suddenly, worry about falling, and practical aspects such as lack of opportunities, money, or information about safety. We focused on how people remained active despite these challenges: themes identified are described below using the following notation: P# denotes interviewed participants with CP, PT# denotes interviewed physiotherapists, PFG# denotes focus group participants, POFB# denotes participants from online forums/ blogs.

The Pain Management Journey

People with CP and physiotherapists referred, directly or indirectly, to the journey of pain management: managing expectations of change and focusing on improving function in daily life despite pain rather than on hope of a cure. *"Some people may decide they are in a recovery journey, some people may still be in a pain jungle where they are looking at how do I get out of this place."* (PFG1). In this paper, *journey* refers to engagement in a physical activity programme for pain management, as our focus was physical activity not wider pain management. Support and information needs change across the journey. Three key points emerged as important at the start: acceptance and understanding of pain, adjusting expectations, and pain management responsibility.

Acceptance and understanding of pain: For some people, the key to more activity and a better quality of life despite pain is acceptance of pain. *"I'd finally accepted the way I am, and had managed to develop a new life, doing new things that I could cope with and gain some measure of success, which made me feel worthwhile again."* (POFB15). Physiotherapists stressed that critical to activity increase is better understanding of CP, and that pain does not mean damage. *"One of the biggest ones is fear and not knowing so they feel that they're going to make things worse or do more damage."* (PT1).

Adjusting expectations: Initially people with CP who attend physiotherapy and pain management programmes may still hope for pain relief. But *"Our focus is not on reducing the pain, but on helping them to improve their ability to do things"* (PT2). Expectations also need to be adjusted to slow but steady progress: *"So what do they expect to change and is that a realistic thing to expect and can we give them any knowledge or information about their body, or about fitness, or about pain that might help to adjust their beliefs or their expectations?"* (PT3).

Activity increase in CP often involves trial and error, thus risk. *"If I were to deliberately go for a walk and just did more everything, I would say due to past experience my mobility would be practically zero for at least 3 or 4 days after."* (P2). Also, while activity is beneficial, underused muscles and joints can become painful, increasing anxiety, so reassurance that activity is not harmful was helpful: *"Healthcare professionals need to tell patients that when you start exercise your pain may increase but it will drop away."* (P10). People who were very active before the pain struggled with low levels of activity: *"Sometimes people who've done quite a lot of sport in the past will often struggle with 'I used to be able to do this amount so I should be able to this amount now'."* (PT3). This emphasises the early need for information and setting realistic expectations.

Pain management responsibility: Some people who were managing their pain better asserted that they took responsibility for their progress. One patient (PFG1) said, "I

think the biggest challenge in all of this is to understand that we are going to have to manage it - with the support of other people - but we are the key rather than the external professionals". Physiotherapists agreed: *"Our job is to give them some kit and then they try to put that together to work out, to problem solve how they're going to approach a given task."* (PT2).

Journey phases: Explore, build, maintain, adjust

Within the journey, we identified three phases that recur: (i) explore capability (set baselines), (ii) build on current capability, and (iii) maintain gains in capability. In case of setbacks, adjustment may mean that capability is reduced in the short term.

Exploratory phase: Exploration of capability for physical activity despite pain was described by physiotherapists as setting initial baselines for different activities, not by requiring physical performance but by *"what they feel that they can do."* (PT2). This may be supplemented by functional tests or observation to assess challenges to physical activity, such as muscle stiffness or tension.

Gradual building phase: This builds on the baselines by steady increments: both people with CP and physiotherapists stressed the importance of building slowly. *"It is quite interesting initially how little you can do but that if you just do that very, very little, how quickly it builds, but if you think, well, I did one today I'll do six tomorrow, you're going to go backwards."* (PFG2).

Maintenance phase: Building activity leads into maintaining gains. *"I walk every day ... on an ordinary day, I do something like half an hour, or 40 min where I do it in small chunks: roughly 10, and 10, and 10 minutes"* (P3).

Strategies for physical activity

People with CP have strategies for activity despite pain. Most people take regular breaks while doing household activities (e.g., washing dishes (P5) or working on the computer (P2)). Others ensure that they frequently change positions, perform stretches, relax or adapt the way they perform an activity to make it more comfortable.

Functional activity vs structured exercise programme:

Physiotherapists commonly divide activities into domains: the physical (e.g., exercises), functional (e.g., housework, everyday activities), and social (e.g., being with friends and family) [15]. They recommend functional activity rather than routine exercises for people with CP because when the activity represents valued goals it is inherently rewarding and motivating, demonstrating improvement in capabilities. PT3 explained, *"Just building up the muscles to do an activity does not translate into confidence in doing the actual tasks that people want to do."* Other physiotherapists added that functional tasks have an advantage over routine exercise: *"People do get very bored by a list of exercises and often when people come to see us they may have seen 5 or 10 or more physios and they've got reams and reams of*

exercises but they're not adding up to the functional change that they want." (PT2).

Correcting movement vs going with the flow: Most people with CP emphasised that they would like "wrong" activity to be corrected, *"It's very beneficial to have somebody correcting you because your body always wants to do it the easiest way and what you've actually got to do is to get your body to do it the correct way."* (P1). However, pain management physiotherapists put much less weight on "correct" ways of moving and more on regaining confidence in movement: *"We look less for a textbook way of doing something and we look much more at the person being able to do the activity they want to do in a way that they can manage."* (PT3). They were concerned that correcting movement increased anxiety about damage, so focused on reassurance that the activity was 'safe', adding or substituting another exercise, counter-stretch or relaxation that was within the patient's capacity.

Being active vs overactive: People with CP and physiotherapists emphasised that while being active is encouraged, being overactive can lead to increased pain, resting to recover, and in the longer term to unreliable progress or anxiety and avoidance of activity. *"Learning to stop before you do too much is one of the hardest things when it's going well."* (P1). Some people found it helpful that healthcare professionals warned them against doing too much while others felt that sticking to gradual steady increases should avert any risk.

Support from physiotherapist/coach: Several interviewees were inspired and motivated to do activity by a physiotherapist. *"I think it helps a lot of people to be told off by the physiotherapist. So I know it may sound silly and it's like a little boy but I do find it helps a bit more than self-motivation."* (P12).

Exercise adherence - routine vs variations: People with CP report that incorporating physical activity into their daily routine helps. *"I sometimes don't get (into) a routine and then I don't do it: once I get out of the habit I find it difficult to get back."* (P4). People felt able to be physically active consistently if planned, and adding physical activity to a daily routine in the form of small short-term goals enhanced confidence. However, several people with CP complained of boredom with their routines but were afraid to change in case it caused problems: *"I would like to (vary routine), but I do have to be quite careful because I do feel limited in what I can do."* (P5). Others struggled with introducing new activities, and a common strategy was making small changes to daily activities.

Exercise adherence when pain is worse or mood is low: People with CP knew it was important to be active even on days when pain was worse: *"Last week I had some twinges in my back and in the old days I would have panicked and become restricted but I went to the gym and the gym work actually eased off the back pain."* (P11). Routine also

varied with mood: *"When you're feeling down [activity] it's not something you want to do; I do have to try and kick myself into doing these things sometimes and I think a lot of people share that"*. (P12).

Motivation for physical activity

Feel-good factor: When asked about what makes them feel good about a physical activity session, most people with CP reported immediate benefit or a sense of achievement. Many said that completing activity or a physical exercise routine was rewarding because they felt better afterwards: *"Kind of I'm tired in that nice way after the exercise"* (P3).

Reward strategies: Some people with CP set themselves incentives for physical activity to strengthen motivation. Physiotherapists did not give advice on incentives or rewards but encouraged people to reflect on what motivated them. *"We encourage people to think about what would work for them so we'll mention setting short term goals, acknowledging achievement, giving yourself reward; but we'll just talk about general examples and say to people you know what would work for you."* (PT2).

FINDINGS: PHYSIOTHERAPISTS' BEHAVIOUR

Observation and recording of physiotherapists leading sessions was followed by interview to explore the verbal and nonverbal behaviours they used, consciously or not, to motivate and support patients. They reviewed the video recordings of their sessions, using a 'naturalistic social cognition' method [10] to identify intentions associated with specific behaviours towards patients, and in particular to identify their use of cognitive and behavioural techniques. The emergent themes are discussed below. OP# identifiers are used to denote the interviewed physiotherapists.

Facilitating control, Transferring control

To help CP people make movements which they otherwise avoid, it is important that they take control. OP2 said: *"When you have pain in a part of the body, your brain sometimes loses the ability to control certain segments of muscles, so it gets harder for people to do very local specific movements of painful parts of the body. That's one of the reasons why we break down movement"*. Positive feedback to reassure and encourage patients was gradually reduced as patients achieved more control and confidence in their movements, to facilitate independence. *"The first time you see them moving their neck - you might kind of acknowledge it at the time and say afterwards 'How was that?' but then if they manage to do the same again next time you might acknowledge them but you might not say anything else; you gradually reduce the feedback for that amount of movement."* (OP2). Physiotherapists focused on neutral or pleasant sensations, such as counting breaths, rather than on the duration of an exercise or position, especially for a demanding exercise using breathing to relax while modelling how the patient could do the exercise alone. *"We want to try and encourage people to hold the stretch for at least 10 to 15 seconds, up to 30 seconds, but*

trying to tie together working out 'how many breaths do I take during that time' and using that to count can work for making sure they are breathing through the exercise, but also putting a bit more of the responsibility on them to choose: 'OK I've done enough of this now. I've done my ten seconds.' Then that habit might be a bit easier when they're on their own."(OP2). Using breathing and similar cues also contributed to reducing muscle tension. *"Trying to physiologically reduce the stress response, so keeping relaxed breathing if they start shallow breathing because they are pushing too far, then that's just going to feed into more of a tense kind of anxious response."*(OP2). Breathing also reduced the need to time movements.

Promoting self-esteem

Self-esteem was promoted by providing positive feedback where necessary, and offering different options in the exercise protocol for the patient to succeed with challenging movements. Physiotherapists used loose descriptions, encouraging patients to move in a way they found feasible, ensuring that there was an achievable target and therefore the basis for positive feedback. Verbal expressions were carefully phrased to foster self-esteem, such as using inclusive words and present participles: *"If we tell the patient 'Next stretch you're gonna have to bend forward', for example, you might already trigger some areas in their brains that go, 'Ooooh, bending forward is really bad', but if you just start doing it and then talk through it as you're doing it, there's something that says to them, 'Oh, actually I am bending'"* (OP4). This helped to keep the focus on doing a movement rather than reaching a specific goal.

Enhancing awareness

Prompts directed patients' attention to their behaviour or movement, indicating that control was patients' to change or adapt behaviour. Prompts were used where increasing awareness could improve the benefits of movement, such as addressing unnecessary tension or pain-related behaviour. *"If you are giving them (patients) the right cues and guidance then it's not looking at how they move, it's about them working out how to move in the way that's best for them. So occasionally, and particularly if I hear grunting or sounds of overdoing, I would have a look and then maybe I add in a sentence."* (OP3). If the patient does not respond to prompts, the physiotherapist might hold eye contact during the prompt. *"I might if I really thought I need to get this message across to them: I might hold my eye contact on them while I said it, but I'd say it in the same tone as everything I was saying before."* (OP2).

Augmenting pleasure and reducing unpleasantness

Physiotherapists chose their words carefully not to direct attention to pain, using terms such as *tightness* and *sensitivity*, and to reduce threat, adding words such as *gently* to instructions. Feedback and descriptive words were used to increase attention to body sensations as normal. *"I can highlight the more normal sensations so they can perhaps start to identify that actually much of what they are feeling is normal sensation."* (OP3).

DISCUSSION OF FINDINGS

The analysis of this multi-faceted data has provided a rich picture of needs, barriers, strategies and stakeholders' roles in CP self-management. We summarise here the main findings and lay the basis for a design study presented in the next section that aims to rethink technology for CP rehabilitation. The overall lesson of our findings reinforces the fact that simply reusing technology designed to motivate physical activity for other conditions (e.g., [16,23]) may be misguided given that emotional states in CP interfere with exercise and activity irrespective of physical capability or pain level. Unanticipated increases in pain generate anxiety about harm and lead to avoidance. Technology, therefore, needs to be designed with this in mind.

Thus redefining what progress means is critical. Our results show that progress is not simply steady physical gains, but gains in confidence and satisfaction in movement. The concept of *pain management journey* in technology design could be useful to define targets and measures of self-management skills. The *journey* shifts the focus from physical skills to people's needs and how these vary along the journey: at the start, the goal may be to recover confidence in movement and to do it with less anxiety; later the focus may be to increase the amount or effectiveness of movement to achieve a particular goal. A measure of progress should recognise that it may be slow and setbacks are likely: during these, capabilities are reduced and expectations should be adjusted. A sense of achievement is provided not only by displaying cumulative change but by offering alternatives, promoting awareness of movement and of pleasurable sensations, and helping to prevent overactivity that leads to setbacks. This builds confidence in activity and bolsters motivation and self-efficacy.

As in other chronic illness [21], our findings suggest that any technology for CP should enable the person to take control and assume responsibility for progress but it also highlights that there is a need for adequate support and reassurance with respect to physical activity. In particular, "correction" of activity can exacerbate anxiety about harm, so reassuring information is essential. Our physiotherapists recommended "going with the flow" rather than correcting. Physiotherapists' main role (and hence of technology) is to provide the skills and tools to identify what is beneficial (rather than what is hazardous) and how to achieve it. As such, technology should be there to provide a space to shape and learn skills. This is very different from the typical approach taken in designing technology for physical rehabilitation [23,28] by instruction and correction of movement and by targets on the basis of physical performance (even if in the form of games).

Following the above needs and initial requirements we ran a preliminary design study to explore how these could be addressed and to start identifying the challenges and opportunities that lay before us.

RETHINKING TECHNOLOGY FOR CP REHABILITATION

In our design study, we focused mainly on the first stage of the journey (building confidence in feared movements) while being mindful of the full journey. Rather than designing a game de novo, we aimed first to understand mechanisms (and their effects) that can be integrated later in games or ubiquitous technology.

Design approach

We approach the problem by exploring the use of aural feedback on movement, a decision motivated by several reasons. First, recent work in CP [2] and on technology design for CP [34] showed that sound feedback facilitates introspection and reduces anxiety. Aural feedback increased awareness of a body function (e.g., breathing) to teach mindfulness skills [34]. Unlike visual feedback, it does not require fixation on a display, so it is compatible with movement. Finally, sound has positive effects in motor rehabilitation (e.g., [23,36]), such as initiating movement and facilitating coordination and improving performances. In our design study we extend these works by exploring how sound can be used to shift attention from a feared aspect of movement to a pleasurable and informative signal, increasing awareness of movement to counter altered perception [14]. In doing so, we aimed to increase exploration of one's body capabilities, to emphasise taking responsibility, set achievable targets and facilitate progress.

We investigated how aural feedback design could accommodate, on one side, the needs of people with CP for monitoring, correction and reassurance and, on the other side, physiotherapists' strategies of not correcting but going with the flow. We proposed the use of sound to design a space for exercising without implying that exercising outside this space is risky. To achieve this and to transfer responsibility from the coach (technology or clinician) to people with CP, the latter should be in charge of designing and calibrating this space. As [11] suggests, by being in charge of calibration, people can build an understanding of what these spaces mean and hence can better appropriate them to address their physical and psychological needs.

Design solution

Following the above requirements, a sound device, *Going-With-The-Flow*, was created to provide aural feedback in response to movement. To evaluate the design, we focused on a challenging physical exercise for people with chronic low back pain (CLBP): a forward reach from a neutral standing position (Figure 1: top-left). This exercise was chosen with clinical advice.

An iPhone attached by an adjustable belt to the participant's trunk measured the degree of bending and provided auditory feedback at fixed intervals of increased stretch. The interval was decided through a calibration process integrated in the application to let individuals tailor it. The calibration process required the person to explore his/her own capabilities by performing the exercise and identifying his/her: (i) neutral standing position (important as people

assume different vertical positions); (ii) most comfortable stretching position (the minimum amount to do also in bad days) and (iii) a maximum stretch desired as the target. The device could use voice commands to capture the parameters and tailor the auditory feedback defining the exercise space to the participants. This space could be re-adjusted when needed following the same procedure. For this application, the person's voice was captured through a Wizard of Oz technique (the researcher) but it could be easily implemented by using voice recognition. Whilst the device was tested on one exercise only, it can be used for any exercise where angles of the body represent the target.

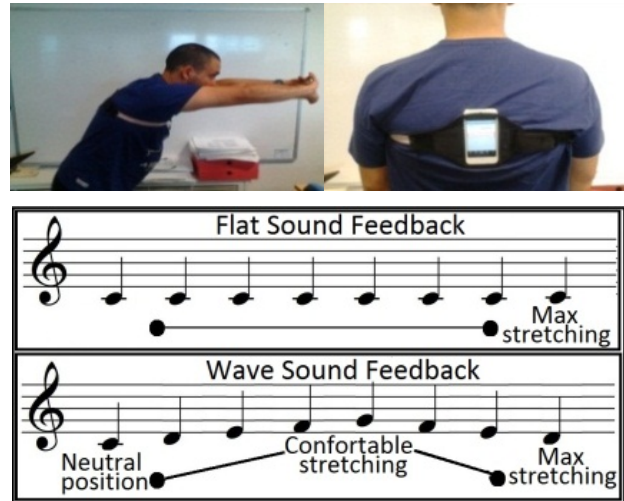


Figure 1: (Top) Device tied to participant's back and forward reach exercise. (Bottom) Sound feedback and exercise spaces.

Two types of sound feedback were designed generating two different exercise spaces with different levels of information (Figure 1: bottom): (i) flat sound and (ii) wave sound. The flat sound feedback was a constant note. A continuously rising tone was avoided for its association with alarms. The wave sound rose until the participant achieved their most comfortable position and then fell towards the maximum position, implying completion. Past the maximum stretching point, sound stopped even if movement continued, to not encourage overactivity. At the same time, the absence of sound was chosen to avoid giving a sense of danger.

Experimental procedure

8 people with CLBP (3 from the 1st study) aged 23–60 years completed short questionnaires about pain and comfort level in stretching exercises. They then performed the movement with auditory feedback, twice in each condition and in the control condition (no sound). The order of the three conditions was counterbalanced. After the second stretch in each condition, they were asked to indicate on a 5-point scale (five bins centered at: 15°, 30°, 45°, 60°, 75°) their perceived bend angle. At the end of the experiment, they were asked to rate their performance (a measure of self-efficacy) in each condition from 0=worst to 6=best). The experiment was followed by a short interview.

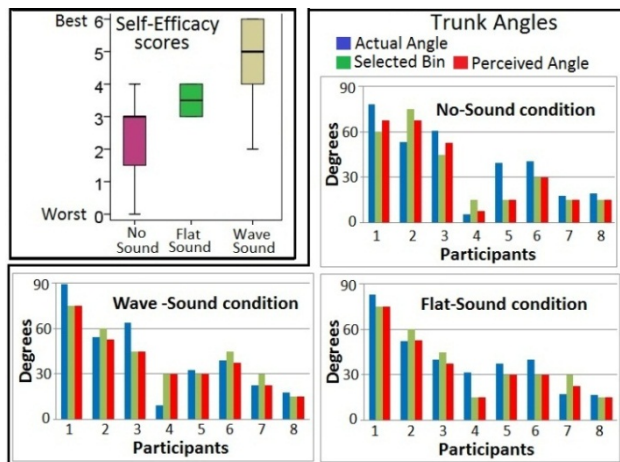


Figure 2: (Top-Left) Boxplots for self-efficacy scores: 1=worst, 6=best. (Bottom and Right) For each participant, actual trunk angles (blue), selected bin angles (green) and approximate perceived angles (APA) (red) at maximum stretch performed

Results

As shown in Figure 2 (top left), most participants reported significantly better performance with sound feedback, particularly with wave sound. Friedman tests showed significant differences for perceived performance scores ($\chi^2(2) = 4.57$, $p = 0.01$). Post hoc tests using Wilcoxon (Bonferroni correction $p = 0.033$ corresponding to a significance level of $\alpha=0.1$) show that both flat ($W = -15$, $p = .027$) and wave ($W = -31.00$, $p = .016$) sound conditions were associated with significantly greater perceived stretch than the no-sound condition; however, difference between wave and flat sound conditions did not achieve statistical significance ($p = 0.044$) but indicated a trend in that direction. Differences were computed between the actual angle and the approximated perceived angle (APA) rather than the central value of the selected bin (Figure 2 – bottom and right). The APA was defined as the closest value to the actual angle among the smaller, middle and max values in the range represented by the selected bin (range = center of selected bin $\pm 7.5^\circ$). Differences between APA and actual angle were smaller for sound feedback than for no sound ($F(2, 21) = 4.18$, $p = .038$, $\eta^2=.37$). Post hoc paired t-tests (Bonferroni corrected) showed more accurate perception during flat sound ($t = -2.39$, $p = .024$) than no sound; no significant effect emerged for the wave condition.

The interviews shed light on how feedback helped and could be further improved. All participants found auditory feedback useful and motivating for the information about their progress, effort, and sense of space and time. All but one participant preferred the wave sound to the flat sound because it helped them “to focus on something other than what you are doing. With the up and down sound, I can hear more clearly how I am doing.” (PCP3). It helped to perceive the extent of movement, as the sound changed, increasing confidence. “I can tell if I am approaching my max stretch.” (PCP7); “Hearing the sound pitch help me be more engaged and makes it easier for me” (PCP6).

Participants reported that they used sound feedback to set challenges and to visualise the effort and challenge of the movement. “With the shape sound, it seems like I was climbing a mountain while the pitch increased. After passing the top position, I would know that I have passed a certain level and it just encouraged me that I might be able to do a bit more than that. Just very clear about where I was. But without the sound, you have no idea.” (PCP2). “The up and down one, it gives me something to achieve and I know how close or how far I am to the goal.” (PCP6). The wave sound feedback also added pleasure: “The [wave] sound is more exciting, welcoming, inspiring.” (PCP5). One participant also suggested using it to transform the exercise into a game showing appropriation of the feedback. “[The wave] gives a feedback of how well I was doing. I can see myself playing games with it.” One person preferred the flat version as she found the wave sound too distracting (PCP1). The complexity of the wave feedback may be why the flat sound led to better accuracy in perception of bending.

DISCUSSION AND CONCLUSIONS

The paper presented two related studies to investigate needs and barriers faced by people with CP when doing physical activity, and how technology could be designed to address or overcome them. A dual perspective was explored: people with CP who are learning to self-manage their condition and physiotherapists with expert knowledge and experience to support them. In this last section we discuss three important points that emerged from this work.

Designing with an understanding of CP complexity

Whilst CP shares self-management approaches with other chronic diseases [21], it is important that technology that supports physical rehabilitation is designed with an understanding of the complexity of this condition. This is particularly critical for CP because its invisibility means that its effects are often underestimated [5]. It is only recently that CP has been proposed as a disease in its own right [30] and integrated biopsychosocial frameworks [5] have been used to describe the interaction of physical, psychological and social factors in the propagation of pain, and in the impact of pain on quality of life. Current game design for rehabilitation has mainly focused in bringing fun into often boring activities [28]. While this is beneficial, our study shows that there are other key psychological factors to be taken into account when designing for CP (e.g., fear of damage, bad pain days). Simply designing technology that promotes physical activity or exergames may further expose people to a negative experience of movement or to feeling isolated with their particular difficulties as reported in CP blogs. It is hence important that these mechanisms are investigated with the different stakeholders.

Revisiting the role of technology in CP

Our study showed that both patients’ and clinicians’ perspectives were very important. Beyond a complementary understanding of the problem, they raised apparently contradictory issues that must be taken into account for technology to be effective. In CP, pain is not a danger

signal, but we have evolved to respond emotionally and behaviourally to pain as threat. Simply requiring a person to execute an exercise without addressing the meaning of pain is unhelpful and undermining of people with CP, leaving them with the feeling that their suffering is disregarded. In our design study, we attempted to address this problem by exploiting self-calibration processes and by shifting the attention to an external pleasurable representation of the feared event (bending). Our results show that the calibration process can be designed as a space for exploration of capabilities and hence appropriation of the technology to address specific needs (e.g., reassurance).

While the design of our device addresses mainly the exploration and possibly maintenance phases of the journey, the integration of the above design in systems able to automatically detect protective behaviour and identify critical emotional states [1,12,13,20,27] could provide support also for the building phase. Our findings show that the type and quantity of feedback provided by physiotherapists is based on the psychological state of the patient and on where s/he is in the journey. Analogously, technology could be tailored to respond, for example, to confident steady performance of a previously feared movement with encouragement to try a small increase or a more complex version of the same exercise. Anxiety when performing a movement could instead be met by a reminder about breathing, as suggested by physiotherapists.

Sound as a feedback for CP physical rehabilitation

Our results show that aural feedback tailored to the psychological needs and physical capabilities of the person can be an informative, effective and engaging motivator of physical activity. However, in the long term simple sound feedback could lose engagement. So the question is, what sound should be used: a simple note, a piece of music, and according to whose taste? Following [34]'s approach, sounds that facilitate movements in CP could be crowdsourced to satisfy a variety of people, different movements (e.g., more or less feared), and even mood. But what should the music model? Whilst we used sound to model movement, other aspects of the physical activity could be modelled. For example, remembering to breathe was considered important to keep anxiety and muscle tension low. Different body parts could be monitored simultaneously (e.g., arm-swing when walking rather than just regulating gait or speed). These could be obtained by mapping different music aspects to different needs and strategies. Systems for run-time authoring of pre-recorded music through non-verbal behaviour (for a review see [17]) allow, for example, a change in music style, or recomposition of existing music in different vocal or instrumental parts according to a body movement or breathing patterns. For example, when passing the baseline threshold (Figure 1 - bottom), more instrument types could be added to the music to inform and to reinforce achievement; disappearance of a vocal part could signal shallow breathing. The results from the second study found

the wave sound to be more useful as it offered more to play with and more to attend to. However, with increased complexity, the design needs to ensure the feedback is still perceptible. Again, through calibration processes the user should be in charge of setting meaningful mappings.

Finally, while the work has focused on CP, some of these findings could be generalised to other conditions where physical activity is important and where psychological barriers to movement (beyond boredom) exist.

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