

MUSICALLY INFORMED SONIFICATION FOR SELF-DIRECTED CHRONIC PAIN PHYSICAL REHABILITATION

Joseph W. Newbold & Nadia Bianchi-Berthouze

UCLIC, UCL

joseph.newbold.14@ucl.ac.uk

n.berthouze@ucl.ac.uk

Nicolas E. Gold

Dept. of Computer Science,

UCL

n.gold@ucl.ac.uk

Amanda Williams

Dept. of Clinical, Educational

& Health Psychology, UCL

amanda.williams@ucl.ac.uk

ABSTRACT

Chronic pain is pain that persists past the expected time of healing. Unlike acute pain, chronic pain is often no longer a sign of damage and may never disappear. Remaining physically active is very important for people with chronic pain, but in the presence of such persistent pain it can be hard to maintain a good level of physical activity due to factors such as fear of pain or re-injury. This paper introduces a sonification methodology which makes use of characteristics and structural elements of Western tonal music to highlight and mark aspects of movement and breathing that are important to build confidence in people's body capability in a way that is easy to attend to and devoid of pain. The design framework and initial conceptual design that uses musical elements such as melody, harmony, texture and rhythm for improving the efficiency of the sonification used to support physical activity for people with chronic pain is here presented and discussed. In particular, we discuss how such structured sonification can be used to facilitate movement and breathing during physical rehabilitation exercises that tend to cause anxiety in people with chronic pain. Experiments are currently being undertaken to investigate the use of these musical elements in sonification for chronic pain.

1. INTRODUCTION

Chronic pain (CP) affects millions of people worldwide [1]. CP is a persistent pain that remains after the expected time of healing [2]. According to the 2009 UK Chief Medical Officer's Report, "Each year, 5 million people in the United Kingdom develop chronic pain, but only two-thirds will recover" and "In England, there is currently only one pain specialist for every 32,000 people in pain" [3]. Due to this large number of cases, and the life changing effect CP has on people's lives, self-management is the main form of therapy. This work focuses specifically on Musculoskeletal chronic pain (MCP) and how sonified movement and breathing can be used to support them during physical activity. Remaining physically active is an important way for people with MCP to manage pain and maintain everyday

functioning [4]. However in the presence of pain it can be difficult to maintain a good level of physical activity as people can become fearful of specific movements. As described by Leeuw *et.al*, this fear of movement is caused "when stimuli that are related to pain are perceived as a main threat" [5]. Anxiety differs from fear as it is defined as the *anticipation* of threat. Anxiety can cause people to become hyper-vigilant of movements they perceive as threatening [5].

It is suggested that a way to reduce fear and anxiety related to these movements is improving self-efficacy [6]. Self-efficacy is the confidence in one's own ability to achieve particular goals and evidence has shown that a person with higher self-efficacy is less likely to display movement avoidance behaviour [6]. This is why it is important that a person with MCP is able to explore and understand their capabilities. Unfortunately, anxiety and over-attention to pain often does not allow people to accurately perceive their capabilities. One way that self-efficacy can be improved is through the use of feedback that can be easily attended to by reducing anxiety and overriding the attention to pain [7]. In Singh *et.al* [7], the authors identify some of the important information of which people need to be aware in order to gain confidence and be able to perform physical rehabilitation. In particular, understanding the range of movement that they are capable of before they start adopting protective strategies (e.g. guarding) or before the pain increases, correct pacing, and the minimum amount of movement for days of increased pain. It was shown that using sonification to represent movement led to increased engagement and self-efficacy in people with MCP. Sonification was used as a method for feedback due to the omnidirectional natural of sound that does not require focusing on a screen. Sound feedback has been shown to initiate motor activity and facilitate motor learning in clinical [8] and educational settings [9]. Additionally sound can be used to convey multiple streams of data at one time in a way that is still understandable [10].

In this paper, we build on that work to provide a conceptual framework to sonify movement and breathing in MCP physical rehabilitation exercises that may induce anxiety. By providing people with MCP information about their body and movement, they can better understand their capabilities and build confidence in their movement. We propose a "musically-informed" sonification approach that makes use of music structure to represent critical information about movement and breathing. By thinking about

music as not as an artistic medium but as a way to organise sound, the characteristics and structural elements of Western tonal music can be used to organise sonification in a way that provides relevant information that is easy to attend to and process. We briefly introduce chronic pain and discuss the barriers to physical activity and review the literature on the use of sound in rehabilitation. We then present our musically-informed sonification framework grounded on aspects of physical activity that are important to facilitate physical rehabilitation. We then exemplify the use of the framework, by proposing an implementation of the sonification of anxiety-inducing exercises typically used in lower back MCP physical rehabilitation.

1.1 Sonic Feedback in Chronic Pain Rehabilitation

Sonification has many benefits over traditional methods for portraying data, for example, ears have a slower rate of fatigue than eyes, the omnidirectional nature of sound means that there is no need to focus on a screen, and the auditory system has the ability to perceive multiple streams of data at once or hone into individual streams [10]. Music has seen application in CP by way of musical analgesics, where music can be used either instead of or in conjunction with traditional pain relief to reduce pain levels [11]. However as shown by Finlay, the effect of music as pain relief, is time limited and short term without cumulative effects [11]. While this may be seen as a disadvantage for its use in MCP management, it does highlight the fact that the use of sound (especially that which is musical in nature) as a feedback mechanism could be beneficial for people with MCP to undertake physical activity without pain being their main point of focus.

Nazemi *et.al* developed a series of “Soundwalks” in order to help people with CP manage anxiety [12]. These soundscapes were designed to be listened to by people with CP while in clinical waiting rooms to reduce their anxiety and help with the afterwards healthcare consultation. The soundscapes used binaural recordings of environmental sounds to emulate the feeling of going on a relaxing journey. Work has been done by Vidyarthi *et.al* to use sound to create an immersive experience for relaxation [13]. Their “Sonic Cradle” is situated in a darkened room in which the person controls different synthesised sounds through their breathing, slowly building a soundscape specific to them. This creates an experience that is not only designed for relaxation but draws on ideas from mindfulness meditation that directs focus on the person’s self in that moment. It is suggested by Vidyarthi *et.al* that such a system could be a powerful tool to help people with CP and other chronic ailments manage anxiety.

The PhysioSonic project focuses on helping people undergoing physiotherapy to better understand their body and their movement through motion capture data sonification [8]. The system used two scenarios, one emulates a woodland scene where people would reach from the ground to the birds in the sky and one where their movement would drive the playback and manipulation of a musical sample/text. The majority of people showed improvement in both shoulder flexibility and reduced evasive movement

Singh *et.al* present the “going with the flow” system, that uses sound to provide information on the current position in a movement [7]. As the person stretches forward, a smartphone on their back is used to measure the current position within a pre-calibrated exercise space, a space calibrated for each individual for each exercise. As the person moves through this space, ascending then descending notes of a major scale are played to represent their current position in the movement. This use of structured sound to provide information on the structure of movement was found to have positive results on how people with MCP perceived their movement and it was reported in interviews that people found the sound feedback helped them “hear how they were doing” [7].

In this paper, we build on the positive results shown in Singh *et.al* [7] to develop a framework for using aspects of Western tonal music that are understood implicitly, to create sonifications that deliver feedback on people’s movement and breathing.

1.2 Implicit Music Understanding

There are several aspects of music that people with no formal music training are able to discern. This is due to the implicit knowledge that is gained through exposure to music in people’s day to day lives (the nature of the specific musical knowledge gained clearly depends on the culture in which a person is immersed day to day; for this work we assume Western tonal music). For the purposes of this framework we will focus on the aspects of melody, harmony, texture and rhythm to be used for the sonification of physical activity for people with MCP.

It has been shown that people are able to easily recognise familiar tunes [14]. Deutsch showed that people are able to identify a well-known tune, “Yankee Doodle”, in three different octaves with 100% efficiency from hearing the first half alone [14]. This work illustrates how different melodies can be easily identified by non-musically trained individuals. The work done in the area of earcons also demonstrates how structured information can be given through the use of melodic phrasing [15].

Bigand demonstrates that the idea of musical stability, whether a piece of music creates tension and expectation (instability) or resolution (stability) can be identified by people with no formal music training [16].

Another aspect of how musical structure is perceived is demonstrated by the way in which people tend to synchronise their movement with music. Sensorimotor synchronisation (SMS) is the synchronisation of people’s body movements with an external reference and can be thought of most simply in the form of tapping to a beat or dancing, see Repp [17] for a review. Aschersleben discusses how this SMS is affected by musical experience, with non-musicians showing a 10ms longer asynchrony than people who reported playing a musical instrument as a hobby [18]. Although this shows that musical training improves this ability, the phenomenon is still observed in non-musicians.

Given that these aspects of music that can be understood implicitly by people with no formal musical training, it seems reasonable that they could be used by a broad range

of people with MCP to provide more effective and engaging sonified movement feedback.

2. CONCEPTUAL DESIGN FOR MUSICALLY-INFORMED SONIFICATION

In section 1.1, it was shown that sound has been used to provide both relaxation and feedback for people with CP. By using the features of music outlined in section 1.2 this information display can be enhanced to provide more effective feedback to the people, regardless of musical training. This paper considers musically-informed sonification as a way of thinking about the space of exercise for people with MCP. We describe below four musical elements that can be used to represent important information during physical rehabilitation. These elements can be used as building blocks to define sonified exercise spaces.

In physical rehabilitation, a purely biomechanical approach has been used to model movement. For example, a physical exercise (e.g., sit-to-stand, reaching forward) can be divided into phases where different phases may be characterized by changes in the movement dynamics and/or by involvement of different body parts. However, in the case of MCP, psychological (rather than simply biomechanical) aspects need to be taken into account as they may bias the perception of movement and its relationship to pain. We hence describe physical activity taking into account these two perspectives and propose how they can be represented through a musically informed sonification. Table 1 summarises a preliminary framework for how these implicitly-understood aspects of music can be used to highlight important aspects of physical activity.

Musical parameter	MCP parameter
Melody	Identifiers for different movement types and phases
Harmonic and cadential structure	Markers for specific points in movements that give either motivation (unstable), conclusion (stable) or a choice for continuation (relatively stable)
Texture	Reward for movement outwith a defined exercise space
Rhythm	Pacing for exercises, synchronisation between breathing and movement

Table 1. This table outlines the preliminary mappings for this framework, showing how musical parameters can be used to highlight aspects of physical activity important to MCP

Melody - Movement phase When a movement triggers anxiety in people with MCP, their physiotherapist breaks it into phases and ask the person to gradually build through those phases as confidence is built [7]. For example, in sit-to-stand, a physiotherapist may ask a person to first gain confidence in bending their trunk forward to gain momentum before they start to exercise the standing phase. Move-

ment phases could hence represent biomechanical phases of a movement, milestones people want to achieve as they go through a movement, or by phases of a movement that people tend to avoid. We suggest representing phases of a movement through melodic phrases. Since people seem to have an innate ability to recognise melodies implicitly, it can be used to convey information on the different phase of the movement being done. At the same time the pitch structure of the melody can provide information about the progress within the phase. A series of melodies can be used to build complex movements whose parts can be easily recognized and provide a perception of where the body is through the movement.

Harmony/Cadence - Structured Motivation Overdoing may lead to setback, at the same time underdoing may lead to further body debilitation. In order to maintain a good level of activity, people with MCP set targets they want to achieve and then gradually build on these targets. At the same time they may reset their targets during bad days (i.e., days when the pain is very strong) to ensure activity without overdoing. Overdoing may lead to setback, at the same time underdoing may lead to further body debilitation. We propose the use of harmonic structure and cadence to represent targets and intermediate milestones that indicate progress towards those targets. We identify three types of targets: (i) a milestone that needs to be achieved but that does not indicate the end of the movement; (ii) a minimum target that needs to be achieved and where a movement may end if desired (e.g., for bad days or for facilitating building); and (iii) a maximum target where the movement need to end to avoid overdoing. The use of these targets depends on the psychological and physical needs and capabilities of the person. As discussed in section 1.2 musical stability can be thought of as the likelihood of a musical piece ending or whether it must continue to resolution and this can be manipulated in part through the use of harmony. The level of musical stability can be used to create a degree of ambiguity as to how far a certain phrase or movement should go before ending. By exploring different levels of stability at key points in a movement, a person could receive additional motivation through the use of tension to continue that movement. At the same time and possibly more importantly, the end of the set exercise space could resolve onto a point of relative stability but not complete resolution allowing the person to continue if they wish, but also the music to have an acceptable ending if not. Cadence points can be used within a melodic phrase or to characterise the ending of a phrase or the transition to a separate phase.

Texture - unstructured motivation Some phases of a movement may not have specific end points and thus cadence and melody may not be suitable to model them. Another musical element that can be used to provide information on progress through movement without a specific ending is texture. Texture as defined by Cohen and Dubnov is “the way of distributing the sound (of defined or undefined pitches) in the dimensions of frequency, time, and intensity” [19]. In this paper we refer to a simplified idea of texture that remains harmonically static but increases in in-

tensity by increasing the number of notes in a given metrical timeframe, an increasing spread in the voicing of those notes and decreasing the duration of each note. This mapping would reward movement with a richer soundscape, but is not limited by a defined exercise space.

Rhythm/Tempo - Pacing Breathing is a very important part of movement. Deep breathing can lead to relaxation whereas shallow breathing indicates and leads to anxiety [7]. In addition, breathing (as a pleasurable sensation) can be used to help keeping the right pacing. Using the idea of sensorimotor synchronisation (SMS) and a simple breathing sonification, the pacing of peoples' breathing could be regulated using a reference rhythmic pattern at a set tempo. Through this mapping a person can refocus on a more positive aspect of activity which is then used to synchronise breathing and movement to a set pace.

3. AN EXAMPLE OF IMPLEMENTATION OF THE FRAMEWORK

Below we outline a series of examples of how the different aspects of the framework could be utilised by people with MCP to develop their own sonification, the individual composition of these sonifications can be left to the specific person with MCP and possibly with physiotherapist to apply this framework suits their individual needs and exercises. The below example demonstrates a possible application of this framework on a common exercise in the physical rehabilitation of chronic back pain: the stretch forward [7]. This exercise can be thought of as having three phases, an initial stretch to a minimum amount of stretch, a stretch to a target point and then a final phase that allows continuation, see Figure 1.A.

3.1 Melodic Design

As in Singh *et.al* [7], the ascending then descending scale can be taken as a base for the simple stretch forward movement (Figure 1.A, with the ascending section corresponding to the first half of the movement (phase 1) where the back is bent and the stretch begins, and the descending section corresponding to the final reach forward (phase 2). This melody can then be used to inform the design of other movements, for example the sit-to-stand movement (shown in Figure 1.B).

The sit-to-stand movement can be broken down into three phases with the bending of the trunk to gain momentum for standing up being the first phase (the one most avoided by people with MCP as perceived as inducing pain). However, by avoiding it, standing becomes harder and they may need to use strategies that in the longer term may indeed induce pain or may in itself reduce confidence in the ability of performing the movement. The same ascending melody used for the stretching forward could be used to sonify the first phase of the sit-to-stand. The sonification of the phase through melody may increase awareness of its performance or the lack of it. This breakdown of movement phases into simple melodies could be a useful way to build more complex movements and could enable collaborative exploration and learning of new movements between the

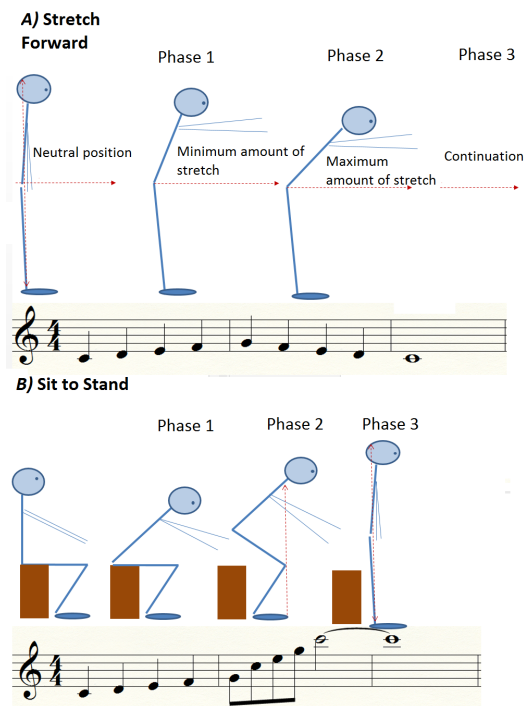


Figure 1. An example of how the melodic design could be used to highlight the similar sections of the two movements, showing a stretch forward and a sit to stand that uses the same melody for the initial stretch forward.

person with MCP and physiotherapist, perhaps in a similar fashion to that demonstrated by Smith and Claveau [9].

However this design requires defining the boundaries of a movement space to increase confidence in moving. As discussed, our framework allows us to define boundaries that may encourage or not trespassing them. Additionally the simplistic musical phrases provide little motivation and engagement and thus far focus only on the person's movement.

3.2 Stability Design

In the stretching forward exercise, the boundaries can be thought as the passing of the minimum amount of stretch desired and the maximum amount of stretch required. Through the use of harmony, we can now mark both a possible conclusion or continuation of a movement when a boundary is reached. For example, the minimum amount of stretch can be thought as a milestone to be reached but we may not want to encourage stopping at that point. Whereas, the maximum target point could be either designed to encourage stopping at that point or to encourage and reward further building on that target. As shown in Figure 2, the same ascending/descending pattern could be used as discussed above, but by more firmly establishing a harmonic context, cadences can be used as the markers of the anchor points and promote continuation or conclusion.

Figure 2.A shows this unstable design, where an imperfect cadence is used to mark the the minimum amount of stretching point as an intermediate milestone and encour-

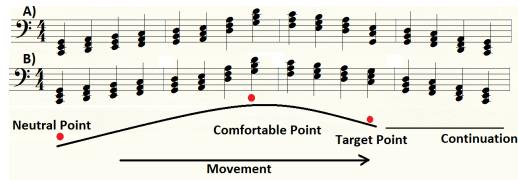


Figure 2. A) Unstable design, uses a second inversion tonic chord to promote an amount of instability at the maximum target point to allow continuation. B) Stable design, resolves to the tonic at the target point to indicate ending. In both designs an imperfect cadence is used at an intermediate point to provide motivation to continue towards resolution.

age continuation. This relatively unstable cadence offers some amount of resolution but also allows continuation. The same can be used for the maximum target point when building over it is encouraged (continuation phase). Figure 2.B shows a counter example for the maximum target point where a perfect cadence is used in place of the imperfect one, so at the anchor points the harmony is resolved and there is no motivation to continue.

It should be noted that in the case of the stretching forward exercise, these designs treat the maximum stretch position as the point of musical conclusion. In future work the return movement could be examined and the final neutral position would be the concluding point, with the cadences above acting as the “turning point” for the movement. This simple design exercise seeks to highlight the benefits that manipulating harmonic stability could provide to an exercise space, however they do not examine some of the difficulties that trying to isolate harmony from other musical factors such as voicing, rhythm and note duration would entail (indeed, greater success might be achieved by explicitly manipulating the combination of these musical parameters: a subject of our future work).

3.3 Texture Design

An alternative mapping could be from movement to texture. In this instance texture can be thought of as the richness of the sound. This mapping would allow the sound to retain its harmonic stability and would not necessitate any specific points be reached. For this implementation the amount of movement from the neutral position could be mapped to the amount of arpeggiation around a base note/chord, with increasing movement leading to a higher probability of a higher number of notes occurring in a given metrical timeframe. This mapping rewards movement no matter how far the person moves and simply decreases back to a single note as they return to the neutral point. This design therefore offers a much greater amount of freedom in the movement, with potentially no set boundaries for the exercise space. This is very important to encourage body exploration (for example) and to ensure that no message of “right” or “wrong” movement can be inferred. This is particularly important in the first phase of CP rehabilitation where the person is learning to gain confidence in moving and managing their anxiety [7]. However the ob-

vious downfall of this design is the lack of structure which would make it difficult for people to gauge how far they have gone or if they have reached a certain point. Although over time judgement may be formed as to the meaning of a given level of arpeggiation, the precision of such judgements would be intrinsically low. This method also does not allow for the definition of multiple movements as it merely correlates the composite richness of texture with extent of movement. More complex movements might be modelled by mapping different movement types to the constituent components of that composite.

3.4 Rhythm Design

By using a sonification of people’s breathing, this more pleasurable sensation can be made the focus of their activity and promote a more relaxed state [7]. Our initial sonification provides a high-pitched note for the inhalation and a lower-pitched note for the exhalation (V-I) with the volume of the notes mapped to the respiration amplitude, similar to the note sonification used by Watson and Sander-son’s respiration sonification used to help anesthesiologists monitor the breathing of patients [20]. By providing a reference rhythm (in terms of the durations of the high and low pitches), the person with CP is encouraged to bring their breathing in time with reference pitches by listening to the sonification. This rhythm could then also be used to pace the movement, while also bring the breathing and movement in to synchrony. Although this design focuses on what may be a more pleasant aspect of movement it may facilitate better pacing.

4. CONCLUSIONS AND FUTURE WORK

We presented a framework where different musical elements are used to inform the sonification of different elements of an exercise space. These sonifications can be used to structure information that is easier to attend to and devoid of pain and hence enable confidence-building in movement. Each of the elements of the sonification spaces has its own benefit and through their combination different sonification spaces can be designed. By using a combination of the melodic and instability designs, cadences can be used to mark milestones for various movements. Movement beyond the target or comfort points can be rewarded through textural changes but without the need for a defined space (and thus a pre-defined harmonic structure). The breathing feedback could be used in unison and with a reference rhythm to provide pacing for both breathing and movement activities. It may even be possible to synchronise breathing and movement with the milestones, as shown in Figure 3.

In future work we will investigate further the effects of these individual musically-informed designs to evaluate how they can be used by people with MCP in their physical activity. We will explore the degree to which the sonifications are understood in the context of prior musical training. This will be done using a series of studies investigating each aspect of the proposed framework individually, evaluating both how the affect peoples physical activity and their

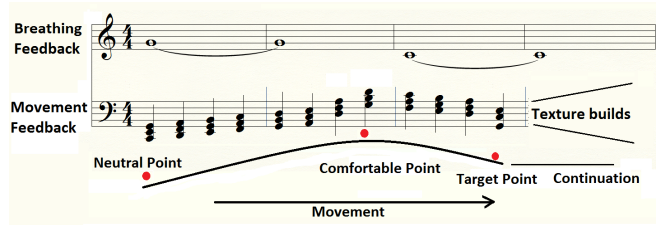


Figure 3. A combination of the designs for a musically informed sonification that uses parts of all four designs discussed in section 3.

perceptions of it, specifically their self-efficacy. It will then be explored how these aspects can be used together as described above as a single musically informed sonification system. This will determine the success of this framework, whether it can use this implicitly understood musical elements to highlight important aspects of feedback. Outside of MCP this style of framework could be used in other areas where it is important to promote awareness, wherein the specific mappings used may vary dependent on the feature to be highlighted, but the principle of using these musical elements to highlight important aspects of the feedback.

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