PhD Thesis

# Musical expectancy within movement sonification to overcome low self-efficacy

**Supervised by** Professor Nadia Bianchi-Berthouze and Dr Nicolas Gold

Joseph William Newbold

A dissertation submitted in partial fulfilment of the requirements for the degree of:

**Doctor of Philosophy** of **University College London** *

*UCL Interaction Centre, Division of Psychology and Language Sciences, University College London

# Declaration

I, Joseph William Newbold confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

# Acknowledgements

Firstly I would like to thank my supervisors, without them this thesis would not have been possible. Nadia Bianchi-Berthouze, who has always pushed me to improve and who has shared her passion for understanding with me throughout, Nicolas Gold who has be a source of ideas and inspiration. In addition, I would like to thank Amanda Williams for coming on as my tertiary supervisor giving me guidance and insight, as well as Nic and Duncan for conducting my registration and upgrade Vivas respectively.

Additionally, I have been grateful to have such supportive colleagues and friends during my time at UCLIC. Thank you all for your advice, comfort and friendship.

This thesis was funded by an EPSRC doctoral training grant, reference: 1481197.

Finally, I would like to thank my family, friends and Milly for helping me through this process and always being there when I needed them.

**Abstract:**

While engaging in physical activity is important for a healthy lifestyle, low self-efficacy, i.e. one's belief in one's own ability, can prevent engagement. Sound has been used in a variety of ways for physical activity: movement sonification to inform about movement, music to encourage and direct movement, and auditory illusions to adapt people's bodily representation and movement behaviour. However, no approach provides the whole picture when considering low self-efficacy. For example, sonification does not encourage movement past a person's expectation of their ability, music gives no information of one's capabilities, and auditory illusions do not direct changes in movement behaviour in a directed way.

This thesis proposes a combined method that leverages the agency felt over sonification, our embodiment of music and movement altering feedback to design *"musical expectancy sonifications"* which incorporate musical expectancy within sonification to alter movement perception and behaviour. This thesis proposes a Movement Sonification Expectation Model (MoSEM), which explores expectation within a movement sonification impact on people's perception of their abilities and the way they move. This MoSEM is then interrogated and developed in four initial control studies that investigate these sonifications for different types of movement as well as how they interact with one's expectation of a given movement. These findings led to an exploration of how the MoSEM can be applied to design sonification to support low-self efficacy in two case study populations: chronic pain rehabilitation, including one control study and one mixed methods study, and general well-being, including one interview study and two control studies. These studies show the impact of musical expectation on people's movement perception and behaviour. The findings from this thesis demonstrate not only how sonifications can be designed to use musical expectancy, but also shows a number of considerations that are needed when designing movement sonifications.

# Impact Statement

This thesis offers a new sonification design method, through using musical expectation within movement sonification. The development of this method has impacts on both the fields of sonification and sonic interaction design. The work in this thesis responds to a need for a better understanding of how the use of musical structure within sonification impacts how the underlying data is perceived. Moreover, it shows the impact different sound design choices have on people's movement behaviour and perceptions, and how these sound design choices can be evaluated through a combination of quantitive and qualitative methods. In addition, this work has impact on the emerging field within human-computer interaction of body centred feedback. The studies within this thesis demonstrate how musical structure can be used to alter people's expectation of their own movement, and in turn, alter the way people move. Moreover, it identifies some critical factors, such as the amount by which this expectation can be altered, which affects how these sonifications are used. These are important findings when considering the design of such body centred feedback and should be taken into consideration when embedding expectancy into sonification.

Outside of an academic impact, this thesis also has ramifications for the design of feedback mechanisms to support physical activity. The work presented in this thesis seeks to not only address environmental and financial barriers to physical activity through the use of wearable and mobile technology but also to address the barriers associated with low self-efficacy. While it is well understood that physical activity is important to people's everyday lives, people with limited belief in their own ability struggle to maintain regular physical activity. The sonification design method presented is based on the need for not only performance feedback but also to help attribute success and encourage progress. These issues are addressed through work with populations who struggle with physical activity due to low self-efficacy. Working both within the context of chronic pain and general well-being, the insights gathered from real people provide a deeper understanding of how to create effective and engaging technology for people who struggle with physical activity.

This work addresses a need for more advanced and adaptive feedback strategies, to accompany the recent advances in movement tracking and automatic recognition. Systems which can potentially detect when an individual needs additional encouragement or, if they have reached their limit, require new feedback mechanisms to support them.

# Publications

## Publications related to this thesis

**Joseph W Newbold**, Nadia Bianchi-Berthouze, Nicolas E. Gold, and Amanda Williams, *"Musically Informed Sonification for Self-Directed Chronic Pain Physical Rehabilitation,"* in Sound and Music Computing, 2015. Presented as part of chapter 4

**Joseph W Newbold**, Aneesha Singh and Nadia Bianchi-Berthouze *"Musically Informed Sonification for Self-Directed Chronic Pain Physical Rehabilitation,"* in Pervasive Health, 2016. Presented as part of chapter 5

**Joseph W Newbold**, Nadia Bianchi-Berthouze, Nicolas E. Gold, Ana Tajadura-Jiménez and Amanda Williams , *"Musically Informed Sonification for Self-Directed Chronic Pain Physical Rehabilitation,"* in CHI, 2016. Presented as part of chapter 5

**Joseph W Newbold**, Nadia Bianchi-Berthouze, Nicolas E. Gold *"Musical Expectancy in Squat Sonification For People Who Struggle With Physical Activity"* in International Conference on Auditory Display, 2017. Presented as part of chapter 5 and 8

**Joseph W Newbold**,Nicolas E. Gold and Nadia Bianchi-Berthouze *"Visual cues effect on the impact of sonification on movement"* in Proceedings of the 5th International Conference on Movement and Computing, 2018. Presented as part of chapter 6

## Additional Publications

**Joseph W Newbold**, Andy Hunt and Jude Brereton *"Chemical spectral analysis through sonification"* in International Conference on Auditory Display, 2015.

**Joseph W Newbold**, Jacob Luton, Anna Cox and Sandy J. Gould *"Using nature-based soundscapes to support task performance and mood"* in CHI, 2017.

Temitayo Olugbade, Luigi Cuturi, Giulia Cappagli, Erica Volta, Paolo Alborno, **Joseph W Newbold**, Nadia Bianchi-Berthouze, Gabriel Baud-Bovy, Gualtiero Volpe, Monica Gori *"What cognitive and affective states should technology monitor to support learning?"* in ICMI, 2017.

Temitayo A Olugbade, **Joseph W Newbold**, Rose Johnson, Erica Volta, Paolo Alborno, Radoslaw Niewiadomski, Max Dillon, Gualtiero Volpe, Nadia Bianchi-Berthouze *"Automatic Detection of Reflective Thinking in Mathematical Problem Solving based on Unconstrained Bodily Exploration"* in ICMI, 2017.

Ana Tajadura-Jiménez, **Joseph W Newbold**, Linge Zhang, Patricia Rick and Nadia Bianchi-Berthouze *"As Light as You Aspire to Be: Changing Body Perception with Sound to Support Physical Activity"* in CHI, 2019 (Accepted).

**Joseph W Newbold**, Sean Rintel, Gavin Doherty and Anja Thieme *"Politeness Strategies in the Design of Voice Agents for Mental Health"* in CHI, 2019, Workshop paper (Accepted).

## Doctoral Consortia

Doctoral Colloquium, Pervasive Health 2016.

Doctoral ThinkTank, International Conference on Auditory Display 2017.

# Contents

# List of Figures

# List of Tables

# Glossary

| **Term** | **Meaning** |
|---|---|
| Musical Expectancy Sonification (MuES) | Sonifications which use musical expectancy to impact movement behaviour and perceptions |
| Movement Sonification Expectation Model (MoSEM) | The model through which MuES are explored and designed |
| Musical expectation | The expectation of how a piece of music should continue or conclude |
| Self-efficacy | The belief in one's own ability to do a certain task |
| Stability | The amount of resolution vs tension in a musical phrase<br>i.e. how likely a piece is to conclude/continue |
| Harmonically stable | Music which sounds harmonically resolved |
| Harmonically unstable | Music which sounds harmonically unresolved |
| Chronic pain(CP) | Pain that persists past the time of of expected healing |
| Sonification | The use of sound to systematically display data |
| Western music | The musical tradition of western culture |
| Tonal music | Music that follows a musical key |
| Cadence | A harmonic structure used to end musical phrases with varying stability |
| Soundscapes | An immersive environment consisting of sound |

| | |
|---|---|
| Chord progression | A series of musical chords played in succession |
| Tempo | The pace of a piece of music |
| MIDI | A protocol often used for the transfer of musical performance data |
| ADSR | The parameters of the amplitude envelope of a sound: Attack(the onset),<br>Decay(of initial energy), Sustain (of the transient) and Release(offset) |
| Stereo pan | A spatial mapping that uses mapping between two speakers right and left |
| Middle C | A standard note often used as a default note by convention |
| Tonic | The most stable point in a given key |
| Dominant | The fifth note from the Tonic in a given key often used to create harmonic tension (instability) |
| SubDominant | The fourth note from the Tonic in a given key |
| Perfect cadence<br>the tonic of a key, generally regarded as stable | A cadence that moves from the dominant to |
| Imperfect cadence<br>the dominant of a key, generally regarded as unstable | A cadence that moves from the tonic to |
| Inverted chord | A chord where the lowest note is not the root of the chord<br>e.g a C major chord is formed using notes CEG, a first inversion |

| | |
|---|---|
| | C major takes the form EGC |
| Texture | The "thickness" of a piece of music, how many sounds are present in a piece of music |

# 1. Introduction

Sound has been shown to be a powerful tool in supporting physical activity. Previous work has shown how sound can be used to inform people of their movement (movement sonification)[Schaffert et al., 2019], encourage movement (music) [Karageorghis et al., 2008]and adapt people's bodily perception (auditory illusions) [Tajadura-Jiménez et al., 2017b]. Each of these approaches has advantages to supporting physical activity; however, when considering people who struggle with physical activity due to low self-efficacy, i.e. one's belief in one's own ability [Bandura, 1977], no approach can fully support people past their perceived barriers to physical activity. While sonification provides real-time feedback on one's movement and allows people to understand their capabilities [Effenberg, 2005], the overall goal of sonification is to inform [Scaletti, 2018], not to offer any encouragement past what one believes they can do, nor to explicitly reward one's efforts and successes. Music has been shown to encourage people to move more, feel less exertion and even change the way they move [Karageorghis et al., 2008, Komeilipoor et al., 2015]. However, it does not provide any information related to the activity being done. Finally, manipulating auditory feedback from one's own movement has been shown to alter not only one's body perception but also one's movement behaviour [Tajadura-Jiménez et al., 2017b]. However, these approaches provide no encouragement towards a specific aspiration or reward.

This thesis explores how by considering a combination of these approaches, by incorporating musical expectation within sonification of movement, sound can be used to inform, encourage and induce changes in one's movement behaviour and perceptions and through this, overcome barriers faced by people with low self-efficacy.

## 1.1. Using sound to support self-efficacy

Building self-efficacy, the belief in one's own ability, and the self-attribution of success is important for people who struggle with physical activity [Bandura, 1977, Sonstroem and Morgan, 1989]. If an individual has limited belief that they can complete physical activity, or that they can complete it "correctly" , they are more likely to abandon their routine and return to inactivity [Shieh et al., 2015]. These barriers need to be addressed in order to support people who struggle with physical activity.

[Schunk, 1995] shows how across domains, self-efficacy is predictive of both performance and motivation. Schunk describes both performance feedback, which informs the individual about what they have done and attributional feedback, which helps individuals link their effort with their success [Schunk, 1982]. Examples of this kind of feedback can also be seen in physical activity. For example, chronic pain physiotherapists will use such affirmational feedback to encourage movement during feared activities [Singh et al., 2014]. In addition, people often use strategies such as "self-talk" to push themselves past their perceived limits [Patel and O'Kane, 2015].

When considering how sound has been used to support physical activity, for the purpose of this thesis it can be divided into three main strategies:

- **Sonification**: that aims to inform people of their physical activity to allow them to improve and gain a better understanding of their ability. Sonifications allow one to reflect on one's own movement and therefore improve technique and track progression.

- **Music**: that aims to encourage physical activity implicitly allowing people to change the way they move. Through following the music, the individual can be guided to alter their movement and increase motivation.

- **Auditory illusions**: that aim to adapt people's body representations allowing for an altered perception of oneself and movement behaviour. Through the use of these external auditory representations of oneself, the internal representation of one's body and capabilities can be changed, leading to a change in the way a movement is performed.

Sonification has been used to support the correction and optimisation of the execution of movements in both sports and physical rehabilitation, see Schaffert *et al.* for review [Schaffert et al., 2019]. The benefit of sonification is that it is driven by one's movement which generates a sense of agency over the sound, allowing people to use it to understand their movement better. Previous sonification mappings, as illustrated in Figure 1.1, generally use an "informative approach", in which either only the desired movement is sonified, or deviations from the desired trajectory are mapped to a deviation/distortion of the sound [Sigrist et al., 2013]. This allows the user to infer from the sound whether their current movement path is correct and to adjust accordingly. While this approach has been shown to be effective, it does not consider how the psychological barriers that some people face during physical activity may disrupt their ability to engage in the correction of the movement. For example, the crossing of a fear-related boundary or one's belief in one's ability to complete more repetitions; these barriers are difficult for people to overcome when self-efficacy is low [Woby et al., 2007, Biddle and Mutrie, 2007].


Figure 1.1: The informative model adopted by movement sonifications that aim to inform people of their movement, the sound is driven by the movement allowing for the individual to use it to optimise their movement

Secondly, the use of music provides a different approach: aiming to encourage individuals rather than directly inform. Music has been shown to encourage movement and provide motivation during exercise [Karageorghis et al., 2008, Mohammadzadeh et al., 2008]. It can be used to encourage people to continue physical activity through motivation and can even encourage people to move in a certain way [Repp, 2005, Komeilipoor et al., 2015, Rodger and Craig, 2011]. As illustrated in Figure 1.2, the individual follows the sound of the music with their movement and therefore, their movement is driven by the music itself. While these music-based approaches have been shown to motivate physical activity effectively, they do not provide any information related to the activity being done. Therefore, it can be difficult to map this encouragement to an individual's own capability, and moreover, it may be difficult for individuals to understand the improvements they have achieved.

The third approach uses the agency felt over sonification to create auditory illusions through movement-altering sound feedback. Sensory feedback from the outside world, received upon an action, is used to constantly evaluate and adjust one's perception of one's body and the environment [Botvinick et al., , Dichgans and Brandt, 1978, Wolpert and Ghahramani, 2000]. If aspects of this feedback are altered, it not only changes


Figure 1.2: The encouraging model adopted by music that uses people's embodied understanding of music to direct their movement, where the individual's movement is driven by the music

one's perception of their own body but can also change people's movement behaviour [Tajadura-Jiménez et al., 2015a, Harvie et al., 2015, Steinicke et al., 2010], illustrated in Figure 1.3. These approaches show how sound can alter body movement directly, e.g. high-frequency footsteps making one feel lighter and move more briskly [Tajadura-Jiménez et al., 2015a] or altering movement performance through friction sounds [Frid et al., 2018]. However, they do not explore how we can leverage this change in body perception to help surpass self-efficacy related barriers.


Figure 1.3: The adaptive model adopted by auditory illusions that alter people's bodily representation through manipulated auditory feedback. Through manipulating the auditory cues people use to build their representation of self, one's movement behaviour and perceptions may be altered.

Examining these three approaches highlights the need for a combined approach in order to overcome the barriers of low self-efficacy in physical activity. While sonification can be used to inform about current capabilities, it offers no encouragement for progress when one's expectation of one's ability is low. Music has been shown to direct the way in which people move but holds no relation to one's own movement/capabilities. Finally, although it has been demonstrated how auditory feedback can alter bodily perceptions and behaviour, it is yet to be seen how this can be leveraged to direct motor behaviour change to overcome barriers related to low self-efficacy, such as fear to pass a certain boundary.

## 1.2. Problem Statement

The three uses of sound shown above, i.e. to inform, encourage and adapt, all offer support for physical activity. However, it is yet to be explored how these methods can be combined to make use of both the agency one feels over real-time feedback and the encouragement provided by music, which supports progress, to use sound feedback to support a change in motor behaviour and perception in order to support self-efficacy, as shown in Figure 1.4.


Figure 1.4: This thesis' combined approach, considering leverage embodied aspects of music within sonification to not only inform but through the agency felt over the sound and the embodiment of the music to alter movement behaviours and perceptions.

Dubus and Bresin offer a systematic review of mapping strategies and demonstrate that the majority of sonification designs focus on either pitch-based mapping or spatial sound mappings and call for more rigorours design and evaluation of sonification methods[Dubus and Bresin, 2013]. This thesis, therefore, develops a sonification design method. By combining embodied and implicit musical structures [Polotti and Rocchesso, 2008, Leman, 2008] with sonification, a musically-informed sonification is designed which aims to both provide a sense of reward/motivation and to direct change in motor behaviour, through encouragement rather than correction.

Specifically, this work explores how musical expectancy can be used within sonification. Music can be thought of a series of implications and realisations [Meyer, 1957]. Through one's past experience as a music listener, an expectancy of how the music should continue is developed, which can either be realised or defied. It is this manipulation of expectancy which leads to the tensions and relaxations that are felt in a piece of music. In addition, there is also an expectation of one's own movement, where there is a specific target to reach. This expectation of movement is especially important for populations with low self-efficacy; due to their limited belief in their own abilities they may require additional affirmational feedback to encourage them past perceived barriers of what they may think is their limit [Singh et al., 2014, Patel and O'Kane, 2015] and to announce the progress they have made [Schunk, 1995].

This thesis proposes that manipulating the musical expectancy within a sonification can either invite the conclusion of movement with musical completion or to promote continuation using musical tension. By designing sonification to leverage the underlying elements and structures of music that create musical expectancy, the implicit understanding that is developed through exposure to music can be used to adapt one's expectation of one's own movement. For example, manipulating musical expectancy through harmonic stability (whether music sounds harmonic complete or not) [Bigand, 1997] could be used to motivate people to continue a movement in order to reach a harmonic resolution.

This mechanism is investigated in the context of movement target points, so as to better support people in the moment of exercise. For this thesis, movement target points are defined as points that one should either reach or pass, e.g. the end of a stretch or the bottom of a squat. Previous works have designed sonifications that the individual can use to be informed that they have reached a certain target [Wallis et al., 2007, Huang et al., 2005, Singh et al., 2014], but they make no assertions of what they should do at that point. Moreover, these methods do not consider the implications of one's expectation of one's own movement, and the need for not only information on their performance of the movement but also encouragement as to how to progress.

## 1.3. Research Questions

This leads to the main hypothesis of this thesis:

*"Musical expectancy can be used within movement sonifications to impact movement behaviour and perceptions for people with low self-efficacy"*

This can be broken down into a series of sub-research questions, seen in Figure 1.5, which form the backbone of this thesis. These cover four main areas: 1) designing the Movement Sonification Expectation Model (MoSEM) for developing musical expectancy sonifications (MuES), 2) evaluating the MoSEM 3) extending the MoSEM by considering the impact of a expectation of a given movement and 4) applying the MoSEM to populations with low self-efficacy.

### 1.3.1. RQ1:Can a model of movement sonification expectation be designed to examine sonification's impact on movement?

In order to understand how musical expectation can be used within sonification, firstly a model to understand how incorporating musical expectancy into sonification may impact people's movement behaviour and perceptions is needed. Chapter 4 proposes an exploratory model to understand sonification's potential effects on movement behaviour and perception. By considering the three approaches to using sound addressed in this thesis and through exploration of different models for musical expectancy a model for understanding its use in movement sonification can be developed. This Movement Sonification Expectancy Model (MoSEM) is developed from Huron's model of how people experience expectation [Huron, 2006] and considers the impact of the individual's agency on the experience [Wolpert and Ghahramani, 2000]. With this agency felt over the sonification, this model proposes that the feedback will adapt people's perception of their movement, through the integration of their movement expectation with the musical expectation, similar to what has been seen when altering the auditory signals from one's body movement [Tajadura-Jiménez et al., 2017b].

This leads to two main predictions of the MoSEM. The first is that when the musical expectation is met at the target point of a movement (i.e. a musically stable ending), the perceived end of the movement will match with the perceived end of music, and as such the movement will feel complete. The second is that when the musical expectation is not met (i.e. a musically unstable ending), when the musical ending is perceived as incomplete at the end of the movement, this feeling of incompletion will transfer to the movement leading to a continued movement and a motivation to go further.

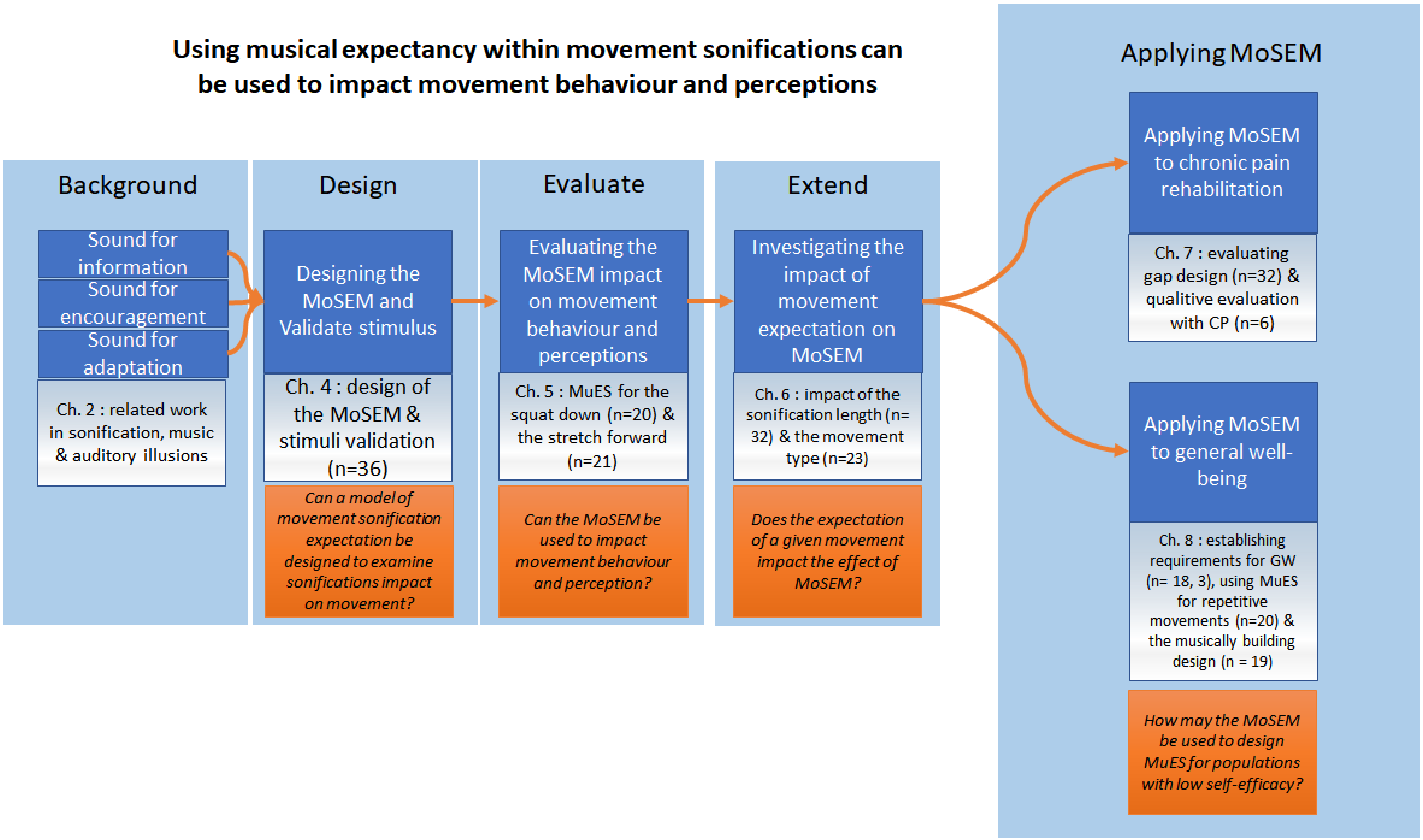



Figure 1.5: A breakdown of the thesis structure showing the main research questions within this thesis, covering the four stages of research: design, musical expectation sonification, movement expectation and applying the movement sonification expectation model

These two predictions of the MoSEM form the basis of future investigations into MuES and are interrogated and developed throughout the thesis. In addition, in Chapter 4 a series of stimuli validation, by means of listening tests, is presented. While previous work has shown that both musicians and non-musicians can perceive the completeness of a given musical cadence when considering which musical endings to use in a musical expectancy sonification the most appropriate choice for which cadence to use must be made. Therefore, a series of listening tests was employed to investigate how the length of a musical phrase and the cadence used impacted the perceived completeness of the phrase.

### 1.3.2. RQ2: Can the MoSEM be used to impact movement behaviour and perception?

From these proposed sonification designs, the MoSEM can be explored within real movements, and the predictions from chapter 4 evaluated. This is achieved through two lab studies, found in Chapter 5, to explore its effect on two different movements: the stretch forward movement and the squat down. These two movements were chosen both because they are suited to populations with low self-efficacy, people with chronic pain for the stretch forward [Singh et al., 2016] and people struggling to engage in general physical activity for the squat down [Myer et al., 2014]) and because they offer very different movement types. The stretch forward is a relatively open movement with no predefined target point and the squat down is instead relatively closed with a clear end point, i.e. squatting down to 90 degrees.

The MuES are tested from both movements in a lab setting, using a smartphone setup to both track the movement and produce the sonification. From these studies, a variety of both behavioural and self-report measures are taken to examine the MuES effect on movement. For the stretch forward movement, it is shown that stable endings lead to a shorter movement, in terms of movement past the target point and the time taken to return, as well as a greater feeling of reward when the target is reached. As for the unstable conditions, there is more movement past the target, and it takes people longer to return. The findings align with what was predicted in the MoSEM and demonstrate that the musical ending of the sonification can impact movement behaviour and perception. However, in the squat down study, no significant difference was found for the amount of movement or the time taken to return. While people report feeling motivated to continue on for unstable endings and a greater sense of achievement in stable endings, there was no significant difference in their movement behaviour. This leads to questions as to why the two movements may be differently affected by MuES and what other factors may be impacting people's motor behaviour.

### 1.3.3. RQ3: Does the expectation of a given movement impact on the effect of MoSEM?

The studies in the previous section demonstrate that MuES can be used to affect movement behaviour and perception. However, they also demonstrate some disparities that remain unexplained by the MoSEM. Namely, the interaction which is seen with the set musical expectation and one's expectation of the movement itself, from either the length of the movement or the level of additional cues at the target point. These two phenomena are examined by exploring how one's expectation of a given movement may alter the predictions of the MoSEM, in Chapter 6.

First, a study explores how the length of the stimulus may impact the perceived stability of the sonification itself, not because of the length of the sonification or any musical cue, but due to the individual's own expectation of how far they should move. For instance, in a longer sonification, they may be expecting the end of the sonification, as they approach the end of their expected movement. However, when the sonification falls short of the expected movement people are not as ready to stop due to their established expectation of the movement. Secondly, a study investigates how the different level of additional cues available during certain movement types may alter how much they are affected by MuES. For example, in the squat down movement, there are clear visual indicators when the end of the movement is approached (i.e. the ground or the bend in the legs), while in the stretch forward movement the end point is less concrete and hence more easily manipulated by MuES.

From these results, the MoSEM can be reconsidered to include the impact of external cues and preconceptions of the movement which may mitigate the effectiveness of the MuES. Namely that when these additional cues are high the MuES effect on motor behaviour may be lessened; however, the changes in people's perception of their movement is still seen. Such differences should be considered when deploying the MoSEM to design sonifications for specific movements.

### 1.3.4. How may the MoSEM be used to design MuES for populations with low self-efficacy?

After the proposed MoSEM has been interrogated and iterated through the series of studies shown in Chapters 5 and 6, two case studies are presented to demonstrate how the MoSEM can be used to design MuES for populations who struggle with low self-efficacy. These two case studies focus on people with chronic pain and general well-being, in Chapters 7 and 8 respectively. From these two case studies, both the potential for using MoSEM to design MuES sonifications for low self-efficacy populations and open questions for the MoSEM can be explored.

Within physical rehabilitation for chronic pain, previous work has demonstrated how low self-efficacy can lead to avoidance of certain movements [Woby et al., 2007] and a need to encourage progress while avoiding over activity [Singh et al., 2014]. This is explored through the stretch forward movement where the amount of movement past a given target point can be manipulated using MuES. To make use of this, a “gap” is employed, so that an unstable musical ending can encourage the individual past a certain boundary, and they will be rewarded by the continuation and completion of the musical phrases, but while not directly being punised for not crossing the gap, an important factor in designing for chronic pain [Singh, 2016]. Similarly, the stable ending can be used to encourage people to end a movement at a certain target while allowing them to explore further if they desire. This design is studied first through a lab study with a general population, and a more qualitative study with people with chronic pain to examine both how effective MuES may be and how people with chronic pain may apply it in their everyday lives.

In the second case study, the focus is on general wellbeing. Previous work has shown how people struggle to maintain an exercise routine, and the impact low self-efficacy can have on people’s ability to see improvement [Biddle and Mutrie, 2007, Sonstroem and Morgan, 1989]. This case study focuses on how MuES can be used to help overcome these barriers. Firstly, a series of interviews with personal trainers and people who struggle to engage in physical activity, were conducted to understand better how these barriers manifest how they are currently overcome. From these findings, some design requirements are formed and investigated through the MoSEM to create a MuES sonification that can both inform people of their technique and encourage repetitions. This is then examined across two studies which explore how MuES can be used to support repetitions of the squat down movement leveraging the changes seen in movement perception.

## 1.4. Thesis structure

This thesis can be broken into five sections, namely: the initial forming of the problem space from the related literature and four stages of research: the developing the initial design model, exploring its impact on movement behaviour and perception, investigating the impact of movement expectation and applying this model to support people with low self-efficacy.

The first is concerned with outlining the background literature on the subject (Chapter 2). The ways in which sonification, music and auditory illusions have been used to inform, encourage and adapt physical activity are reviewed, highlighting the contrast between sonification methods, which use information about body movements to correct movements, how we use music in physical activity to encourage movement and how auditory feedback can be used to alter bodily perceptions.

From this, the methodological approach and core research questions of the thesis are outlined (Chapter 3). Specifically, it proposes that musical expectancy can be used within movement sonification to alter the way people perceive the completion of a given movement.

Then a design model for these sonifications is proposed (Chapter 4). The movement sonification expectancy model (MoSEM) based on Huron's ITPRA model for musical expectancy [Huron, 2006], highlighting how this expectancy is impacted by making the individual an active agent within the sound feedback [Wolpert and Ghahramani, 2000]. This model serves as the organising principle for this thesis' investigations on this kind of sonification, testing and expanding it with future empirical studies.

These sonification's effect on motor behaviour and perception is then explored for two movements, the stretch forward movement and the squat down (Chapter 5). The results of these two studies demonstrate the impact MuES can have on motor behaviour and perceptions.

From these results disparities in how motor behaviours are affected based on the expectation of the given movement. Chapter 6 explores this in terms of the expected length of the sonification and the expectation of the two kinds of target-point, open target points (low-level of additional cues) and closed target points (high level of additional cues). The impact of these cues is then further explored and discussed in relation to how people may experience expectancy during physical activity.

These results can then inform the design of MuES which can then be used within the context of two example populations (Chapter 7 and 8). The MoSEM is explored in the context of chronic pain rehabilitation and how people with chronic pain can be encouraged to progress past fear-related boundaries and to avoid over-activity. Secondly, the MoSEM is explored in the context of general wellbeing to support people who struggle to maintain regular physical activity to encourage progress toward goals during the squat down movements. Through these case studies, the MoSEM can be explored within populations with low self-efficacy and how it can be applied to design MuES.

## 1.5. Contribution

Through the studies presented in this thesis, the Movement Sonification Expectancy Model (MoSEM) is proposed, interrogated, adapted and used to apply Musical Expectancy Sonifications (MuES) to populations with low self-efficacy. This MoSEM is the lens through which the understanding of these sonifications are understood and used as a model to both demonstrate their impact on people movement behaviour/perception and to design future applications of MuES.

This thesis, therefore, offers three main contributions to the domains of HCI and audio-interaction:

1. The MoSEM as a model for understanding and designing sonifications with musical expectancy

2. A series of control studies which demonstrate not only the MoSEM's impact on movement behaviour and perception but also how it is itself impacted by one's expectation of the movement

3. Demonstration of how the MoSEM can be used to design sonification for populations with low self-efficacy and a series of considerations for future MuES

designs

# 2. Background

**In this Chapter:**

∗ Self-efficacy and physical activity

∗ Sonification to inform physical activity

∗ Music to encourage physical activity

∗ Auditory illusions to adapt physical

## 2.1. Introduction

In this chapter previous work in which sound has been used to support physical activity will be examined. Firstly, the importance of self-efficacy for people who struggle with physical activity will be examined and previous methods for supporting physical activity outlined. F Each section then explores how previous works have used the design of sound to support physical activity and how they can be brought together to be used for populations with low self-efficacy. This chapter gives an overview of these areas to demonstrate the potential of using musical structure within sonification to support people with low self-efficacy; however additional literature is surveyed in the specific chapters of this thesis.

## 2.2. Self-efficacy

### 2.2.1. Self-efficacy and physical activity

In the previous chapter, the three main uses of sound for physical activity that are explored in this thesis were outlined: informational sound, encouraging sound and adaptational sound. However, none of these methods addresses the issue of low self-efficacy, a common barrier for people who struggle with physical activity. Bandura defines self-efficacy as

> “People’s judgments of their capabilities to organize and execute courses of action required to attain designated types of performances” [Bandura, 2002]

Within the context of physical activity, self=efficacy can be thought of as the belief in one’s ability to complete a given movement or exercise. As discussed by Biddle, it is difficult to understand why people do not adhere to an exercise routine as often only "surface reasons" are given, masking deeper barriers that affect motivation [Biddle and Mutrie, 2007]. Previous work has shown how people's internal motivation and self-belief are strong indicators of their continued participation in physical activity [Standage et al., 2003, Frederick and Ryan, 1993]. Sonstroem and Morgan highlight the link between exercise and self-esteem [Sonstroem and Morgan, 1989] in their proposed model to measure the effect of physical activity interventions on self-esteem. They present a model that associates the self-perception of self-efficacy, competence and acceptance as the contributors to one's self-esteem with regards to physical activity. They postulate that: *"Physical fitness is more highly related to physical self-efficacy than to physical competence and global self-esteem"*.

Previous work in this area has demonstrated how one's perception of one's own competence, i.e. self-efficacy, is impacted by one's self-determination [Markland, 1999]. Examining women taking part in an aerobics routine, Markland found that whether people felt they engaged in physical activity because they had to or because they wanted to, and whether they perceived themselves to be competent, impacted their intrinsic motivation. Women with low self-determination felt more intrinsic motivation to complete their exercise routine when they had high self-efficacy. This demonstrates the importance of promoting self-efficacy within exercise. Moreover, the work of Shieh *et al.* show how self-efficacy shows a strong association to both nutrition and exercise behaviours [Shieh et al., 2015]. They explored nutritional and exercise behaviour's association with self-efficacy and self-regulation with 108 participants. It was found that while self-regulation showed a direct association with the consumption of fruits and vegetables and exercise, self-efficacy showed association only with how often people engaged in physical activity. People with low self-efficacy are less likely to continue on an exercise routine and this work demonstrates how it should be considered in the design of health interventions.

Bandura describes how the feeling of self-efficacy is one of the core factors in whether someone will complete an activity [Bandura, 2000]. People's perception of their own behaviour, overcoming obstacles achieving goals are all guided by belief in one's ability to do so. Fitzsimmons *et al.* show how self-efficacy can be used to modify the performance of weightlifters [Fitzsimmons et al., 1991]. Through proving false performance feedback, i.e. people were told they had lifted more or less than they had, the impact of this feedback on people's performance and perceived self-efficacy was measured. It was found that when participants were told they were lifting less, they could lift more, though this effect was mediated by previous experience. This demonstrates how by altering the feedback, people's performance can be altered as well as showing the strong effect belief in one's ability has on what one can do.

Additionally, within physical rehabilitation low self-efficacy may lead to movement avoidance and one of the primary factors that can stop people from engaging in physical activity is fear. This fear of movement is caused *"when stimuli that are related to pain are perceived as a main threat"* [Leeuw et al., 2007]. People with chronic pain (CP) may fear those movements and activities that they perceive as being the cause of pain or re-injury, leading to avoidance behaviours and catastrophising thoughts. Catastrophising thoughts, *"an exaggerated negative orientation toward noxious stimuli"* [Vlaeyen and Linton, 2000] can, in turn, lead to increased fear of movement, causing a vicious cycle where because the feared movement is avoided, those movements become harder and more painful to do, as seen in the fear-avoidance model [Leeuw et al., 2007]. As confidence in certain movements and activities decreases, as a result of fear or inactivity, self-efficacy can diminish as well. However, as suggested by Bandura [Bandura, 1977], a person with high self-efficacy is more likely to continue in the face of obstacles, in this case, pain. Additionally, it is thought that if a person's self-efficacy is high, they are less likely to exhibit the avoidance behaviours seen in the fear-avoidance model [Woby et al., 2007]. As described by Singh *et.al* it is important in rehabilitation for CP to promote awareness and facilitate control, as well as reward/promote self-esteem [Singh et al., 2014]. Across these domains, there is a need to support self-efficacy within physical activity.

Bandura demonstrates four guiding principles for developing self-efficacy: enactively, vicariously, persuasively, and somatically [Bandura, 2000]. Enactive mastery experiences allow individuals to experience and attribute success through action and through building achievements and overcoming barriers. This calls for a need for resilience in the face of barriers and learning from mistakes. Self-efficacy is developed vicariously through social modelling, i.e. by seeing others succeed in the same task and mirroring their actions. Thirdly, persuasion can be used to encourage people to believe in their own ability. However, the individual must be perceived as both knowledgeable of the task themselves and trustworthy. Finally, Bandura describes how self-efficacy can be developed somatically, through linking effort to emotional and physical states, with negative mood and physical fatigue likely to decrease one's feeling of self-efficacy in physical activity. Bandura recommends building positive mood and through *"changing misrepresentations of bodily states"*. This highlight ways in which self-efficacy can be supported.

Furthermore, Schunk shows three kinds of intervention to support self-efficacy: models (observing models complete a task competently), goal-setting (creating obtainable and measurable goals to meet) and feedback (providing feedback on how well one is doing) [Schunk, 1995]. Schunk describes both performance feedback, which informs about the performance of a task, and attributional feedback, which supports the attributing of that effort to successes. For example, being told, *"you have been working hard"*, as opposed to *"you will have to work hard"* was found to lead to higher motivation and self-efficacy in children learning maths [Schunk, 1982]. By supporting the attribution of success and offering encouragement to continue on, the barriers of low self-efficacy can be overcome. This perspective considers not only the need to inform people of their ability, so as to understand their capabilities, but also the need for encouragement in the face of obstacles to help increase those capabilities. In addition, it has been shown how providing encouragement to continue on past one's perceived limits can help support populations with low self-efficacy [Singh et al., 2014, Patel and O'Kane, 2015].

These works demonstrate both the impact self-efficacy can have on physical activity and how it may be supported. Bandura shows how self-efficacy may be cultivated [Bandura, 2000], specific to this thesis; it is shown how the experience of information and encouragement can help people build belief in their abilities. Schunk likewise demonstrates how both performative feedback and attributional feedback are beneficial to build self-efficacy [Schunk, 1982].

### 2.2.2. Technology to support physical activity

Technology for general wellbeing and physical activity has become prevalent in recent years. With the use of devices such as activity trackers [Harrison et al., 2015], exercise games [Biddiss and Irwin, 2010] and many exercise-based apps [Handel, 2011], there are numerous ways in which technology can be used to aid physical activity. In this section different methods for supporting people with low self-efficacy outside of sound are surveyed, to highlight how performance and attributional feedback have been used separately in previous work.

Technology has also been used to provide in the moment feedback to help people optimise their movement. These interventions focus less on motivating people to increase their general activity levels and more on supporting people during their physical activity. For example, Oakes et al. present a system to deliver real-time feedback to help athletes maintain good form during high intensity squatting exercises [Oakes et al., 2015]. By using a light-based display on the leg, feedback could be given to participants when they had reached the pre-calibrated squat position. Similarly, it has been shown how the impact load during running can be reduced using real-time feedback of accelerometer data [Hao et al., 2015]. These systems allow people to see these objective measures of their movement and correct any deviations from the desired form.

Hayes and Silberman provide an overview of how video games can be used to promote physical activity [Hayes and Silberman, 2007]. They highlight how commercially available videos games can be used to enhance learning about physical activity, learn strategies for physical activity and enhance motivation. Biddiss and Irwin specifically highlight the advantage of "active video games" that directly promote physical activity through games by way of a systematic review [Biddiss and Irwin, 2010] in which 18 articles were selected for quantitative analysis. Across the reviewed work it was concluded that these games were beneficial for promoting light to moderate exercise in an accessible environment. However several issues were also highlighted such as the issue of over-activity and there is limited evidence regarding their long-term benefits.

Building on the importance of psychological barriers to physical activity, many researchers have proposed that technological interventions focus on behaviour change theories to increase the amount of activity people do in their day-to-day lives. As outlined by Sullivan and Lachman, goal setting and rewards are often used in conjunction with activity tracking to motivate increased activity [Sullivan and Lachman, 2017]. Goal setting is often used within fitness trackers as a way to motivate people to engage in physical activity [Mercer et al., 2016] and, as shown by Munson and Consolvo [Munson and Consolvo, 2012], can be beneficial within self-monitoring of physical activity.

Goal-setting and tracking provide people with a clear target to achieve and measures of their achievement. Additionally, motivation prompts to be more active through text messages or through an automated activity programme have been shown to increase people's activity levels effectively [Notthoff and Carstensen, 2014, Hurling et al., 2007]. Furthermore, physical rewards, such as a refreshing drink or monetary compensation [Khot et al., 2015, Patel et al., 2016] have shown to impact people's motivation to do physical activity. However, virtual rewards may not have as substantial an impact [Munson and Consolvo, 2012].

While these previous works may demonstrate some efficacy for increasing people's general levels of activity, the focus is on the quantity of activity over the quality. These kinds of intervention, while motivational, do not give any support to facilitate engagement with challenging movements in real-time, which is important not only for optimising technique but for engaging in physical activity that is beneficial to wellbeing and health.

### 2.2.3. Summary

In conclusion, these two types of technological intervention target different aspects of physical activity. Tracking and motivational tools focus on encouraging people to engage in physical activity, while real-time feedback methods focus on improving the quality of the movement. These highlight how self-efficacy can be supported by providing performance feedback through real-time feedback, and by providing attributional feedback, through tracking and goal-setting. However, there has been little research on how these methods can be used together, providing feedback that helps people improve their technique while at the same time providing implicit motivation within the feedback to improve self-efficacy. The next sections of this chapter explore how sound specifically may be used to overcome barriers to low self-efficacy through this combined method and create feedback which can in itself encourage and reward movement.

This thesis explores three uses of sound within physical activity within the context of designing sonification which can support populations with low self-efficacy. As can be seen in Table 2.1 these works span a variety of contexts and sound design strategies, although Dubus and Bresin highlight most sonification designs use pitch or spatial based mappings for physical attributes [Dubus and Bresin, 2013], many applications have explored this within a musical framing. However, what remains unexplored, is how sonification and musical structure can be used together, to adapt one's movement and perceptions, and in turn aid with attributing success and encourage movement.

Table 2.1 shows a cross-section of literature covering the three areas in which sound has been used to support physical activity. Each offers some benefit to addressing low self-efficacy; sonification helps people understand their capabilities, music helps encourage people past their current capabilities, and auditory illusions help change people's perceptions of themselves. However, none individually can fully support people with low self-efficacy, who need both information and encouragement. In the following sections, each area is explored in depth to show how aspects of these methods can be taken together to design sonifications to support people with low self-efficacy.

| | Paper | Movement | Sound Design | Sound parameters | Population |
|---|---|---|---|---|---|
| Inform | [Effenberg, 2005] | Jumping | Non-musical sound | Frequency and amplitude | Judging exercise |
| Inform | [Smith and Claveau, 2014] | 3d motion paths | Non-musical sound | ADSR envelopes<br>deviations in pitch | motor-learning |
| Inform | [Yang and Hunt, 2014] | Bicep curls | Non-musical sound | White noise filtering | exercise optimisation |
| Inform | [Hale et al., ] | squat down | Non-musical sound | pitch-based mapping | exercise optimisation |
| Inform | [Vogt et al., 2009] | Shoulder flexibility | Non-musical sound | Progression of soundscape,<br>Deviations "inhibitory sound" | Stroke |
| Inform | [Cesarini et al., 2014] | swimmer symmetry | Non-Musical sound | stereo sound | swimmers |
| Inform | [Kleiman-Weiner and Berger, 2006] | Golf swing | Non-Musical sound | vowel sonification | Golf players |
| Inform | [Schmitz et al., 2018] | Arm movement | Non-Musical sound | Frequency modulation | Stroke |
| Inform | [Huang et al., 2005] | arm movements | Musical sound | Progression of chords.<br>Dissonant sounds for incorrect movement | neuromotor control<br>rehabilitation |
| Inform | [Wallis et al., 2007] | Grasping movement | Musical sound | Progression of lead instrument,<br>Harmonic resolution on completion,<br>Alerts for undesired movement | Stroke |
| Inform | [Singh et al., 2014] | stretch forward | Musical sound | Progression through a melody | Chronic pain |
| Inform | [Khan et al., 2018] | squat and wall sit | Musical sound | progression of a melodic<br>sequence | Blind/visually impaired |
| Inform | [Schaffert et al., 2011] | rowing | Musical sound | piano notes | elite rowers |
| Inform | [Scholz et al., 2015] | Arm movement | Musical sound | Playing through a melody | Stroke |
| Encourage | [Repp, 2005] | tapping | Musical sound | Rhythmic beat | review |
| Encourage | [Aschersleben, 2002] | tapping | Musical sound | Rhythmic beat | Musicians/non-musicians |
| Encourage | [McIntosh et al., 1997] | walking | Musical sound | Rhythmic beat | Gait rehab |
| Encourage | [Karageorghis and Terry, 1997] | exertion | Musical sound | Music | exercise |
| Encourage | [Karageorghis et al., 2008] | exertion | Musical sound | Music | exercise |
| Encourage | [Mohammadzadeh et al., 2008] | exertion | Musical sound | Music | exercise |
| Encourage | [Komeilipoor et al., 2015] | Finger movement | Musical sound | Dissonant and constant sounds | |
| Encourage | [Rodger and Craig, 2011] | tapping | Musical sound | Rhythmic beat | |
| Adapt | [Nogalski and Fohl, 2016] | walking | Non-Musical sound | Altered environment sounds | Virtual environments |
| Adapt | [Serafin et al., 2013] | walking | Non-Musical sound | Altered walking sounds | Virtual environments |
| Adapt | [Tajadura-Jiménez et al., 2015a] | walking | Non-Musical sound | Altered footsteps | body illusions |
| Adapt | [Tajadura-Jiménez et al., 2015b] | tapping | Non-Musical sound | Altered tapping sound | body illusions |
| Adapt | [Tajadura-Jiménez et al., 2017a] | Finger pulling | Non-Musical sound | Pitch change | body illusions |
| Adapt | [Boyer et al., 2013] | Hand movements | Non-Musical sound | Length of sound | motor-learning |
| Adapt | [Frid et al., 2018] | Throwing | Non-Musical sound | swishing/creaking | Virtual environments |
| Adapt | [Dyer et al., 2017] | Hand movements | Musical sound | melodic sonification | motor-learning |
| Adapt | [Fritz et al., 2013] | gym machines | Musical sound | controlling parameters of musical loops | exercise |

Table 2.1: Overview of the literature surrounding the use of sound to support physical activity, showing the three ways in which sound may be used to: inform, encourage or adapt movement. This overview shows the range of movements and sound designs which have been used within physical activity.

## 2.3. Using Sound to inform people of their movement: Movement Sonification

### 2.3.1. Movement sonification

Movement sonification has been a subset of sonification that has received a lot of research focus over the years, in sport, physical rehabilitation and performance [Schaffert et al., 2019, Sigrist et al., 2013]. Body movement, in itself, is hard to monitor as it provides little feedback other than natural proprioception. To this end, movement sonification can be used to help people learn new movements and optimise movements [Schaffert et al., 2019]. In this section, some of the different ways sonification has been used to support physical activity, showing both different sound designs and different applications are reviewed. These designs can be used to highlight different aspects of movement, improve understanding of one's abilities and have even explored musical sound to augment the listenability of the sound.

Most often the main focus for movement sonification is as a means of informing people about movement, see Schaffert *et al.* for a review [Schaffert et al., 2019]. By using sonification as an external representation of the movement, it can help support understanding of the movement performed. For example, Effenberg demonstrated how sonified movement could be used to improve motor-learning when assessing and recreating a new movement [Effenberg, 2005]. In both cases, findings suggest that the audio does improve the perception of these events and the subject's ability to recreate the movement.

Sonification of movement parameters can help support understanding aspects of movement that can be hard to monitor visually or through one's proprioception. For instance, Cesarini *et al.* present a system for sonification for swimming [Cesarini et al., 2014], based on the hydrodynamic pressure felt on the hand of the swimmer. It was thought this pressure is what elite swimmers describe as "feeling" the water. By sonifying this pressure both the swimmer and the coach could better understand the swimmer's movement. Similarly, Schmitz *et al.* present a movement sonification design for stroke rehabilitation. Over a series of sessions with stroke rehabilitation patients [Schmitz et al., 2018], they measure upper body movements and map them to a frequency modulation synthesiser, mapping the angle of the movement to the panning of the sound, the radial amplitude to the brightness of the sound and the velocity of the movement to the amplitude of the sound. This was to replicate the ecological relationships between sound amplitude and energy, i.e. more energy means a louder sound. Yang and Hunt used the transformation of sound to provide feedback during bicep curls on both movement and muscle activation [Yang and Hunt, 2014], to support beginners learning the optimal movement range. Hale *et al.* demonstrate how sound feedback could be used to improve squatting form [Hale et al., ]. Using concurrent feedback on both flexion of the leg and pressure distribution on the foot, they found that participants with the feedback showed more improvement than those without. These works show how our understanding of sound can be used to support the design of movement sonification. By using sound, people can be better informed of these difficult to track aspects of movement, which is beneficial as it may be difficult to follow a visual display of such information during physical activity.

As well as mapping parameters of movement to aspects of sound, many sonifications instead map deviations to either an alarm-based sound or deviations of the sound played in an "sonification of movement error" [Sigrist et al., 2013]. Kleiman-Weiner and Berger describe a system for learning an optimal golf swing using auditory feedback [Kleiman-Weiner and Berger, 2006]. They describe the three important factors of a good golf swing: club velocity, the rotation of the shoulders relative to the hips (known as X-factor) and swing tempo. They used a database of optimal swings and mapped deviations from these optimal paths to changes in a vowel-based synthesis so that the perfect swing would give an "ah" sound. Smith and Claveau present a system designed to improve motor learning, for complex 3D motion paths [Smith and Claveau, 2014], an activity where relying on visual indicators and proprioception alone can be difficult. As the student recreates a set movement, deviations in the spatial path are mapped to deviation in the pitch of the sound. Timing is mapped to the attack (onset) of the sound envelope. For example, if the student is too quick, the attack is shorter, and if they are too slow, the attack is longer than that of the set movement. Through mapping errors in the movement to deviations in the desired sound, the feedback allows one to correct one's movement to get the desired sound.

Moreover, these two methods for informing about movement performance can be combined as in the Physio Sonic project which focuses on helping people undergoing physiotherapy to understand their body and their movement through sound [Vogt et al., 2009]. The system utilises motion tracking to isolate areas of the body and defines movement space for a certain activity. The system used two scenarios; one emulates a woodland scene where patients would reach from the ground to the birds in the sky, manipulating the layers of the soundscape with their movement and one where their movement would be responsible for the playing and manipulation of a musical sample/text. Additionally, inhibitory sounds were included to avoid deviation from the appropriate movement. It was found that participants improved using the system; with a relatively small sample size, a majority showed improvement in both shoulder flexibility and reduced evasive movement. However, some participants showed worsening in these areas, suggesting that there was some overloading of the musculature. Despite this, the auditory feedback was perceived as beneficial to the participants. This shows how while sonification can be effective in promoting movement, there must be some consideration about when it should and should not be encouraged.

These sonifications used a variety of strategies to map movement data to sound and while many take great care to create sound mapping metaphors that are more than completely arbitrary designs, i.e. consider ecological metaphors for the movement, the overall goal for the sonifications is to inform people of their movement and "extend" their proprioception.

### 2.3.2. Musical sonification

While previous examples show the use of more abstract sound designs, e.g. using pitch or other foundational aspects of sound, there has also been a series of movement sonifications that consider aspects of music as parameters for their sonification. These musical sonifications use aspects of music to promote both engagement and increase the efficacy of the sonification. By using musical sonification, the sound can not only be made more pleasant to listen to, but it has been shown that people can use their understanding of music to help support them in performing the exercise correctly.

Huang *et al.* showed how multimodal feedback using musical sound could be used to aid neuromotor control rehabilitation [Huang et al., 2005]. The auditory feedback gave users information about the movement; as the user performs a movement, the system moves through a set chord progression if the trajectory of the movement is smooth the sequence is played through smoothly. However, if the trajectory is not smooth, the performance reflects this with a "jerky" rendition of the progression. It also used dissonant feedback to stop the user from doing any undesired movement. This demonstrates how the use of musical understanding can be used within sonification design, instead of simply distorting the sound or providing an alarm, aspects of the movement are directly linked to the generated music. Through this, a smooth movement is encouraged as music is expected to be smooth and undesired movement should be avoided to avoid musical dissonance, which the user would perceive as unpleasant.

Scholz *et al.* demonstrate a musical sonification therapy to support motor function after stroke [Scholz et al., 2015]. Focusing on arm movements, patients could move their arm to trigger specific sounds at specific locations, much more akin to music making than most predefined sonifications, allowing for the sound to support their rehabilitation for repetitive movements. This intervention was shown to improve motor function in two stroke patients (compared to two in a control group) in gross motor functions. While this work leans more on music therapy to supporting rehabilitation the focus of the sound is still to inform the person of their arm position. Though music was chosen due to its use in aiding neuroplasticity in music therapy, there is no investigation of how the musical sound may impact the way the movement is performed or how it changes people's perception of the movement.

Schaffert *et al.* used auditory feedback to improve the efficiency of movement in elite rowers [Schaffert et al., 2011]. The system aimed to help rowers shift between the "drive" and "recovery" phases of their movement and to transition between the two steadily. Using the acceleration of the boat feedback was generated via MIDI. The musical note middle C was used as the point of zero acceleration, and any negative or positive change in acceleration could be heard in the changing pitch of the sound. They found that sessions in which the rowers had the feedback, the overall velocity was improved. This work shows how sound can be used to highlight the rhythm of a movement, in this case, the musical rhythm produced by the note mapping represents the rhythm of the movement as it moves from drive and recovery. In a questionnaire, rowers described how the sound had helped them be more aware of their movement. By using the feedback, participants were able to modify their movement to achieve their desired sound (and by proxy movement), as such this work shows how by using sonification people are able to use this external representation as a means of adjusting their movement in real time.

Singh *et al.* utilise a mobile application that provides sound feedback to inform users of their movement during activity for chronic pain rehabilitation [Singh et al., 2014]. The system focuses on building confidence in feared movements. A smartphone was attached to the users back to measure the amount of bending, and an exercise 'space' was created by using a neutral position, comfortable stretch and a maximum stretch. Once these intervals are set, the user can be given auditory feedback related to their movement and position within the exercise. The system uses two different sound conditions, a flat sound that used a single tone that is triggered by the movement and a wave sound that uses an ascending scale up to the comfortable position and then back down to the maximum stretch. The system was found to be useful and engaging by test participants, with most preferring the wave sound condition as it had more to attend to.

Khan *et al.* present "musical exercise" for people with visual impairments. They explore the squat down, and wall-sit exercises and use two note-based paradigms to help inform blindfolded participants on technique [Khan et al., 2018]. The first uses a series of eight notes, played based on the motion of the participant, that are played together to make one continuous sound during the movement. The second uses only three notes during the movement, sounding as three discrete tones. It was found that this discrete version of the feedback was easier to follow for some participants and that the audio feedback, in comparison with visual feedback, was able to inform participants about their technique. However, they do not show how the musical aspect of the sonification changed the way people performed the movement.

Wallis *et al.* developed a system for aiding stroke rehabilitation [Wallis et al., 2007]. The system is based on improving arm mobility, primarily in a reaching and grasping task. The patient's arm is animated in a virtual environment, and their movement is sonified. The auditory feedback was arranged into two musical elements a single foreground instrument and background instruments. The "lead" instrument is selected from a range of percussive instruments and the intervals between notes is controlled by the acceleration of the movement. This is to provide information on both the movement's speed and smoothness. The movement also controls a chord progression; if the set "grasping zone" is not reached the progression does not meet harmonic resolution. This is to incentivise reaching the end of the movement. The system also used auditory alerts, one to indicate a successful movement and two more to indicate an undesired movement, for example slouching or compensatory moments. The background score is also controlled by the user's elbow openness and trajectory. This work again begins to demonstrate how the inclusion of musical parameters into sonification can be used to change motor behaviour. Harmonic resolution is used as an information source to signal the end of the movement, and they do not investigate the effect of harmonic resolution on movement behaviour and perceptions directly.

These musical sonifications demonstrate how people's understanding of music can be used to support sonification design. For example, understanding the rhythm of their movement through the "music" the sonification creates [Schaffert et al., 2011], understanding dissonance in the sound helps to understand deviations from the desired movement [Huang et al., 2005] and even using harmonic resolution to signal the end point of the movement [Wallis et al., 2007]. However, these designs still use these aspects of music to support the goal of informing people about their movement and have yet to explore how their use of musical sound disrupts the representation of the movement.

Many authors have considered the definitions of the differences between sonification and music [Scaletti, 2018, Vickers et al., 2017, Roddy and Furlong, 2015]. In these considerations, they warn of the dangers of conflating "informational sonification" and "aesthetically pleasing music" and call for sonic information designers to take care when including music with sonification design to not distort or obfuscate the underlying representation of the data. However, with the rich implicit and embodied understanding people have of music, there is a potentially missed opportunity in limiting its use with sonification.

In Scaletti's "Music ≠ Sonification" the goal of sonification is defined as *" to understand better, communicate, or reason about the original model, experiment or system "* [Scaletti, 2018]. In this work, the separation between music, in which the aim is creating pleasing sound art, and sonification, in which the goal is to inform, is discussed, and it is suggested by better separating sonification from music, people can begin to use and understand more abstract sound structures. Poor design can obscure or distort the structure and meaning inherent in the original data set.

In Vickers's *et al.*, they argue that this boundary between improving the aesthetics of sonification and retaining its representational integrity should be treated with care [Vickers et al., 2017]. They argue that due to the way in which we perceive sound and our predisposition to hearing sound musically that while music may improve the aesthetics of a sonification, it could come at a cost to the sonification usability. They warn of the impact of people's propensity to hear sound musically may impact the way they interact with sonifications. This leads to concerns over the design of meaning in sonification, whether there is a single "true" way to understand sonified data or a multitude of ways depending on the individual. They present the idea of subject position as a middle ground where the design of sonifications can be used to evoke certain responses. For sonification aesthetics, understanding the way in which the design of a sonification impacts one's perception, and in the case of movement sonification one's behaviour, is essential for designing understandable and effective sonifications, especially when considering the conceptually rich and embodied structures in music, which as of yet there is limited research exploring the impact these structures have how sonifications are perceived.

Roddy and Furlong's work demonstrates how this embodied relationship with sound can be used within sonification [Roddy and Furlong, 2015] to show people's embodied relationship with music and its effect on interpreting the physicality of a sonification. They explore how the way data is sonified can be used to promote a certain perspective of the data, particularly how different scale models are interpreted within pitch and tempo based sonifications. The scale models investigated are either an amount scale or an attribute scale; an amount when listeners perceived an increase in pitch or tempo as an increase in data value, or an attribute when an increase in pitch or tempo represented a decrease in the data value. They found that for different kinds of data people were more likely to project one model or the other on the data, depending on the data given. This work helps to show how embodied cognition can be used to show how people understand sonifications within the context of the data being sonified. Roddy presents this as a model for exploring how these embodied aspects of sound are understood within sonification [Roddy, 2016]. However, it is yet to be explored how these changes in the perception of the sonification may specifically impact the perception of the underlying data, or in relation to behaviours, such as movement. This again reflects a need for more considered and theoretically grounded and empirically evaluated sonification designs [Serafin et al., 2011, Rocchesso et al., 2008], to better understand how these musical sonifications are interacted with.

These works show how musical structure can be used to support sonic-information design [Serafin et al., 2011, Vickers, 2017]. People's familiarity with music and understanding of musical structure mean that it may be used to improve the understandability of sonifications, as demonstrated in the design of earcons, which use melodic content to help with the identification of different items [McGookin and Brewster, 2011]. Musical sonification has also been considered as a way to promote on-going engagement with sonifications, by making them more aesthetically pleasing [Middleton et al., 2018]. Moreover, it has been highlighted how our musical and embodied understanding of sound may change the way we perceive these sonifications [Vickers et al., 2017, Roddy, 2016]. However, overall the main design goal of sonification is to inform and the impact of musical structure within sonification to deliberately people's motor behaviour, and perception is currently underexplored.

### 2.3.3. Summary

All these works demonstrate how sound can be used to provide information on one's movement. However, this does not consider how sonifications may support people with low self-efficacy. Schaffert *et.al* showed how feedback on boat acceleration helped elite rower optimise their strokes using the rhythmic pace of the feedback to adjust the rhythm between their rest and drive [Schaffert et al., 2011]. The rowers describe being able to understand new aspects of their movement and how this awareness helped them to adjust their movement in realtime. The work of Wallis *et.al* uses concepts of musical structure and harmony to convey aspects of the movement performed [Wallis et al., 2007], however in these works it is used to help directly inform the individual.

The majority of these sonifications take an informative approach to support physical activity, either through sonifying incorrect movement with an unpleasant sound or by only providing the "correct" sound if a movement is executed correctly. While these methods may be optimal to improve movement execution, they do not consider those who struggle with physical activity, for whom encouragement of movement is more useful than the correct execution. Additionally, musical sound has been used to varying degrees within sonification, and the impact of musical structure and embodiment on the field of sonification design discussed [Vickers, 2017, Vickers et al., 2017, Roddy and Bridges, 2018]. However, the design of sonification for physical activity has yet to explore how our embodied relationship with music may impact an individual's perception of their movement and how in turn that may be utilised to overcome specific barriers to physical activity.

## 2.4. Using Sound to encourage changes in movement: Music in physical activity

### 2.4.1. Implicit and embodied understanding of music

The ability to identify musical structures is not inherently linked to formal musical education; simply through the general everyday exposure that people have to music, they are able to understand and recognise many aspects of music [Polotti and Rocchesso, 2008]. The reason why people seem to be so interconnected to music is a question that is yet to be answered. However, people do appear to have an innate sensitivity to music [Loui et al., 2010, Krumhansl and Kessler, 1982] and even an emotional connection with it [Meyer, 1957] . Moreover, embodied music cognition puts forward the idea that people mediate their understanding of music through their bodies [Leman, 2008]. This can be seen in the way even a non-musician may begin to tap their foot or dance to a piece of music [Repp, 2005] or identify a well known tune/melody they have heard before [Deutsch, 1972]. In addition, music has been shown to manipulate the way people move directly, hence its use while people are working out at the gym [Karageorghis and Terry, 1997, Karageorghis et al., 2008]. By exploring how music has been used in previous work to affect people's behaviour, a better understanding of how musical structures can be used in sonification can be gained.

Several aspects of music have been shown to be perceived implicitly without the need for formal training, and while non-musicians may be unable to describe these underlying structures of music, they can feel changes in pieces of music based on them [Polotti and Rocchesso, 2008]. For example, it has been shown that people are able to recognise melodic patterns [Deutsch, 1972] over different octaves. Deutsch showed that people are able to identify the tune "Yankee Doodle", in three different octaves, with 100% accuracy from hearing the first half alone [Deutsch, 1972]. The study used the extract in five conditions, the first was played in the key of F, the second was also in F but an octave higher, the third an octave below, the fourth was played in F but had each tone was played in a randomly chosen octave from the first three conditions, and finally the fifth condition was played uses a series of clicks so that all pitch related information was removed leaving only the rhythmic pattern. In a pilot study, the first three conditions were all universally recognised correctly. 51 students were recruited to participate, 35 in the experimental group and 16 in the control group. The experimental group would hear the condition played at random octaves and asked to identify it. They then heard the correctly played tune and were asked to identify what tune it was; finally, the random condition was played again. the control group heard the rhythmic condition then the correct condition. All participants were able to recognise the regular condition in both groups. However, only 11.76 % correctly identified the random octave condition and 18.75 % the rhythmic pattern.

Although it is difficult to say why people are so adept at taking in these high-level musical concepts, it is something we learn at an early age. Schellenberg demonstrated how the underlying structures of western and eastern music might be learned implicitly by children and show how we start to build an expectation of how musical passages will progress[Schellenberg, 1996, Schellenberg et al., 2005]. When evaluating how well given tones continued melodic fragments it was found that non-musically trained participants gave similar ratings to musicians. These works demonstrate how both non-musicians and musicians are sensitive to these high-level structures of music and through this implicit learning changes in a given piece of music can be identified.

In addition to being accessible to both musicians and non-musicians, music has been shown to be linked through our embodied understanding of our bodies and the way we move. It has been shown there are implicit associations between sounds and movement (e.g., sound pitch and direction of movement). Maeda et al. explore the mechanisms of pitch in relation to physical space [Maeda et al., 2004]. They demonstrate that descending and ascending pitch correlates with people's ratings of upward and downward visual movement. Embodied cognition of music is an area of musicology that applies the concepts of embodiment [Varela et al., 1991] to explore how the cognition of music is both situated within an environment and "put into practice through action" [Leman, 2012]. It considers the body as a mediator for a person's experience of music and how the actions of the body are related to the perception of music.

Though there have been a few different ways in which embodied cognition has been understood, the one explored here is concerned with how people learn things through physical action, and it is from these actions meaning is then abstracted. This can be seen most concisely through some of the languages people use to describe the world, for example in mathematics numbers are either described in terms of amounts, or as points on an increasing/decreasing scale. From an embodied cognition perspective this stems from our physical experience of either collections of objects or moving an increasing distance. In terms of musical cognition, this translates to a view of music based on their "sonic forms" and the physical action/energy associated with their performance [Leman, 2008]. In addition, we see similar mappings in the language used in music to physical spaces, "higher"/"lower" notes and the descent/ascent based on a metaphor for movement through a space [Zbikowski, 2009]. These models of cognition have seen a few applications in music/sound, both in understanding musical gestures [Caramiaux et al., 2014], using sound to manipulate the body [Komeilipoor et al., 2015] and in the understanding of conceptual metaphors for sonification and auditory display [Roddy and Furlong, 2015].

### 2.4.2. Music and physical activity

Embodied music cognition allows a framework for understanding how it is people come to an understanding of the underlying structures of music. This understanding, in addition, translates to people's understanding of physical spaces and people's own bodies through sound [Maeda et al., 2004, Caramiaux et al., 2014]. From these works, it can be seen how the embodied cognition of music, the way in which the body is used a mediator for understanding music, may be reversed to allow music to modify the way people move. Additionally, music therapy is perhaps one of the biggest fields in which sound is used for rehabilitation, in terms of both pain relief and relaxation. Although it is a hugely varied subject, Bruscia proposed a working definition for music therapy as:

> ...a systematic process of intervention wherein the therapist helps the client to promote health, using music experience and the relationships that develop through them as dynamic forces of change. [Bruscia, 1998]

Music therapy is used within physical rehabilitation to support motivation, the timing of movements and providing structure to interventions [Weller and Baker, 2011]. In a review of music therapy interventions for physical rehabilitation, Weller *et al.* show how music can be used to support the pacing of movement, to support engagement and to decrease perceived exertion. Overall music therapy has been shown to be effective in supporting physical rehabilitation, and although largely the focus is on the use of musical rhythm, interaction with music has been shown to support physical activity.

Previous works have also examined people's perception of musical rhythm and how people synchronise their movement with music outside of rehabilitation. Anshel and Marisi show how synchronising movement with musical rhythm supports performance and endurance [Anshel and Marisi, 1978]. Sensorimotor synchronisation (SMS) is the synchronisation of 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 [Repp, 2005] for a review. Aschersleben discusses how 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 [Aschersleben, 2002]. Although this shows that musical training improves this ability, the phenomenon is still observed in non-musicians. Alternately this phenomenon is known as "entrainment", and is attributed to be a fundamental biological response to rhythmic stimuli/movement seen across the animal kingdom [Merker et al., 2009]. Entrainment has been shown as a method for gait rehabilitation for Parkinsons [McIntosh et al., 1997]. The effect of the rhythmic auditory stimulus on gait, walking cadence and stride was measured in 31 patients. It was found that in the rhythmic conditions, walking-rhythm synchronised with the external rhythm. Presener *et al.* describes how music therapy can be used for pain and anxiety management for the treatment of burn patients [Prensner and Yowler, 2001]. Their work shows how the rhythms of the musical accompaniment can be used to alter the rhythm of people's breathing.

Outside of musical rhythm, it has also been shown that listening to different kinds of music can have an effect both on the affective states and motor performance in physical activity [Karageorghis and Terry, 1997, Karageorghis et al., 2008]. Karageorghis et al. explore how musical tempi effects motivation, music preference and flow in exercise [Karageorghis et al., 2008]. Participants were instructed to walk on a treadmill while being presented with fast tempo, medium tempo and mixed tempo music, as well as a control (no music) condition over a four-week period. At the first trial, the participants chose from a selection of musical artists and were instructed to look forward at a blank screen to avoid any visual stimulation. They then engaged in a warm-up and were then brought to an intensity that was 70% of their maximum heart rate (measured preceding the study) for 1 minute. It was found that the medium tempo music had the greatest response to intrinsic motivation, flow and preference. They postulate that this was preferred to the other tempi of music as it best suited the pace of the walking task instead of "forcing" the pace of the movement.

Mohammadzadeh et al. show how music affects both the perceived exertion and performance of trained versus untrained participants [Mohammadzadeh et al., 2008]. 24 participants were separated into trained (exercised in the past three months) and untrained (not exercised in the past three months) groups. They underwent a "Bruce treadmill test" which is used to assess oxygen consumption during physical activity. The participants underwent the test until exhaustion twice, once with music and once without, over the course of two sessions (separated by two days). Music was found to have an effect on perceived exertion, with an interaction between the effect of music and fitness. For untrained participants, music had a greater effect on their performance than for trained participants. The performance was measured as the time take till exhaustion, and in the music condition participants lasted longer. These works show how music can have a direct effect on people's physical activity and shows the strong relationship between music and physical activity.

Specific to this thesis's exploration of musical expectancy within sonification, musical expectancy has been demonstrated to impact people's movement at given target points. The work by Komeilipoor et al. [Komeilipoor et al., 2015] showed how musical dissonance affects people's ability to synchronise their movement with an external musical stimulus. Participants moved their finger between two points while listening to musical stimulus. It was found that participants were able to better synchronise with a consonant sound (one that fits expectation) than a dissonant sound (one which defies such expectations). Additionally, it was found that the consonant sound improved both form and accuracy. This shows how people's movement was changed to fit the musical expectation when the sound was consonant and complete; it encourages the listener to complete the movement in turn. However, the dissonant sound implied to the listener that the music had not reached the expected conclusion; they were less able to synchronise with the movement. From these works, the strong link between music and the way in which people move can be seen. Not only is our understanding of music both implicit and embodied, but through listening to musical sound changes in our movement behaviour can be encouraged.

### 2.4.3. Summary

This work shows how people understand music and how that understanding is embodied and shared by musicians and non-musicians alike. Due to this implicit acquisition of these musical perception skills, it means that they could be incorporated into the proposed sonification system for use with a non-intrinsically musical populous. This embodied cognition of sound, and moreover, music [Leman, 2008] demonstrates the inherent connection between people's movement and music. Furthermore, it can be seen how this connection can be used to impact the way people move [Repp, 2005, Aschersleben, 2002] and motivation during exercise [Karageorghis and Terry, 1997]. These works demonstrate how music can be understood in an implicit and embodied way and how it can be used to encourage physical activity, however, though music has been shown to encourage additional movement and even change the way movements are performed, the sound provides no information or context for the specific movement being done [Karageorghis et al., 2008].

Komeilipoor et al. 's work [Komeilipoor et al., 2015] shows how the completeness of a piece of music can affect behaviour at a movement target point. However, this work do not explore how this relationship between the body and music can be exploited to update the brain's representation of the body in a way that modifies movement. If, however, these structures were combined with real-time tracking and feedback of movement, these musical structures could be used to overcome the psychological barriers to physical activity. In the majority of cases, music is used to direct physical activity, by leveraging people's embodied relationship with music to encourage specific movement. This encouragement-based approach may help to motivate physical activity; however, it does not tell people anything about their own movement and progress to their specific movement goals. Considering people who struggle with physical activity, this lack of feedback leaves little room for them to improve the execution or understanding of their movement. Nonetheless, by exploring how musical stimuli have been used effectively in the past, we can better understand how an embodied sonification using musical structures may be designed. By extracting these underlying structures and elements from music and applying them to the movement sonifications, they can have increased depth and be used to affect change in the user.

## 2.5. Using Sound to adapt bodily representations: Auditory Illusions

### 2.5.1. Adapting movement through manipulate feedback

The majority of sonification approaches aim to inform the individual about their movement, as outlined in Section 2.3. Similarly, it can be seen how people's embodied understanding of sound and music allow it to encourage changes in physical activity, as seen in 2.4. However, there have also been a number of works that look at how our motor behaviour may be directly manipulated by modifying the feedback we receive from the world around us. Sensory feedback from the world around us is used to help us understand both the world we interact with and ourselves. Wolpert and Ghahramani provide a theoretical framework for the neuroscience of motor behaviours [Wolpert and Ghahramani, 2000]. They describe the interplay between one's desired movement, the context of that movement and the use of sensory feedback. One has a desired movement and an estimation of their current movement state, through which a prediction of how it will be achieved is made. From this, the brain issues a motor command to reach this state. The individual then uses the sensory feedback available to them to update their current estimation of what must be done. By altering this feedback, one's perceptions of motor behaviour can be altered, and in turn the movement itself. For example, through what is seen, touched and heard people constantly evaluate and adjust their perception of their body and environment to match that of the feedback provided to them [Botvinick et al., , Dichgans and Brandt, 1978].

This has already been demonstrated in the visual domain to be able to alter movement behaviour to overcome barriers. Altering visual feedback has been shown to directly modify people's movement in the use of virtual environments. Harvie *et al.* show altered visual feedback can elicit increased pain-free movement in neck pain suffers

[Harvie et al., 2015]. Using a head-mounted VR display, the rotation of the participant's neck is measured, and they are given visual feedback through the virtual reality that is either 20% less than the actual rotation, 20% greater or equal to the actual rotation. It was found that in the understated feedback condition the range of motion before the onset of pain was increased compared to the actual feedback. However, in the overstated condition, the range of motion was decreased. This work shows how sensory feedback can affect perceived pain levels. However, more importantly, it demonstrates how altered feedback can be used to people's perception of their own body and their movement.

Previous works demonstrate how the auditory cues from our bodies are used when we engage in movements, see Pizzera and Holmann for a review [Pizzera and Hohmann, 2015]. For example, Kennel *et al.* show how by masking the natural auditory cues made during hurdling, through white noise and delaying the cues, people were significantly slower and changed the way they completed the movement [Kennel et al., 2015]. Castiello *et al.* show how playing congruent versus incongruent audio cues in a hand grasping task either facilitate or interfere with the completion of the visually guided task [Castiello et al., 2010]. These works demonstrate the importance of auditory cues on movement activities and how by manipulating these cues it can impact movement performance and behaviour.

In virtual environments, motion can be difficult because the differences in the shape and size of the environment may be different than that of the real environment it is being experienced in. Serafin *et al.* demonstrate how redirected walking may be achieved through manipulated sound feedback [Serafin et al., 2013]. The participants were blindfolded and using a single sound source that could be moved around the room based on the position of the participants, they were guided through the space. They found that people's walking rotation sound is manipulated and that a curve walking could be achieved with only sound feedback. From this, it can be seen that it is not only visual feedback [Harvie et al., 2015] that can be altered to manipulate people's movement but through auditory feedback as well. Nogalski also demonstrates how redirected walking may be caused by manipulated sound feedback [Nogalski and Fohl, 2016]. The participants were given ambient sounds to mask the laboratory sounds and give some amount of orientation, sounds to turn towards and sounds to walk towards.

This work shows further how people's movement can be directly altered through altered feedback, being able to manipulate several aspects of walking behaviour without them being aware of the change. However, so far these works only demonstrate how people's movement orientation and perceived distance can be altered and do not investigate the mechanisms through which people's movement can be altered.

### 2.5.2. Altering perceptions and movement behaviour

In addition to the use in virtual reality, bodily representations and movement behaviour can be altered through altered auditory feedback. Frid *et al.* show adding friction based sounds to haptic feedback increases the effort in a virtual throwing task [Frid et al., 2018]. They tested different combinations of visual, haptic and auditory feedback for a virtual throwing task and it was reported that the task felt more intuitive with haptic and audio feedback. The two audio feedbacks used a creaking and swishing sound, and it was found that these friction-based sonifications combined with haptic feedback led to improved performance due to alterations in force of the movement.

In addition, recent work has focused on creating "body-centred feedback" [Tajadura-Jiménez et al., 2017b] which aims to leverage people's use of external feedback to alter body representations. Tajadura-Jimènez *et al.* show how, when one feels agency over the sound, and it is congruent with other kinaesthetic cues (i.e. arm displacement) one's mental representation of their arm can be altered [Tajadura-Jiménez et al., 2015b]. Participants tapped on a surface in the absence of visual cues and the spatialisation of the auditory cues was manipulated. It was found that participants estimated their arm to be longer when the sound originated from further away.

Tajadura-Jimènez *et al.* show how by manipulating the pitch of someone's footsteps both their body perception and the motor behaviour can be changed [Tajadura-Jiménez et al., 2015a]. "Sonic shoes" were worn by participants along with a backpack housing a frequency equaliser. Microphones from each shoe are then fed to the equaliser allowing for the modulation of the footstep's sound frequency content. Participants were given three conditions: a high frequency, low frequency and a control condition where the equaliser was used to adjust the frequency bands heard by the participant. They showed that when the high frequencies of a person's footsteps where presented, they felt their body was lighter, and a gait pattern was consistent with a lighter body. Similarly, they found the inverse when low frequencies where presented.

This effect has also been demonstrated with artificial sounds as well as body-related cues. Tajadura- Jimènez *et al.* demonstrate an “auditory Pinocchio” effect when using an ascending pitch sonification when pulling on one’s finger [Tajadura-Jiménez et al., 2017a]. Participants pulled on their right index finger, without any visual cues and heard either an ascending, descending or constant pitch. It was found that when people heard an ascending pitch, they felt as though their finger was getting longer. Similarly, Boyer *et al.* show how longer sounds can lead to longer trajectories for hand movements, as well as improving precision [Boyer et al., 2013]. These works show the manipulation of auditory cues can have a powerful impact on movement behaviour and through our use of auditory cues to build our internal representation of our body, by manipulating these auditory cues people’s bodily representation can be adapted.

These designs have focused on how auditory cues can alter bodily perception to adapt movement behaviour. In recent work, some have also begun to consider how musical structures may be used to direct these adaptations in movement behaviour. Dyer *et al.* show how melodic content with sonification can be used to support motor learning and performance of movements [Dyer et al., 2017]. By comparing melodic versus rhythmically based sonifications and they found that not only did the melodic sonification have greater retention, after 24 hours a replay of the melodic content allowed participants to improve their performance without the use of the concurrent sonification. Fritz *et al.* show how applying musical agency to strenuous exercise can reduce the feeling of exertion [Fritz et al., 2013]. Similar to work reviewed in Section 2.4, they show how the feeling of exertion can be reduced during physical activity; however, they show that having agency over the music can increase such an effect. Participants in their musical agency condition controlled a range of effects on a series of musical loops, such that during the exercise they had a feeling of control over the musical output. These works show how musical feedback can also impact movement behaviour and show how our embodied relationship with music can be leveraged within real-time feedback to support physical activity. However, it is yet to be seen how specific aspects of music can be used to encourage movement in a specific direction, that is to overcome self-efficacy related barriers to physical activity.

### 2.5.3. Summary

This section has shown how people's perception of feedback they received affects their perception of the physical world and the brain's representation of their own body [Wolpert and Ghahramani, 2000]. These works show how by altering this feedback people's perceptions and movement behaviour can be modified implicitly without their awareness [Harvie et al., 2015, Serafin et al., 2013]. However, as of yet, only limited ways in which people's movement can be altered have been explored. Body centred feedback shows how the brain can be "tricked" into changing the manner in which the body moves during different activities [Tajadura-Jiménez et al., 2017b], and there have even been a few works which show how music can be leveraged in these kinds of feedback to support changes in motor behaviour [Dyer et al., 2017]. These works may be useful when considering populations with low self-efficacy, where simply informing one about their current capabilities may not be sufficient to overcome barriers to physical activity. Instead, people's motor-behaviour may need to be intrinsically modified to help overcome these barriers.

## 2.6. Conclusion

The literature surveyed in this chapter outlines the three main areas in which sound has been utilised for physical activity; for informing, encouraging and adapting. It shows how sonification can be a powerful tool for improving physical activity. By leveraging the agency people feel over body-movement sonification, it can be used to optimise technique and avoid incorrect movement. Additionally, it shows how, even as non-musicians, people have an implicit understanding of musical structure through mere exposure and how this implicit and embodied understanding can lead to music changing the way we move.

Sonification provides real-time information on one's movement during physical activity, without the need to fixate on a screen and has been shown to be effective for improving technique for both elite athletes and people undergoing physical activity. The information provided by these sonifications can be used to correct physical activity, either by necessitating a correct movement to hear the ideal sound or with incorrect trajectory being signalled by an unpleasant change in the sound. These works show how effective this feedback can be for supporting physical activity. Music has the benefit of being both pleasurable and encouraging, even able to encourage people to exercise longer as shown by Karageorghis et al. and Mohammadzadeh et al. [Karageorghis and Terry, 1997, Mohammadzadeh et al., 2008].

Additionally, Komeilipoor et al. [Komeilipoor et al., 2015] show how musical structures can be manipulated to alter people's movement. These works show how music can be used to direct physical activity, using people's relationship with music to encourage activity and while the specific mechanism of why music has this effect on people's physical activity it can be seen as an effective way to support physical activity. Finally, it has been shown how auditory cues can be used to change movement behaviour and perceptions through adapting body representation, in virtual environments [Serafin et al., 2013], body centred feedback [Tajadura-Jiménez et al., 2017b] and even through music[Dyer et al., 2017, Fritz et al., 2013].

While these uses of sound provide good support for physical activity, when we consider people who struggle with physical activity, they cannot fully support them in overcoming the psychological barriers to physical activity. When self-efficacy is low, both motivation/encouragement and actionable feedback are needed [Schunk, 1995]. In this thesis, the use of musical expectation to embed encouragement into movement sonification is investigated. This allows for a better understanding of how leveraging our relationship with music can be intentionally utilised to disrupt the sonification as a representation of the individual's movement. However, in order to do so an understanding of how musical expectation impacts one's movement behaviour and perception must be developed and evaluated. From this evaluated model, musical expectancy can then be used to design sonifications to support populations with low self-efficacy.

# 3. Methodology

**In this Chapter:**

∗ The main aims and research questions addressed in this thesis

∗ An outline overall methodology and program of study for this thesis

## 3.1. Introduction

The related work discussed in Chapter 2 demonstrates that while real-time feedback can be used to support physical activity, there has yet to be an exploration of how such feedback can be designed to support the overcoming of low self-efficacy within physical activity. Specifically, within sound, the use of both sonification, to support technique, and the use of music to support motivation has been shown to be effective in supporting physical activity.

This thesis, therefore, aims to use the implicitly understood aspects of music to structure sonification and in doing so develop a feedback mechanism that not only provides information about technique but also encourages change in movement behaviours and perceptions, to support low self-efficacy. While work such as Vickers *et al.*, Scaletti and Roddy demonstrate how the use of music within sonification may alter the sonified representation of the source data [Vickers et al., 2017, Scaletti, 2018, Roddy and Bridges, 2018], little work has been done to explore how these altered representations may be leveraged to support changes in behaviour.

Specifically, for this thesis, the focus is on embedding musical expectation into movement sonification. When considering populations with low self-efficacy, that is limited belief in their own ability's, performance feedback, (informing on their current ability [Schunk, 1995]) may be insufficient. For an individual with limited expectation of their own movement, can the agency felt over the sonified version of their movement, the embodied understanding of the music's expectation and their use of auditory feedback to update their bodily representation, be used to encourage changes in their movement behaviour and perception?

This thesis uses a mixture of quantitative and qualitative methods to explore this sonification design method. To achieve this aim, an HCI focused research approach was adopted using a combination of developing theory [Dix, 2008], control studies [Blandford et al., 2008] and qualitative interviews [Blandford et al., 2016].

Firstly, previous work and established theory are used to develop an initial model for exploring musical expectancy in sonification, which allows for a critical understanding of the sonification [Rocchesso et al., 2008]. From this, the measurable impact on people's interaction with the sonification is examined to allow for detailed evaluation of this design [Serafin et al., 2011, Degara et al., 2013]. Finally, a user-centred approach is taken [Barrass and Vickers, 2011] to explore the experience of these sonifications and how they may be used to support people with low self-efficacy in real-life scenarios .

## 3.2. Program of Research and Methods

This thesis aims to explore the use of musical expectancy within movement sonification and how it may be used to support people who struggle with physical activity. Leading to the overall hypothesis addressed in this thesis:

> **Musical expectancy can be used within movement sonifications to impact movement behaviour and perceptions for people with low self-efficacy"**

To address this hypothesis, four sub-questions were developed, as outlined in Figure 3.1. Firstly, an understanding of how Musical Expectancy Sonifications (MuES) may impact people's movement behaviour and perception is needed. This is done through the design and evaluation of the Movement Sonification Expectation Model (MoSEM).

These two aspects, MuES and the MoSEM, and the relation between the two, form the foundation of this work. MuES is the sonification itself, which is designed to create musical expectation. The MoSEM on the other hand is a model which seeks to explore how MuES impact people movement behaviour and perceptions. The model is developed in relation to previous work and is interrogated, extended and finally used to design specific MuES to support people with low self-efficacy.

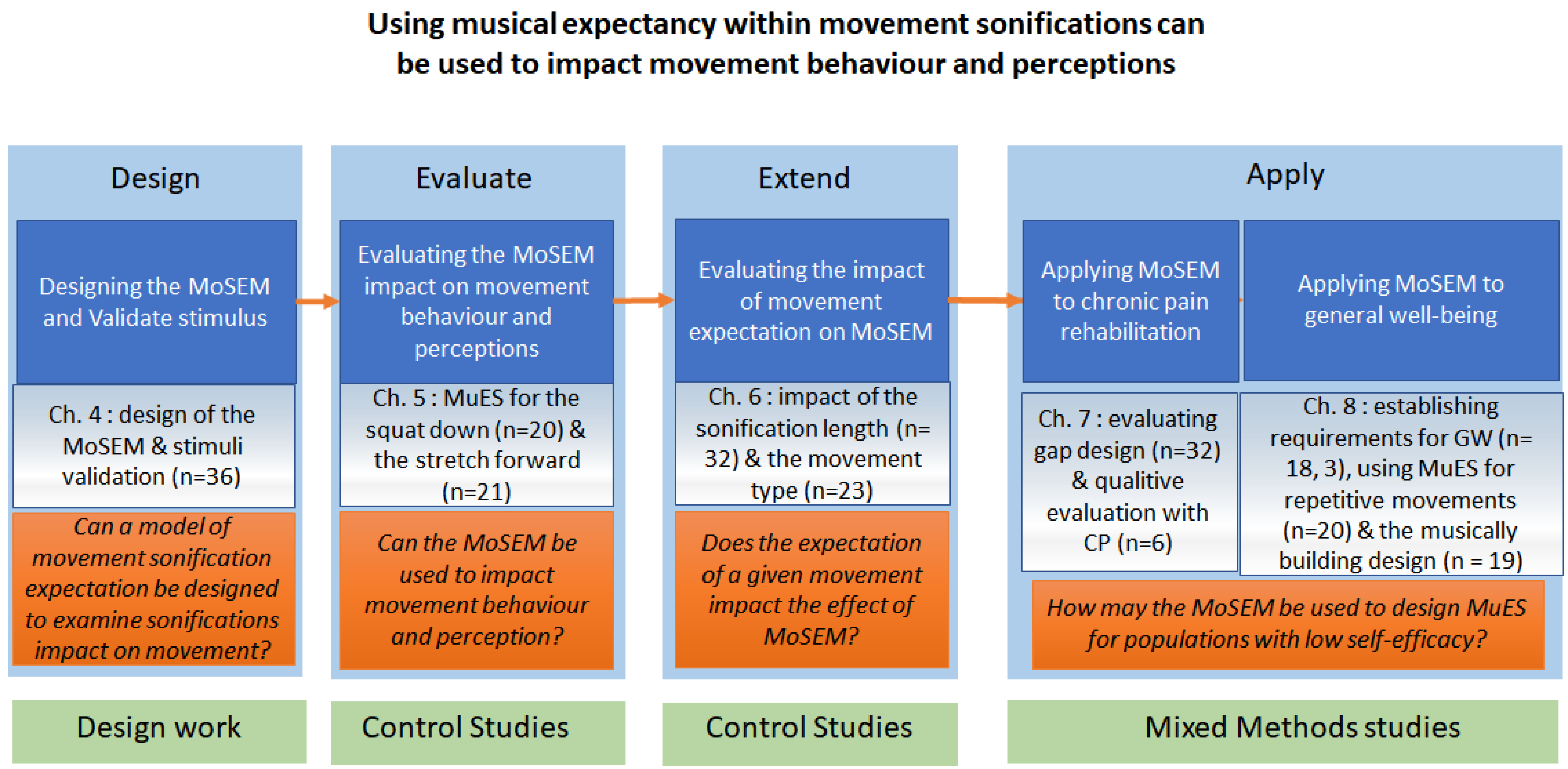



Figure 3.1: The outline of this thesis. The four stages of this thesis and their associated research activities. From the initial design of the MoSEM, evaluating MoSEM impact on movement behaviour, the impact of movement expectation on MoSEM and applying MoSEM to populations with low self-efficacy. In green are the approaches used within each stage of this research.

In Figure 3.1, the programme of research in this thesis is outlined as well as the research questions addressed and the general methodological approach for each stage of this research.

The first stage of this research involved the design and presentation of the MoSEM, which use previous research and theoretical frameworks to develop a theoretical model to predict how people may react to musical expectancy sonifications. The development of this MoSEM examines different aspects of expectation and sonification to structure theoretical model [Dix, 2008] and to establish some predictions of how these sonifications may impact movement behaviour.

This model is evaluated and then extended, in terms of how MuES impacts movement behaviour and perceptions. These stages of the research focus on the use of control studies to examine the measurable impact of the different sonifications [Blandford et al., 2008, Degara et al., 2013]

Finally, two case studies are presented, exploring how the MoSEM can be applied to support people with low self-efficacy to develop further the understanding of the MoSEM's potential and its limits. Through leveraging qualitative methods, a better understanding of the experience of using these kinds of sonifications can be gained [Serafin et al., 2011] as well as insights into how they may be applied to real-life scenarios [Braun and Clarke, 2013].

Risk assessments were undertaken and full Ethical approval was obtained for the various studies; the information and consent forms can be found in appendices A through F. Care was taken in each study to ensure participants did not feel pressured to do more movement than they felt comfortable with. Participants were told they should only participate if they felt physically able to and that should they want to stop or take a break at any point, they could.

### 3.2.1. Designing the Movement Sonification Expectancy Model: Exploring how musical expectancy sonification may impact movement behaviour and perceptions

The first stage of this thesis proposes the MoSEM which is used as a model to understand how MuES impacts movement behaviour and perceptions. Based on the previous work covered in Chapter 2 showing sounds use for informing, encouragement and adaptation, a model is developed to explore the potential impact of a musical expectancy based sonification. Previous work in sonic interaction design calls for a more theoretically grounded approach to designing sonification [Serafin et al., 2011, Rocchesso et al., 2008]. Therefore, different models of musical expectation are examined, and Huron's ITPRA theory [Huron, 2006] is used to develop a model for how musical expectancy may impact movement sonification. By considering the individual as an active agent in musical expectation, as opposed to the passive role normally considered within music, the sound produced can be used as external feedback for the movement itself [Wolpert and Ghahramani, 2000]. From these previous works, a theoretical model can be created to examine the impact of musical expectancy on movement sonification, which is later integrated and extended throughout this thesis. This Chapter addresses the first research question of this thesis: *RQ1: Can a model of movement sonification expectation be designed to examine sonifications impact on movement?* Building on previous works that demonstrate how auditory feedback can be used to adapt movement behaviour and perceptions [Tajadura-Jiménez et al., 2015a, Boyer et al., 2013, Dyer et al., 2017] and combining the implicitly and embodied structures from music which can change movement behaviour, [Karageorghis et al., 2008, Komeilipoor et al., 2015] with sonification, the MoSEM provides a series of predictions on how different musical endings may impact people's movement behaviour and perception. From this MoSEM, the studies presented in this thesis can be evaluated and used to extend the understanding of how musical expectation impacts the design of movement sonification. From this, the impact of different aspects of the sonification and the music are considered.

1. The expectation of the unaided movement is considered;
2. The impact of a purely informative sonification which aims to inform movement;
3. How a musical sonification may enhance the feeling of completing a movement with musical conclusion;
4. How the musical sonification may be altered to adapt one's expectation of their own movement.

From this, the impact of musical expectation and how it may adapt one's estimation of their own movement can be outlined. These aspects again are considered in relation to

Huron's theory of expectation, Wolpert and Ghahramani's principles of movement, as well as the role low self-efficacy may play.

Within this stage, a stimuli validation is also presented, which was used to create the initial musical stimuli used within the MuES used in Chapter 5 as an instantiation of the MoSEM. The validation took the form of online and offline listening tests, building on previous work showing how musicians and non-musicians perceive the completion of musical cadences [Sears et al., 2014, Bigand, 1997], to select the appropriate musical endings for the MuES and explore the potential of the length of stimuli's impact on its perceived completion. This leads to the design of the initial MuES used in Chapter 5 and serves as a baseline for how the different musical endings are perceived.

### 3.2.2. Evaluating and Extending the MoSEM: investigations into Musical expectancy Sonification's impact on movement behaviour and perceptions

The primary aim of this thesis is to understand how musical expectancy may impact behaviour and perceptions. Therefore, the MoSEM is first examined through a series of control studies which focus on a largely quantitative approach to identify the impact it has on physical activity. These studies explore the quantifiable effect different sonifications have on movement as well as the change in perception felt by participants. They also focus on a general population and seek to explore how musical-expectancy within sonification may impact certain movements.

From these designs, the initial investigations on MuES can be completed, and the proposed MoSEM interrogated. This second stage of the thesis address the question *RQ2: Can the MoSEM be used to impact movement behaviour and perception?* Based on the predictions from the MoSEM, the studies in Chapter 5 explore how different musical expectations change people's movement behaviour and perceptions within two movement types: the stretch forward and the squat down. These two movements provide two movements utilised by populations with low self-efficacy, the stretch forward in chronic pain [Singh et al., 2014] and the squat down in general wellbeing [Myer et al., 2014]. Additionally, they offer two movements in which the target points are very different. In the stretch forward the target point is very flexible and open and the individual stretches into open space. However, in the squat down there are several additional cues that the endpoint of the movement is approaching, for example, the ground. In these studies, while the predictions of the altering in movement perceptions posed by the MoSEM hold true, the impact on movement behaviour is only seen in the stretch forward. Additionally, the length of the sonification, altered to avoid learning effects during the study, also impacted movement behaviour. This implies that the musical expectation created by the sonification are not the only factors that should be considered within the MoSEM.

Specifically, there seem to be two additional factors that impact the efficacy of MuES: the length of the sonification and the type of target point. In this stage, these factors are examined to address the question: *RQ3: Does the expectation of a given movement impact the effect of MoSEM?* This is investigated in Chapter 6, through two control studies; the first explores how the length of the sonification, in comparison to the length of the expected movement can impact how the MuES is perceived. The second explores further the impact of additional cues to the ending of the movement, to see how different types of movement may be impacted by MuES. The results from these studies help to augment the MoSEM by considering the impact an individual's expectation of a given movement, be that based on the movement length or from the use of additional cues, can have on how they are affected by MuES.

These control studies in Chapters 5 and 6 are all situated in a laboratory environment. This was done to investigate the impact of MuES in a controlled environment. The sonification was designed based on the MoSEM and produced in by means of a smartphone application. Using an Android Nexus 5 phone's onboard gyroscope, 50 frames per second, the angle of the given movement was measured. The phone is calibrated between the participant's starting position and their target position. The calibration consists in dividing the range of movement between the standing position and the target point into a number of movement segments with each segment triggering the next chord, thus playing the full chord sequence as the movement progresses towards the target point, detailed in Figure 3.2. Video examples of the sonification method can be found at https://jwnewbold.com/video-and-audio-examples/.

For each of these studies, movement data was processed in MATLAB to establish two key behavioural measures: the amount of additional movement past the target point and the time taken to return. The gyroscope data was taken from the point at which the

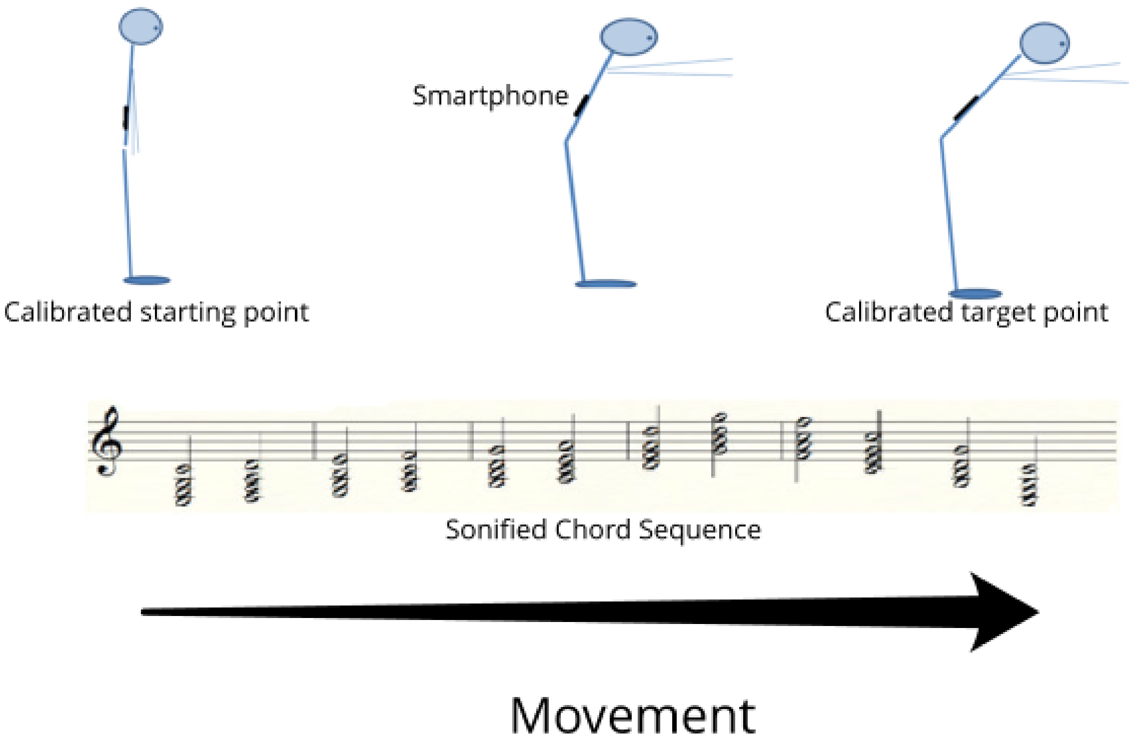



Figure 3.2: The gyroscope of the smartphone is used to track the movement and to drive the sonification. The smartphone is calibrated between the starting position of the movement and the target point of the movement. Within this space, the movement drives the progression of the chord sequence. This method was used for all the experiments within this thesis

last chord was sounded (at the point where the threshold of that segment was crossed) up until the point where the maximum point (where the participant begins returning to the neutral position). The **additional movement** was measured as past how far the participant continued after they reached the end of the sonification. The **time of return** was measured as the time taken between the final chord and the point of maximum movement before the participant begins to return, i.e. how long they keep moving past the target point, as shown in Figure 3.3. From these measures the reaction response to the different MuES can be examined, allowing for the predictions of the MoSEM on people's behaviour can be evaluated. These behavioural measures allow for an objective evaluation of the impact of the different sonifications have on how people interact with sonifications [Degara et al., 2013, Serafin et al., 2011]. These measures are used to explore the **Reaction response** portion of the MoSEM, as seen in Chapter 4, showing the intial reaction to the harmonic ending of the sonification. The self-report data was

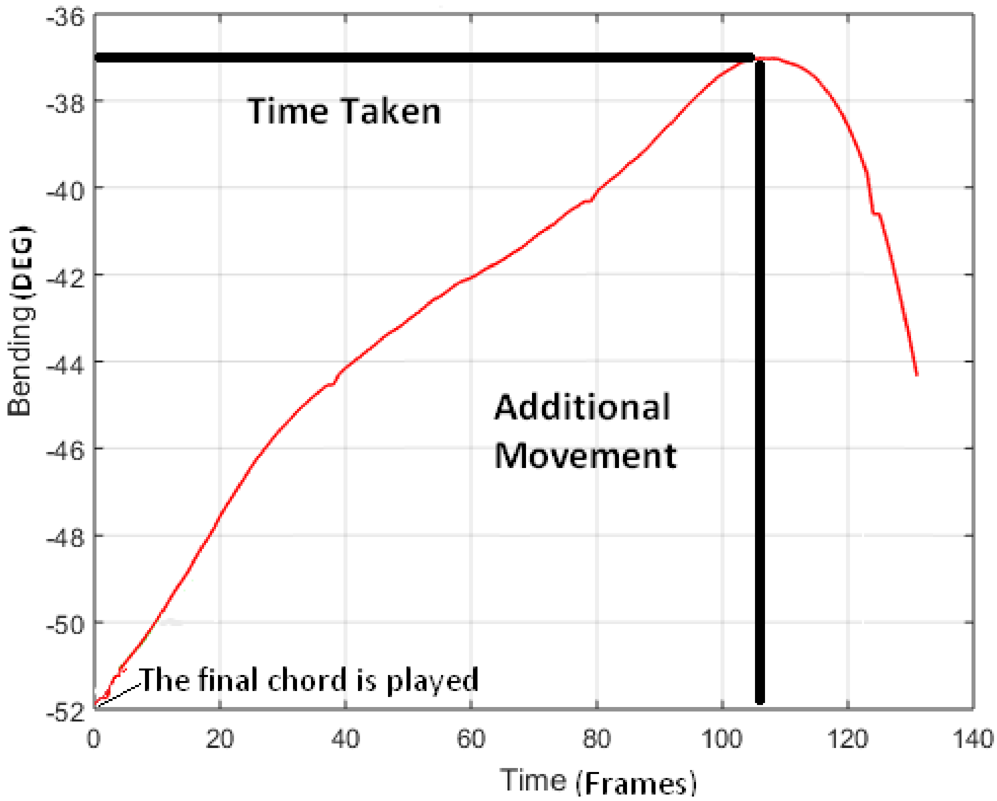



Figure 3.3: An example output from which the behavioural measures were taken. It shows the movement past the final chord, that is the end of the sonification: showing the additional movement past the cadence and the time taken to reach the maximum movement.

gathered by questionnaire on a 7-point Likert scale, examples of the questionarie used in each study can be found in Appendices H through M. These were use to examine the **Prediction response**, in which people's rating of the stablity of the sonification is used as secondary meausdre of the success of their prediction, and the **Apprasial response**, in which the impact of the sonification on one's perceptions of their own movement is measured through sense of reward, achievement and motivation to continue. The general musical sophistication subscale of the Gold-MSI was used to assessing their musical experience, in order to establish that music experience was not a factor in how much perceived stability's effect on movement [Müllensiefen et al., 2014], as seen in appendix G.

These control studies are used to gain an understanding of the measurable impact these sonifications have on people's movement behaviour and perceptions. These studies have the advantage of giving quantifiable measures of the experience [Blandford et al., 2008], which is advantageous when considering the impact different sound design choices have on how a sonification is interacted with [Serafin et al., 2011, Degara et al., 2013].

Descriptive statistics are reported in the form of plots for behavioural measures, showing mean values with standard error bars, and tables for self-report, showing median values as well as the range. Various statistical tests are used within this thesis. While each study outlines the specific methodology and tests used, an overview of the most commonly used are presented here. For behavioural measures, a repeated measures Analysis of Variance (ANOVA) was used to examine the impact of the different conditions on the movement behaviour [Blandford et al., 2008]. Normality was tested with a Shapiro-Wilk test and where needed common data transformations [Field, 2013, McDonald, 2014] were used meet assumptions of normality, as described in each study.

For non-parametric data, such as the self-report measures taken, non-parametric tests were chosen [Blandford et al., 2008]. Initial Friedman tests were used to establish differences across conditions and follow up Wilcoxon signed rank tests, with a Bonferroni correction, were used to compare each condition [Field, 2013, McDonald, 2014].

From these descriptive and inferential statistics, the impact of the different sonifications can be seen. The results of which are discussed in relation to the evaluation/extension of the MoSEM, to the literature and how the findings may be applied in sonification design.

### 3.2.3. Applying the MoSEM: Explore Musical expectancy sonification in populations with low self-efficacy

After the proposed MoSEM has been examined through this series of investigations, two case studies serve as examples of how MoSEM can be used to design sonifications to support people with low self-efficacy and show *RQ4: How may the MoSEM be used to design MuES for populations with low self-efficacy?*

The first case study focuses on chronic pain rehabilitation, in which low self-efficacy can lead to avoidance of certain movements [Woby et al., 2007]. Based on Singh *et al.'s* work, which shows the need to balance encouraging progress and avoiding over-activity, the MoSEM is used to design a gap based sonification to either encourage progress past a given target point or encourage the completion of a movement before overextension. This design is first evaluated with a general population to investigate its efficacy and then evaluated via a mixed method approach with people with chronic pain to explore how it may be used by people living with chronic pain.

The second case study focuses on people who struggle with general physical activity; previous work shows how low self-efficacy can impact people trying to engage in physical activity [Shieh et al., 2015, Biddle and Mutrie, 2007]. Firstly, a series of interviews with people who struggle with physical activity and personal trainers who specialise on beginners were performed. These interviews help to understand how barriers related to low self-efficacy impact people's ability to engage in physical activity and how they may be addressed by MuES. From these findings, sonification designs to support repetitions of the squat down movement are investigated, to see how MuES can be used not only to encourage movement past a certain point but to encourage towards a goal.

These case studies take a more user-centred design approach, working with the given populations to establish design requirements, develope prototype designs and evaluate these designs with the given population as a way to better understand how they may be used by real users [Preece et al., 2005].

In these later evaluations, a mixed-methods approach is adopted to gain a broader understanding of both the specific elements related to people's behaviour as well as the broader impact this may have on people's relationships with physical activity. While still exploring the measurable effect on movement and self-report measures on movement perceptions, these studies also have a greater focus on qualitative feedback and interviews to better understand the use of MuES through its use in real-life practice and how it is experienced [Serafin et al., 2011].

This mixed-methods approach allows for multiple viewpoints of the data [Strauss and Corbin, 1998], through combining some of the control study methods used in the previous sections with a more qualitative approach the understanding of the MoSEM and its use to support low self-efficacy can be established.

Qualitative methods were used to develop a rich understanding of how participants experienced [Braun and Clarke, 2013] using the MuES, to better understand the quantitative measures and to gain additional insights to how people feel about the sound and their potential use [Blandford et al., 2016]. These methods help explore previously unconsidered aspects of the MoSEM and better understand the way people feel about MuES. In order to establish the rigour and validity of this qualitative analysis work, a methodological framework was established prior to the data collection [Blandford et al., 2016]. This framing considered both the kinds of questions and responses the study would look at, how the data would be transcribed and how it would be analysed. In this analysis, there was a focus on iteration, comparison across the data and returning to the source data [Braun and Clarke, 2013].

Qualitative data was collected through semi-structured interview questions, to allow the same areas to be addressed with the different participants while allowing for the exploration of new areas as they emerged. Similarly, the areas of discussion were developed iteratively through the interview process to focus in on specific areas of interest. The responses were either recorded through written note taking or a combination of note-taking and audio recording. The specifics of what questions were covered and how responses were recorded can be found in the individual study Chapters.

Responses were then analysed using a thematic analysis method, a flexible approach for exploring key features of qualitative responses while maintaining the richness of the data set [Braun and Clarke, 2013]. This work closely followed the six steps of the thematic analysis presented by Braun and Clark [Braun and Clarke, 2013]. Specific to work in this thesis, responses were first converted into transcripts. These transcripts were made from the written notes and audio recordings and were then used for the analysis of the data. The transcripts aimed to maintain the responses from participants while maintaining the clarity of the transcript, as such false starts or filler words were removed from the transcript.

Once all the data was transcribed, some data familiarisation and identification of potential codes and themes was done. This followed a pragmatic approach to analysing the data [Blandford et al., 2016], in which some initial "rough" themes were established. This aided the future analysis of the data as an initial understanding of the transcripts was achieved. After this a selective coding scheme was used to examine areas of interest within participant responses [Braun and Clarke, 2013]. From these codes, themes emerged and were revised and grouped into higher level themes to explore commonality and patterns within the data; this was done iteratively to develop themes first within participants and then developing themes across participants. This cyclical approach, allowed for the themes to be coalesced and be developed around one another, highlighting the connection between different codes and themes [Blandford et al., 2016].

These themes are then used to explore and discuss the related research question, including the results from the collected quantitative data and previous research. The tools used for this analysis was *F4 Transkript* for transcription, and *F4 analyse* for coding and the development of themes, alongside handwritten paper notes, during initial data collection to help facilitate transcription and the initial development of themes.

# 4. Designing Musical Expectancy Sonifications

**In this Chapter:**

*RQ1: Can a model of movement sonification expectation be designed to examine sonifications impact on movement?*

∗ How do people experience musical expectancy?

∗ Developing a model for musical expectancy for movement sonification: the MoSEM

∗ Choosing stimuli for evaluating the MoSEM

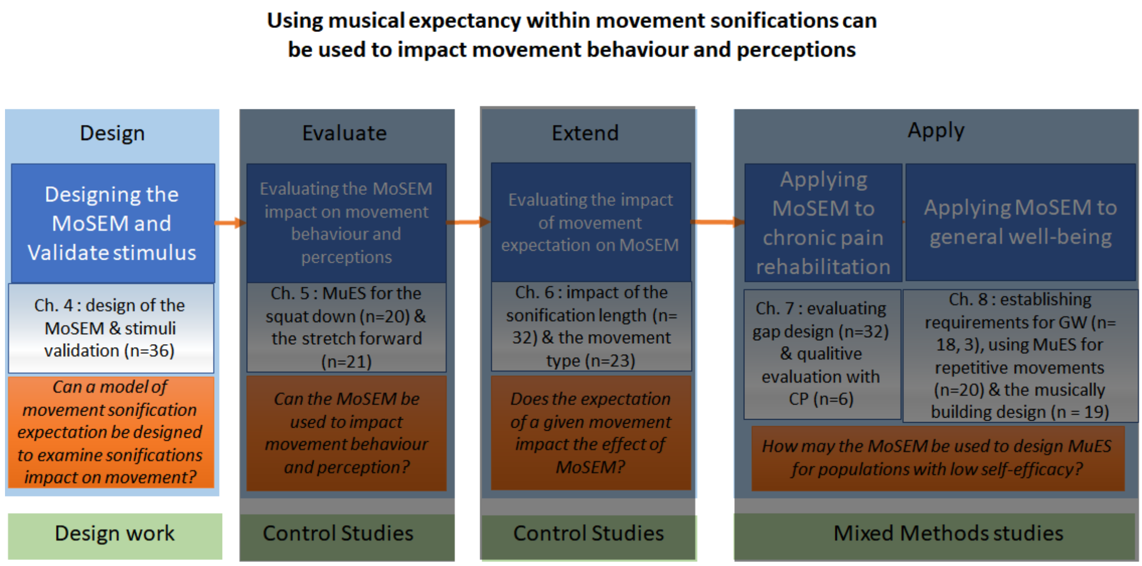



Figure 4.1: This chapter focuses on devloping the MoSEM. Based on previous work in sonifcation, music and movement understanding, the MoSEM is developed to explore MuES use within physical activity. This work addresses the how movement sonification expectation impact on movement can be modelled

## 4.1. Introduction

This thesis explores musical expectancy as an embodied and implicit aspect of music. However, in order to understand how musical expectancy may be utilised with sonification, first an understanding of how people perceive expectancy must be established. Our musical expectations are built from our listening to music and learning the meaning of certain structures and relationships. As described in Meyer's Emotion and Meaning in Music it is the defying/ delaying or meeting of these expectations that lead to the tensions or relaxation that are felt in music [Meyer, 1957]. For instance, near the end of a piece of music a composer may insert a pause before the final chord. A listener familiar with that certain practice of music would be expecting the final chord and the pause would elicit a feeling of suspense and surprise, then when the final chord is sounded that feeling changes to one of relaxation and completeness. The mechanisms used to manipulate this expectation are many and varied, be it a repetition of a melodic phrase, the completion of a set number of beats, through a certain rhythmic or harmonic pattern or even through silence in the middle or at the end of a phrase [Bigand and Poulin-Charronnat, 2006]. Manipulating this musical expectation is one of the key ways music can produce an emotional response in the listener. As noted by Meyer, it is not merely the meeting of expectation that leads to our emotional response to music, but through defying or inhibiting the realisation of our expectation which activates our need for a return to stability and conclusion [Meyer, 1957].

## 4.2. Implicit understanding of Musical Expectancy

This musical expectation, while being a rather high-level musical concept, is not something people need musical training to perceive. Narmour's " implication-realisation" (IR) model can be used to predict people's judgements of ongoing melody [Narmour, 1990], which demonstrates how expectation is built in music based on one's previous experience. Schellenberg presents a revision of Narmour's initial model which explores further how through our implicit understanding of music, an implication of how it should continue is generated, which can either be realised or defied dependent on the progression of the music [Schellenberg, 1996]. The IR model was then explored in a series of experiments with children in France, Australia and Canada. They evaluated certain aspects of Western Music; the results showed that harmonic content effects response time to questions about the piece [Schellenberg et al., 2005]. They found that while musically trained children were more accurate and faster, non-musically trained children were still able to complete the task reasonably well. Through a series of different studies with children of different ages and cultural backgrounds, it was found that participants responded faster to questions on given melodic phrases when they ended on the established tonic, hence meeting their musical expectation. The effect was seen in children as young as six and in children with and without formal music training.

Similarly, Bigand and Poulin-Charronnat present a review of the capabilities of non-musicians in terms of perceiving some of the underlying musical elements in Western music [Bigand and Poulin-Charronnat, 2006]. They put forward the idea of "experienced listeners" that through even a non-musician's everyday exposure to music a sophisticated degree of understanding is developed. In one study, they compared musicians and non-musicians' ability to identify variations on a theme that while having very different surface features maintained the underlying structure [Bigand, 1990]. For their studies they categorised musicians as *"students at national music conservatories who have learned musical and instrumental techniques for 10 years on average and whose abilities have been confirmed each year by formal examinations"* and non-musicians as *"students of the same age who have not had any specific musical training"* [Bigand and Poulin-Charronnat, 2006]. One hundred and sixty subjects were given a series of melodies with the same underlying structure interspersed with phrases that did not fit the structure and were asked to identify whether or not a given set of phrases belonged together or not. While they found musicians did perform better at the task, with a 72% correct response compared to 58%, the performance of the non-musicians was still above chance; demonstrating a presence of some implicit yet sophisticated understanding. These findings of implicit understanding of music expectation are important when considering musical expectancy as a design tool within sonification, as it must be accessible for musicians and non-musicians alike.

A later study investigated the perception of musical stability: as a way for describing the impact of expectation within music. Through the use of certain patterns, music can generate strong musical tensions and an expectation for them to be resolved, (known as unstable events), or create relaxations of these tension points, (known as stable events

[Bigand, 1997]). These tensions and relaxations can be attributed to a variety of musical elements, notably tonal and rhythmic patterns. For example, the two melodies used by Bigand are rhythmically identical and contain almost exactly the same notes [Bigand, 1997]. However, because one melody is in A minor and the other is in G major, the relaxations and tensions fall in different place in the melody. In order to compare the perception of this stability a set of 40 musicians and 40 non-musicians were asked to rate the musical stability at a series of "stop notes". They found that both the musicians and non-musicians were able to perceive the stability of the sounds, although in some tones the effect of on the stability rating was greater for the musicians, such as resolving on the tonic. This idea of stability is useful as a method for reliably utilising musical expectation through manipulating the stability of a sonification design; it can be made to either defy or meet one's musical expectation.

Stability can be altered through the use of various musical features [Bigand and Poulin-Charronnat, 2006, Farbood, 2012]. Perhaps the easiest one to alter consistently within sonification is through the use of harmonic cadence points as they are where stability is used most obviously in western tonal music [Huron, 2006]. There have been several works which explore how people perceive the conclusion of different harmonic cadences [Tillmann et al., 1998, Vallières et al., 2009, Bigand, 1997, Sears et al., 2014]. A musical cadence can be thought of as the punctuation of music, normally consisting of two chords, it determines whether a phrase will conclude (a stable cadence) or whether it must continue to resolution (an unstable cadence). Tillmann *et al.* also demonstrate this implicit understanding of musical expectation. In a comparison between how musicians, non-musicians and amateur musicians rate the completion of different cadential structures [Tillmann et al., 1998], they found that, although musicians did perform the best, all three groups had similar ratings to different cadences, leading to the observation that although musicians may have better strategies for analysing stability, non-musicians use the same perceptual skills just less efficiently. Vallières *et al.* had musicians and non-musicians identify whether short segments of music were the beginning middle or end of a musical piece [Vallières et al., 2009]. It was found that the perfect cadence (and example of a stable cadence, i.e. one that returns to the tonic of the key or its "home") was perceived as musically complete by both groups, based on how it was established in the preceding musical stimulus. This work also showed how harmonic content was the primary marker used by both groups as the primary marker for the ending of the musical piece.

Sears' recent work on the perception of cadence also demonstrates the ability of non-musically trained people to identify differing stabilities of cadences [Sears et al., 2014]. The ratings for different cadences, taken from Mozart's keyboard Sonatas, were given by musicians and non-musicians. It was found that similar completion ratings were given by both musicians and non-musicians for a series of musically stable and unstable cadences. These works all point to people having an implicit understanding of musical expectation. This demonstrates how harmonic stability may be manipulated within sonification in a way that can impact one's musical expectation that is effective for both musicians and non-musicians alike.

## 4.3. Experiencing musical expectancy

These previous works demonstrate how different aspect of music can be altered to change one's expectation of the music. However, in order to design Musical Expectancy Sonifications (MuES), firstly an understanding of how musical expectancy is experienced must be established. From this their impact on people's movement behaviour and perceptions can be examined. There have been many models of musical expectancy. The Implication-realisation model discussed previously, outlines how the implied continuation of the music creates tension [Narmour, 1990, Schellenberg, 1996]. Likewise, Chew's model for tonality which examines the "distance" between different notes dependent on the key of the music [Chew, 2000] showing how tension is increased as one departs from the tonic "home". Also, the work of Abdallah and Plumbley, which takes an information dynamics approach for exploring people's perception of expectation [Abdallah and Plumbley, 2009], demonstrates how it is people's learning of patterns of music which are used to build an expectation of the final musical outcome. However, while these models offer valuable insight into how musical expectation is created and understood, none fully consider how individuals experience expectation as they hear it.

To address this latter question, Huron developed a model for the psychology of musical expectancy, with his five expectation-related emotional response systems or ITPRA theory [Huron, 2006], adapted in Figure 4.2. Huron based this model on the neurological responses to expected events and built a theory of expectation to examine how people experience these events in terms of the predictions made and what can be learnt from it. These are broken down into the five ITPRA responses as a combination of responses pre-event and post-event. These five responses are as follows:

- **Imagination response**(where the expected outcome is established). Imagine reaching into a variety box of chocolates. As you pick a chocolate, you may begin to imagine what you expect the taste of it to be. This imagined outcome becomes more confined as more information becomes available, the shape of the chocolate or the colour of the wrapper, your certainty of this outcome increases.

- **Tension response** (where the arousal is heightened as the person awaits their desired conclusion). As this expected outcome is established, the expectation and anticipation of it builds. As you bring the chocolate to your mouth, there is a preparation for this event as you anticipate how the chocolate will taste.

- **Prediction response** (where the prediction of expectation is evaluated as either correct or incorrect). Once this expected event happens, it is evaluated by the individual in comparison to what was expected. Did the chocolate taste as good as you expected, or did you mistakenly pick your least favourite flavour? With a correct prediction, there is a positive reinforcement in the form of a positive feeling of reward.

- **Reaction response** (where the result of that evaluation is unconsciously reacted to in the short term). Based on this prediction response, there is a coinciding reaction to whether the prediction was correct or not. This is the immediate and subconscious reaction based on the expected event. If the prediction of which chocolate, you selected was correct, you might smile involuntarily or begin to chew a bit faster. However, if your prediction was incorrect, you may feel a sense of surprise or screw you face up if the taste is unpleasant.

- **Appraisal response** (where the result of the evaluation is consciously reacted to in the long term). After this short-term response the conscious assessment of the prediction begins. This may be reinforcing some of the ideas that led to your correct prediction, or you may begin to examine what led to an incorrect prediction, perhaps the chocolate company changed the colours of their packaging or perhaps someone has played a cruel trick on you.

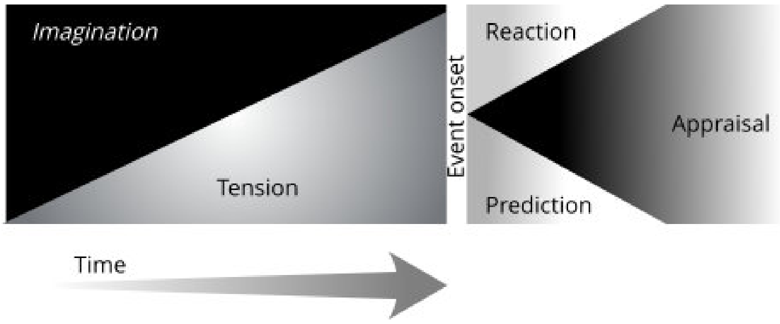



Figure 4.2: Huron's ITPRA response of expectation adapted from [Huron, 2006]. Before an expected event, it is imagined and as it is anticipated a tension builds as the individual prepares. As the event occurs, the prediction is rendered either correct or false, and there is an initial evaluation and reaction to it. Then post-event, there is a final appraisal on the individual's prediction

Huron presents this as a general theory of how expectation is experienced. However, Huron primarily explores this theory as it is applied to music. Our expectation of music is built on our experience of hearing music from which one's experience of hearing new music is altered. As one hears the opening notes of a piece of music, an expectation of how it should go on is developed. Then as the music goes on one predicts and reacts to the various changes in music. This process of listening to music then builds to a final expectation of a musical ending, where these feelings of expectation and tension are often strongest and where composers can manipulate the feeling of tension by delaying resolution [Huron, 2006, Meyer, 1957]. When the music finally completes, one's final prediction is evaluated, leading to either a feeling of resolution or unresolved tension.

From Huron's theory of expectation it can be seen how musical expectation is developed through our predictions and reactions to expected events. However, it is yet to be seen how providing an individual agency over the sound, through sonification, may impact their reactions to different musical expectancies. Through combining one's expectation of one's movement and the expectation of the music generated, sonifications can be designed to exploit these feelings of tension and resolution to impact movement behaviour and perception.

## 4.4. Movement Sonification Expectation Model

To understand the design of MuES, an exploration of how one's expectation of one's movement may interact with a musical expectation is needed. This Movement Sonification Expectancy Model (MoSEM) will be used throughout this thesis to interrogate and to understand how people interact with these MuES and how that expectation is experienced through their movement behaviour and perceptions. This thesis aims to develop a model for expectancy from within sonification. In this design, how this active role may alter the perception of the expectancy is explored and how the embodied link between body movement and music can be utilised to direct movement through sonification.

Huron's theory of expectation [Huron, 2006] alongside the use of external feedback to update our perception of our movement [Wolpert and Ghahramani, 2000], provide a lens to understand the closed-loop interaction between one's movement and a sonification which creates in itself a music expectation [Serafin et al., 2011]. As one performs a movement and such feedback is produced, the sensory input is used to update one's perception of the movement and in turn the ongoing movement. Here the MoSEM is developed to understand how layering musical expectation onto this process may impact movement behaviour and perception. From this some testable predictions can be made as to how MuES will enhance and alter the experience of one's movement.

### 4.4.1. Stage one: Expectation of movement

First, consider the expectation of an individual's movement towards a target endpoint without any external feedback. As shown in Figure 4.3, the person begins their movement with a given expected end-point. They then begin moving towards this ending, and in doing so the expectation of this final end-point, (the movement tension) increases. On reaching this end-point, the expectation is met and therefore the prediction/reaction response provides the feeling that the movement is complete, and they return appraising said movement as completed [Wolpert and Ghahramani, 2000].

However, when considering populations with low self-efficacy, the expectation of the movement may not be as strong due to the limited expectation of their own abilities [Woby et al., 2007, Sonstroem and Morgan, 1989]. This uncertainty leads to people being unsure of what they can achieve or how far they have moved, seen in Figure 4.3 as the

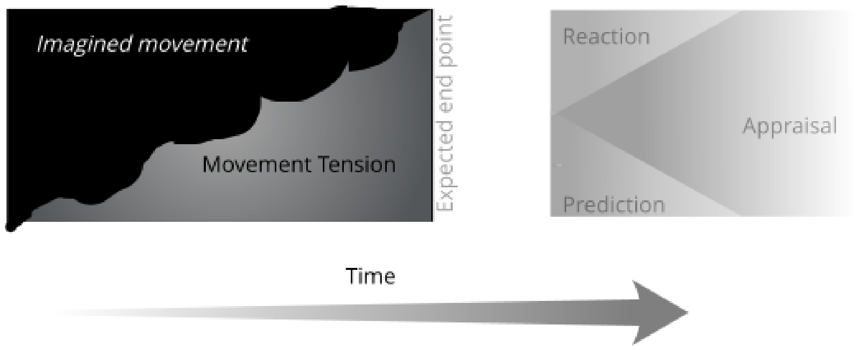



Figure 4.3: Applying Huron's theory of expectation to an unaided movement, the individual starts with some expectation of their movement, which building in expectation as the movement goes on. However, in the case of low self-efficacy, this imagined movement and the anticipation of the movement may be hard to track due to limited belief in one's ability. Finally realised when one's proprioception is used to establish that this point has been reached; however, the low expectation of one's movement means it is not appraised as having achieved much [Schunk, 1995].

blurring between the imagined movement and the anticipation of the movement. Low self-efficacy also makes it difficult to assess one's completed movement(the performance of the movement) and to appraise the movement, (the attribution of the success of the movement) [Schunk, 1995].

### 4.4.2. Stage two: informational sonification

The goal of sonification is said to be to represent the underlying data [Scaletti, 2018], in the case of movement sonification to extend the proprioceptive feedback. A purely informative sonification would improve the information available to the individual to make their prediction of expected movement and may help with the evaluation of whether it was correct. While in practice this is difficult due to the musical/embodied way people tend to interpret sonified data [Vickers et al., 2017, Roddy and Furlong, 2015], it is considered here to examine how the information provided by sonification may impact one's experience of the movement.

Sonification aids people in tracking their performance of a movement, which may be difficult when one relies purely on proprioception, in which the sound can augment understanding of the movement [Schaffert et al., 2019]. This has been shown to support

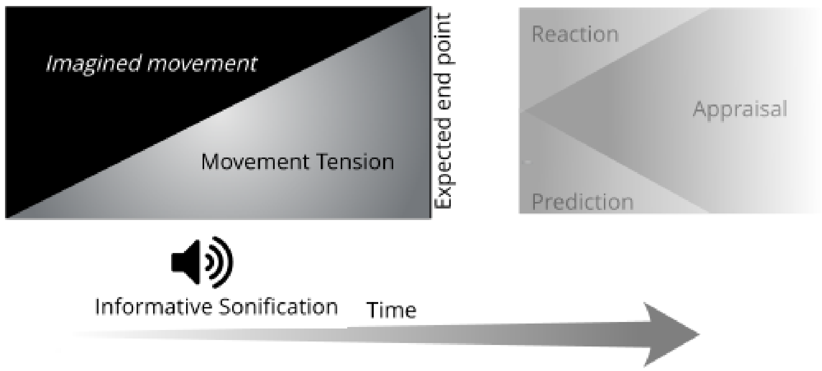



Figure 4.4: Applying Huron's theory of expectation to a purely informative sonification, the imagined movement and the anticipation of the expected end is more clearly defined, as the sonification can be used to track the movement. However, the movement itself and the appraisal of the movement remain unchanged.

physical activity in which people can use sonification to know how much they have moved [Khan et al., 2018, Singh et al., 2014], providing the performance feedback necessary to enhance self-efficacy [Schunk, 1995]. This can be seen in Figure 4.4, where the expected endpoint is better defined and the relationship between the imagined movement and the anticipation of the movement clearer. However, the expectation of the movement remains the same as in Figure 4.3, meaning it may still be limited by the expectations of the individual.

### 4.4.3. Stage three: music to enhance movement expectation

Now consider a musical sonification which, as the individual moves, provides feedback in the form of progression through a musical phrase, as seen in [Huang et al., 2005, Wallis et al., 2007, Singh et al., 2014, Khan et al., 2018], the expectation of the movement is enhanced. With the addition of this musical sonification, the expectation in the movement is altered. As the sonification is generated from the movement and the individual feels agency over the sound, it builds a musical expectation, on top of, but related to the expectation of the movement in Figure 4.3. In addition to the feedback from the sonification on the individual's movement, the design of the sonification causes an effective and emotional response [Serafin et al., 2011]. The combination of expectation of the music and expectation of one's own movement then impacts the way movement itself is experienced, with the two reflecting on each other. Due to the agency felt over the sonification and its use to enhance the proprioception of the individual, the musical aspects of the sound become linked to one's perception of one's own movement.

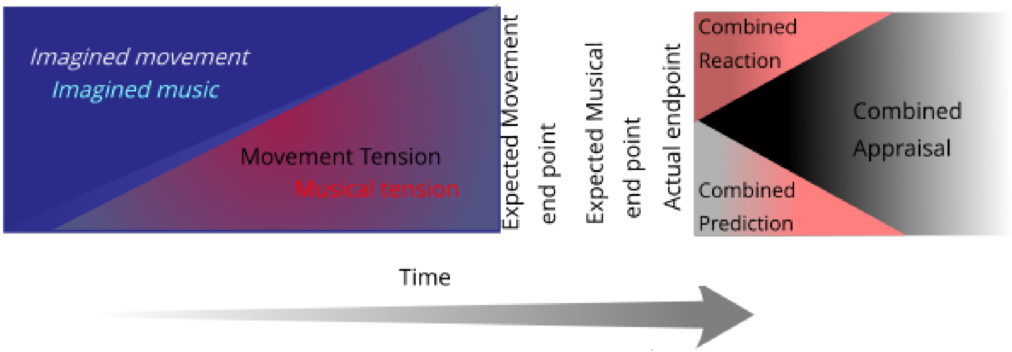



Figure 4.5: Matching musical expectation with movement expectation. The movement begins, and tension starts to build to an expected ending, at the same time a musical expectation is created by the sonification. At the endpoint of the movement, the combination of the two is reflected in the person's reaction/prediction responses at the conclusion of the movement, as the musical expectation matches the expected movement, there is an attribution of the musical feeling of completeness to the movement itself. Then as the music is appraised as complete, the completeness of music is also felt towards the movement.

Considering Huron's ITPRA responses, firstly, the **Imagination response** begins to build the individual's expectation of the music and, by linking this to the ongoing movement used to trigger the sonification, entangles the two. From this, the **Tension response** develops as the tension in the music builds to this expected point; this is reflected in the continuation of the movement to the expected stable outcome. As the musical expectation and movement expectation match, when the endpoint is reached the **Prediction response,** gives a positive reinforcement that a correct prediction of the music's completion is found and thus the **Reaction response** shows this reflected in the movements at the target point to begin the return as the movement, in turn, is perceived as complete. From this the **Appraisal response** assesses the correct prediction of the movement completion, and because the musical expectation is also met, there is a sense of reward from the completed music. This can be seen in Figure 4.5 where the context is established, an expectation is built and then met, leading to a feeling of completion and the conclusion of the movement. This is seen in the combination of the expected movement and the expected musical endpoint being aligned creating an actual endpoint of the movement in which there is a feeling of musical resolution.

In addition, this builds on Huron's discussion of the "prediction effect" a byproduct of the misattribution of the positive feeling that comes from a correct prediction of the outcome of the music to the music itself. In this case, the MoSEM shows how this prediction effect may affect one's perception of the movement which caused the sound, leading to a feeling of reward for the "complete" movement.

This has the benefits of announcing the movement and providing attributional feedback [Schunk, 1995], through a sense of completion created by the sound. The emotional connection to the music created [Meyer, 1957], and its connection to one's movement helps support one's ability to self-attribute the feeling of success, which is needed to overcome low self-efficacy. This supports how sonification can be designed to promote positive affect [Serafin et al., 2011] and how musical structure can be used to enhance sonification's impact [Vickers, 2017]

#### 4.4.4. Stage four: music to adapt movement expectation

Now consider a musical sonification which seeks not to match one's expectation of the movement, but to alter it. This idea utilises the idea of the feeling of that musical tension needs to move to resolution. Considering the works reviewed in Section 2.5 on using auditory feedback back to alter behaviour, it can be seen how auditory feedback can be used with the normal sensory inputs we use to build our internal representation of ourselves [Botvinick et al., , Dichgans and Brandt, 1978] to alter our perceptions. Again, because of this link between one's understanding of the feedback produced and one's ongoing movement, altering the sound heard can be used to alter one's perceptions and movement behaviour [Tajadura-Jiménez et al., 2017b]. In addition, there is a link between the idea of musical expectation and movement felt in the embodied experience of music, and through leveraging the conceptual metaphor linked to the continuation or resolution of music to one's movement, one's perception and, hence, behaviour may be altered, as seen in Figure 4.6.

For example, Chew *et al.*'s work explores cadential tipping points [Chew, 2016] where a point of musical tension is likened to *"a physical object balanced at its tipping point,* *like a train atop the hill of a roller coaster, before it falls back into motion"*. Huron also presents a *Qualia survey* [Huron, 2006], in which responses from people trained in western classical music who described different scale degrees (intervals between two musical notes in a major key) were analysed. While the tonic was described as *"home"* and *"contentment"*, scale degrees which were perceived as musically unstable were described with words *"pointing"* or *"restless"*. These descriptors imply an association with musical instability and the desire for on-going movement, while conversely, musically stable sounds invite a feeling of finality and pleasure. Through associating these musical aspects with one's movement, sonification can be designed to evoke certain responses from the user.

Again, considering Huron's theory of expectation, it considers one singular ITPRA response. However as both the sonification is heard and the feedback is used to inform ongoing movement, there are many ITPRA responses going on based on the sensory feedback given. In reality, there is a series of ongoing prediction and reaction responses as the individual takes action to continue their movement based on the feedback, that is having not reached the endpoint of the movement, the reaction is to move more. It is through this ongoing building of expectation that the movement and music become intertwined as the continued movement continues to generate sound. If then, the expected musical endpoint is altered to not align with the expected endpoint of the movement, for instance through harmonic instability, because the sound is also acting as an extension of the proprioceptive feedback, informing on the movement itself, the actual endpoint of the movement is altered by the desire for musical resolution. This leads to a subconscious reaction in the form of continuing the movement.

For instance, where the music is left unresolved at the expected endpoint, the musical expectation signals that the movement should continue. Instead, the tension felt delays the **Prediction response**, **Reaction response** and **Appraisal response** because the music has yet to end as expected, the individual continues moving, towards some expected resolution. This leads to an extended movement and a drive to continue moving. However, if the musical expectation is resolved before the expected endpoint of the movement, the **Prediction response,** that the music has reached its expected conclusion and thus the **Reaction response** creates the feeling that the end of the movement has been reached. From this the **Appraisal response** assesses the correct prediction of the musical completion, which again is reflected in the perceptions of the movement being complete.

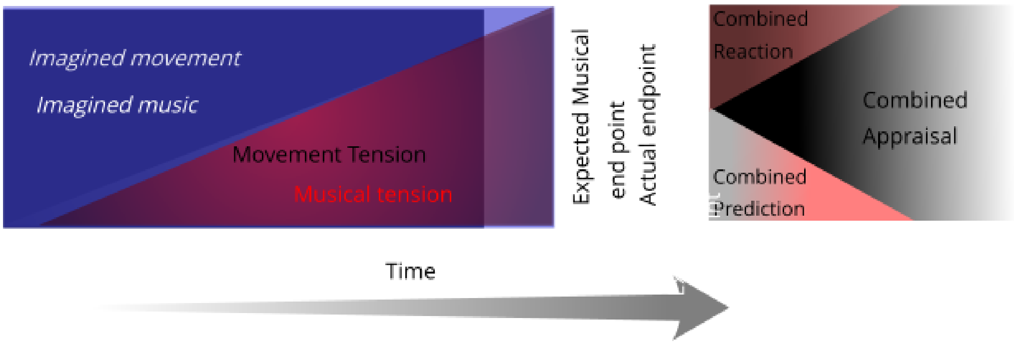



Figure 4.6: By altering the musical expectation, again shown in blue/red, felt through the sonification, the movement expectation is altered in turn. As in Figure 4.5, The movement begins, and tension starts to build to an expected ending, at the same time a musical expectation is created by the sonification. However, in this instance, the conclusion of the music does not match the expected end of the movement. Due to the interconnectedness between the individual's movement and the sonification, this, in turn, leads to the movement and the appraisal of the movement being adapted to match the musical expectation.

## 4.5. Summary of the MoSEM

The MoSEM in its entirety demonstrates the interplay between one's expectation of the music created by the sonification and one's expectation of their own movement. Stages one and two, show how this expectation of movement is generated and augmented through informational sonification. Stages three and four show how expectation can be altered through movement sonification, either matching one's movement expectation or defying it. This expands the ITPRA model of Huron by examining how expectation of music changes when the individual has agency over the sound generation. Moreover, by considering expectation of both movement and music together and how they impact each other. From From this model some predictions on MuES impact on movement behaviour and perception can be made.

1. Should the sonification end with musical stability, the movement will be concluded and will elicit a feeling of completion and reward;

2. Should the sonification end with musical instability, the movement will continue toward the implied resolution and will elicit a feeling of motivation to continue past the endpoint.

By considering how this joint expectation is built (through **imagination** and tension **responses**), the **prediction**, **reaction** and **appraisal** responses can be estimated and potentially altered through changes in the sonification design. From this MoSEM some initial MuES designs will be generated to investigate and verify the effect of expectation sonification of movement.

## 4.6. Creating MuES using the MoSEM

Within this thesis, harmonic stability will be used to alter the musical expectation at the endpoint of a movement. Using a series of chord progressions to create the MuES section of the MoSEM, some which build tension and conclude (stable), and some which build to tension and do not resolve (unstable). From these MuES, the reaction response, in the form of movement behaviour, and appraisals of the movement, in the form of self-report will be measured. The sonifications will be produced using a smartphone-based setup, as described in Section 3.2.2. The movement space for the individual is calibrated, and as they move through that space, they progress through the chord sequence, as seen in previous works [Huang et al., 2005, Wallis et al., 2007, Singh et al., 2014, Khan et al., 2018]. However, it should be noted that there are many other ways in which this musical expectation may be built, for instance through rhythmic and melodic material, however, for the explorations of the MoSEM in this thesis, the manipulation of expectancy is limited to harmonic resolution at the end of the sonification.

To examine the instances where the expectation of the movement aligns with that of the music, a stable target point will be used, as seen in Figure 4.7. As the individual moves, the imagination/tension response is built through the chord progression. Then at the end of the movement, the stable cadence is used to meet the individual's musical expectation. The impact this has on people's prediction/reaction response is measured in the movement behaviour after the final chord in the sequence, as detailed in Section 3.2.2; where it is expected that due to the sense of completion from the sonification, that people will conclude their movement. The impact on appraisal response of the movement is measured through feeling after the movement, where it is expected that people will feel a greater sense of reward.

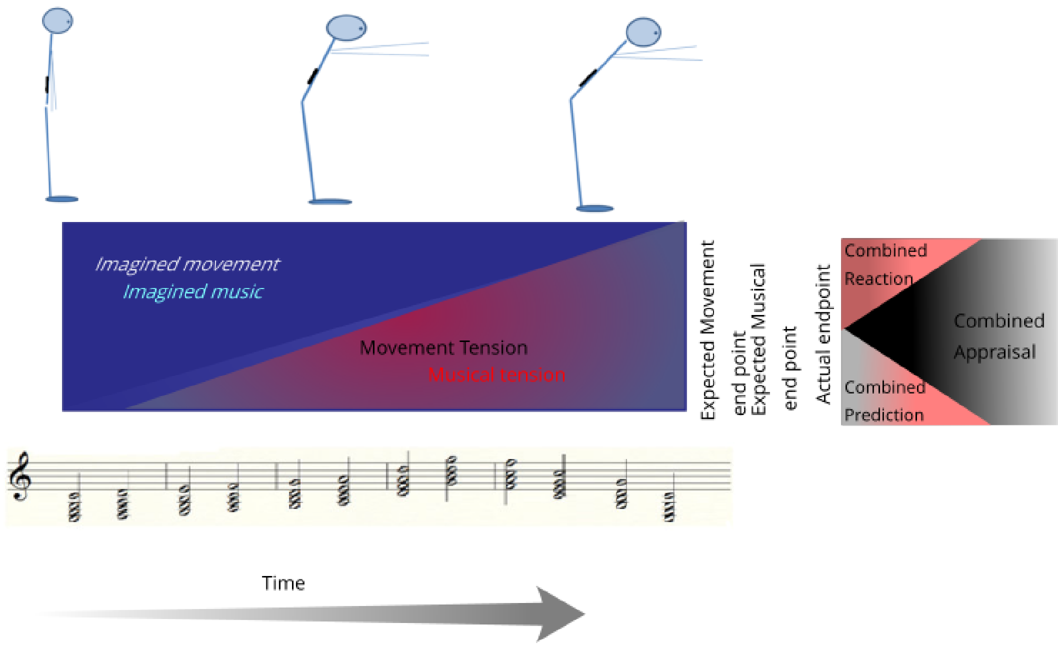



Figure 4.7: Using the MoSEM to create a stable ending sonification, where the musical expectation is met at the end of the movement. The movement drives the chord progression to create the musical expectation alongside the expectation of the movement.

On the other hand, instances where the expectation of the movement does not align with that of the music, an unstable target point will be used, as seen in Figure 4.8, to imply a musical completion past the expected endpoint of the movement. As the individual moves, the imagination/tension response is built through the chord progression, as before. However, at the end of the movement, the unstable cadence implies that the music should go on. The impact this has on people's prediction/reaction response is measured in the movement behaviour after the final chord in the sequence, as detailed in chapter 3.2.2; where it is expected that people will continue their movement on to some expected resolution. The impact on appraisal response of the movement is measured through self-report questionnaires; where it is expected that people will feel a greater sense of motivation to go past the endpoint.

The rest of this thesis aims to evaluate and build on this MoSEM, through a series of experiments to provide a detailed understanding of how musical expectancy can be

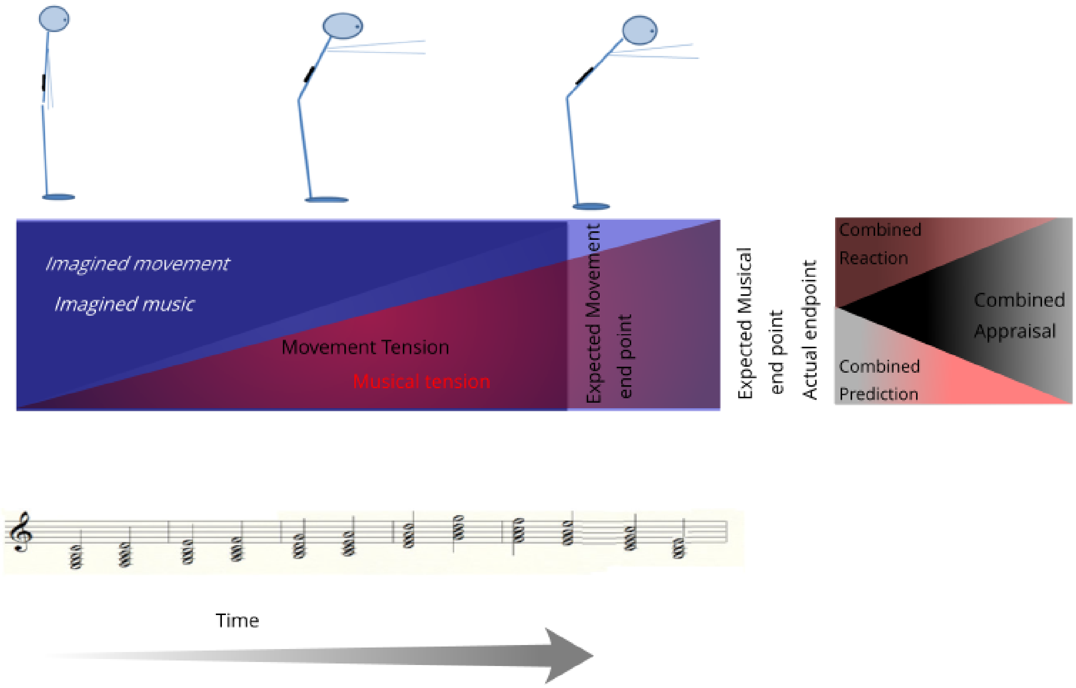



Figure 4.8: Using the MoSEM to create an unstable ending sonification, where the musical expectation is not met at the end of the movement. The movement drives the chord progression to create the musical expectation alongside the expectation of the movement. However, in this case, the implied endpoint of the music is beyond that of the sonification.

used as a tool with movement sonification design. To achieve this, the MoSEM is used to develop two initial MuES, one which ends with a musically complete ending and one which ends with a musically incomplete ending. Through these instances of the MoSEM the impact of MuES on movement behaviour and perception can be demonstrated and evaluated. However, first, an initial set of MuES must be developed and to ensure the effect of harmonic stability in these designs a stimuli validation is presented.

## 4.7. Stimuli Validation: listening tests

In order to evaluate the predictions outlined by the MoSEM, some stimuli must be created for use in such a sonification. For the evaluations of the MoSEM presented in this thesis an example MuES is designed. This MuES makes use of a chord progression mapped to the individual's movement, such that as the movement continues the next chord in the sequence is played. At the endpoint of the movement the ending is either musically stable (ends as expected), or musically unstable (implies continuation). Through this, the impact of musical expectation can be explored. To create this sonification, a stimuli validation was done to ensure the perceived stability of the designed stimuli would be as expected. Through a listening test, the stability of some example stimuli was tested. The goals for choosing the stimuli were:

1. To find the cadences which would best represent stable and unstable endings;

2. To ensure that altering the number of chords preempting the cadence did not drastically impact their perceived stability so that they could be altered during the evaluation studies to avoid learning effects.

Two main factors were considered: the ending cadence and the length of the stimulus, (the number of musical chords used). These were tested, in order to establish what kind of musical stimulus could be most effective within the sonification. The results for these listening tests were gathered both locally and online via a Google form. For this stimuli validation, it is expected that the results will map to similar research investigating musical completion and classical cadences [Sears et al., 2014, Bigand, 1997], however in our case rather than taking stimulus from real music, the stimuli used a simple scale pattern for use in sonification.

### 4.7.1. Participants

From the online and local versions of the stimuli validation, a total of 36 participants were recruited, of which 21 were from the online trials (age = 17-54, 13 male and 9 female) and 15 from the local trials (age = 20-54, 5 male and 10 female).

Of the 21 participants in the online trials, 13/21 and of the 15 participants in the local, 12/15 scored less than mean on the general musical sophistacation index found in the general population reported by Mullensiefen *et al.* (81.58) [Müllensiefen et al., 2014], therefore, it is assumed the effects seen here are not caused by musical expertise.

### 4.7.2. Materials

A range of different kinds of cadences were assessed; from this, the effect of these different harmonic combinations have on perceived stability can be explored, with rhythmic content kept constant. This set of stimuli were selected based primarily on the previous work that shows the implicit perception of stability and basic western music theory [Sears et al., 2014, Bigand, 1997, Tillmann et al., 1998]. The stimuli used can be seen in Table 4.1 and were chosen to cover a range of expected stabilities.

| **Example Stimulus** | **Expected stability** |
|---|---|
| Imperfect cadence to the dominant 7th | Very Unstable |
| Interrupted cadence | Unstable |
| Imperfect cadence | Slightly unstable |
| Perfect cadence to lower tonic | Very stable |
| Perfect cadence using inverted tonic | stable |
| Perfect cadence to higher tonic | Slightly stable |

Table 4.1: Example stimuli for stability experiments and their predicted stability based on the work of Bigand and Sears [Bigand, 1997, Sears et al., 2014]

To create both stability or instability, it is necessary to define the music with a certain musical key. As such to avoid any differences other than cadence across the stimuli, the same chords were used to provide the same musical context for the cadences. This can be seen in Figure 4.9.

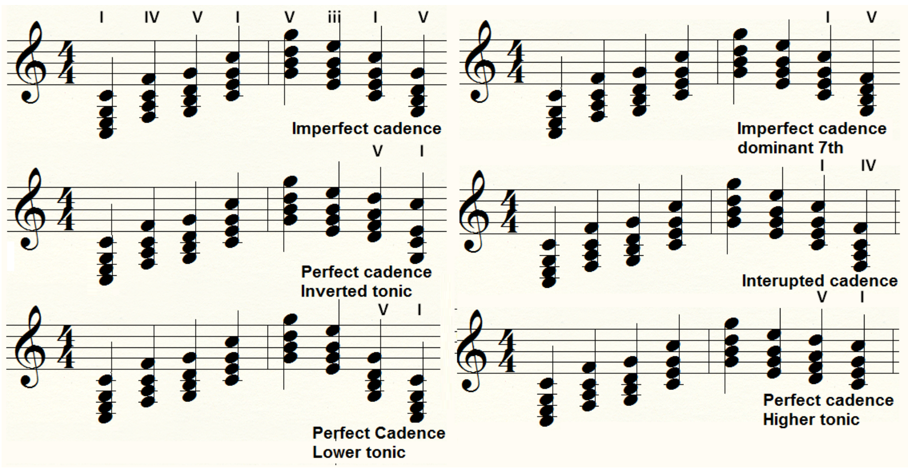



Figure 4.9: The different stimuli used to investigate the different cadence's effect on perceived stability developed from previous work on harmonic stability [Bigand, 1997, Sears et al., 2014] with their expected stabilites outlined in Table 4.1

In addition to measuring different cadence stability, the effect of stimulus length on perceived stability was also investigated. In this context, the length of a stimulus is defined as the number of musical chords it contains. For example in Figure 4.10 the different modification to the stimulus length can be seen, with chords being removed at the specified points in the sequence. This second stage of the validation was used to identify what effect, if any, length had on stable and unstable cadences, so as different length stimuli could be used in future experiments. Using a set of six stimuli, half stable (using the perfect cadence to lower tonic) and half unstable (imperfect cadence) of three different lengths: with 9, 10 and 11 chords long (short, medium and long). To determine the musicality of participants the general musical sophistication index (GMSI) presented by Mullensiefen *et al.* was used [Müllensiefen et al., 2014].

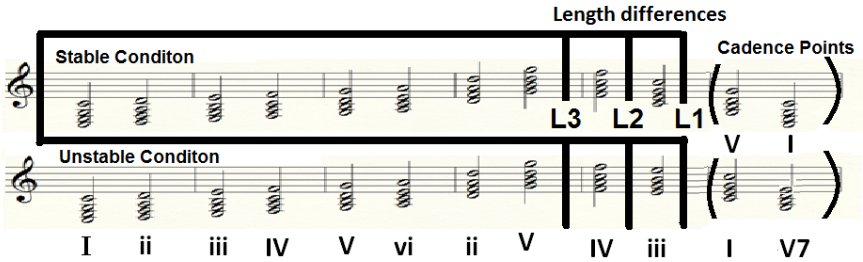



Figure 4.10: The different stimuli used to investigate the length of stimulus on stability, each length variation removed one chord from before the cadence point, shortening the stimulus. For the longest stimuli: chords played up to L1 before the cadence point, for the medium length chords: played until L2 and up until L3 for the shortest.

### 4.7.3. Experimental design

A within-subjects design was implemented for this experiment and for each participant the six stimuli were presented in a randomised order for both cadences and lengths. For the first task the independent variable was the cadence type, outlined in Table 4.1 and the primary measure was the stability rating provided by the participant. The perceived stability of the stimuli was measured using the method proposed by Bigand [Bigand and Poulin-Charronnat, 2006], using a seven-point scale, with 1 being very unstable and 7 very stable. For the second task, there were two independent variables: length of the stimulus (three levels) and stability (two levels).

### 4.7.4. Experimental procedure

In this experiment both the effect of cadence and stimulus length were investigated to explore the effect they have on the perceived stability. The participants were first introduced to the experiment, and the idea of musical stability was explained. Stability was described to participants as how likely the piece was to finish at that point, i.e. stable meaning conclusion of the music and unstable meaning it had not concluded. They were also told they could rank two stimuli at the same stability level if they wished. Participants were allowed to listen to the stimuli as many times as they wished before finalising their ratings.

The participants were then played the first stimulus and asked to rate its stability on the seven-point scale. Once this was complete the next was played and so on for both tasks, first the cadence then the length. Finally, they were asked to fill out a questionnaire to assess their musical expertise. The experiment measured musical expertise using an adapted form of the Goldsmiths Musical Sophistication Index (Gold-MSI) [Müllensiefen et al., 2014], specifically the subscale of "General Musical Sophistication" was used.

### 4.7.5. Results

#### Online results

As seen in Figures 4.11 and 4.12, showing the median values and the interquartile range, the cadences and lengths were rated as expected.

A Friedman test shows a significant difference between the results ($\eta^2 = 55.227(5)\, p < .001$,) for cadence and ($\eta^2 = 61.189(5)\, p < .001$,) for length. Follow up Wilcoxon signed rank tests with a Bonferroni-correction were then used to compare the different levels of expected stability. Significant differences were found between:

- the imperfect dominant 7th cadence and the imperfect cadence ($Z = -3.206, p = .001$), the perfect cadence to the higher tonic ($Z = -3.507, p < .001$), perfect cadence to the inverted tonic ($Z = -3.618, p < .001$), and perfect cadence to the lower tonic ($Z = -3.942, p < .001$).

- the interrupted cadence and the imperfect cadence ($Z = -3.313, p = .001$), the perfect cadence to the higher tonic ($Z = -3.603, p < .001$), perfect cadence to

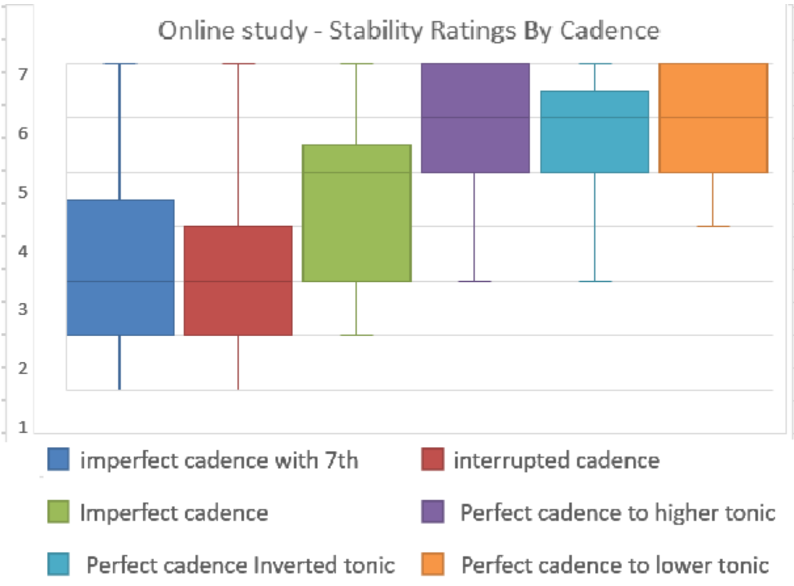



Figure 4.11: The Median (IQR) ratings for perceived stability of different cadence stimuli for participants in the on-line trials

the inverted tonic ($Z = -3.839, p < .001$), and perfect cadence to the lower tonic ($Z = -3.945, p < .001$).

However, no significant differences were found between the imperfect cadence and the stable cadence, nor between the stable cadences.

Again, for the effect of length, the results were analysed using a Wilcoxon signed rank test with a Bonferroni-correction to compare each expected length to the next for each stability. However, no significant effect of length was found on the perceived stability.

### Local trials results

As seen in Figures 4.13 and 4.14, showing the median values and the interquartile range, the cadences and lengths were ranked as expected.

A Friedman test shows a significant difference between the results ($\eta^2 = 33.549(5)\, p <$ .001,) for cadence and ($\eta^2 = 54.272(5)\, p < .001$,) for length. Follow up Wilcoxon signed rank tests with a Bonferroni-correction were then used to compare the different levels of expected stability. Significant differences were found between:

- the imperfect dominant 7th cadence and perfect cadence to the lower tonic ($Z = -3.190, p = .001$).

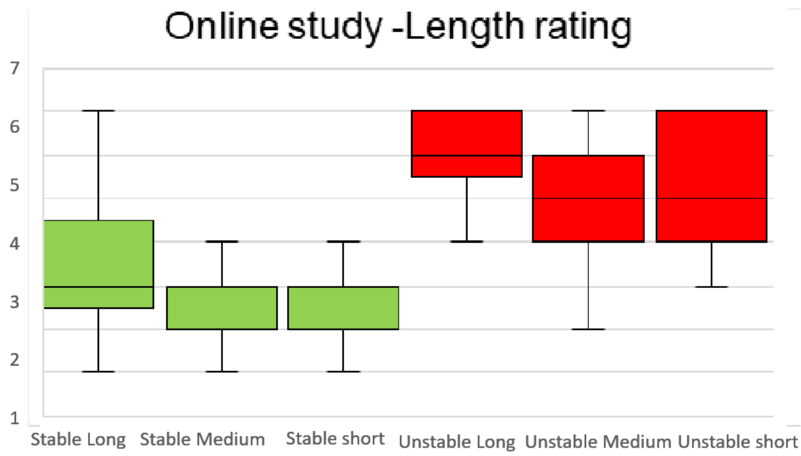



Figure 4.12: The Median (IQR) ratings for perceived stability of different length stimuli for stable and unstable cadence in the on-line trials

- the interrupted cadence and perfect cadence to the lower tonic ($Z = -3.413, p = .001$).
- the imperfect cadence and perfect cadence to the lower tonic ($Z = -3.302, p = .001$).
- the perfect cadence to the higher tonic and perfect cadence to the lower tonic ($Z = -2.961, p = .003$).

Again, for the effect of length, the results were analysed using a Wilcoxon signed rank test with a Bonferroni-correction to compare each expected length to the next for each stability. However, no significant effects of length were found on the perceived stability.

### 4.7.6. Discussion

From these results, the appropriate stimulus for the musically-informed sonification can be selected. By taking the highest rated stable cadence (the perfect cadence to the lower tonic) and the lowest rated unstable cadence (the dominant 7th imperfect cadence), the biggest effect of stability should be seen. While both the dominant 7th imperfect cadence and the interrupted cadence were perceived as very unstable, there was no significant difference found between them. However, while the interrupted cadence may feel "incomplete", there is also a danger it would be perceived as completely incorrect when used in sonification, due to the harsh deviation from the expected completion.

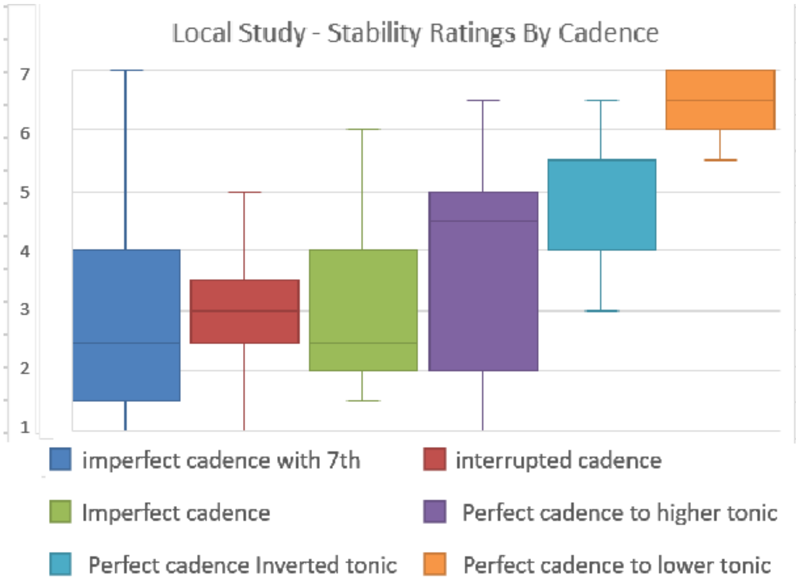



Figure 4.13: The Median (IQR) ratings for perceived stability of different cadence stimuli for participants in the local trials

However the leading tone in the dominant 7th chord implies the continuation, as seen in Huron's Qualia survey [Huron, 2006], therefore the dominant 7th was chosen. These results align with previous work in the literature demonstrating implicit perception of stability [Bigand, 1997, Tillmann et al., 1998, Sears et al., 2014], which demonstrate the implicit understanding of musical completion for harmonic cadences. This work demonstrates that even when taken out of a more general musical context, people can identify stable and unstable cadential endings.

Additionally, we can assume that the length of the stimulus can be changed without significantly affecting the stability. While it is likely that sufficient context for the given key is needed to establish an expectation [Bigand, 1997], the results for these studies suggest that the length of the sonification can be altered for use within the evaluation studies to avoid learning effects from participants learning where the end of the sonification lies. Overall these results allow for the selection of stimuli for use within MuES to create sonifications that end with either harmonic stability or instability. However, it should be noted that these studies do not consider other aspects of music that impact expectation, for example, rhythmic and melodic content [Bigand and Poulin-Charronnat, 2006, Farbood, 2012].

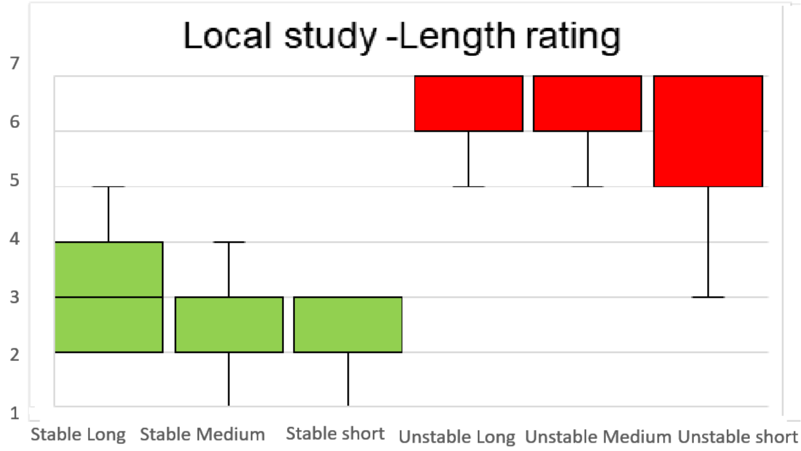



Figure 4.14: The Median (IQR) ratings for perceived stability of different length stimuli for stable and unstable cadence in the local trials

## 4.8. Conclusion

In this chapter, the design of the Movement Sonification Expectation Model (MoSEM), used in this thesis to explore musical expectation within sonification, is shown. Developed from an understanding of how musical expectation is experienced and previous work in auditory feedback, music and auditory illusions, seen in Chapter 2, this model uses Huron's theory of expectancy to explore how the combined expectation of one's movement and of the music created by the sonification interact. This model gives a series of predictions to be evaluated in the next stage of this thesis and provides a lens to unpack how people interact with MuES. In addition, the stimuli for use in these evaluations have been validated in terms of their perceived stability and are ready for evaluation within movement sonification.

**Contributions**

∗ Shows how musical expectation is experienced and understood in an embodied and implicit way

∗ Develops the initial design for the Movement sonification expectation model (MoSEM) used to explore musical expectation with movement sonification

∗ Validates stimuli used to create harmonically stable and unstable sonifications

# 5. Musical expectancy sonifications impact on movement behaviour and perception

**In this Chapter:**

*RQ2: Can the MoSEM be used to impact movement behaviour and perception?*

∗ Evaluating the MoSEM's impact on movement behaviour and perception

∗ Differences between a "closed target movement" and an "open target movement"

∗ Emerging questions for the MoSEM

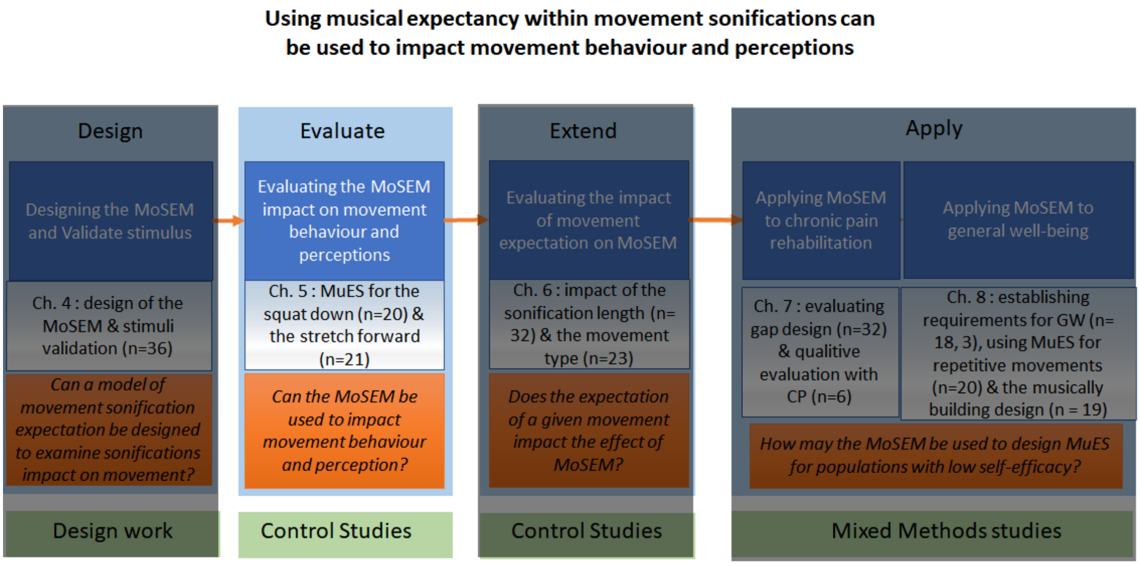



Figure 5.1: This Chapter focuses on evaluating the initial predictions made by the MoSEM. Through two control studies, one using the stretch forward movement and one using the squat down movement, this work addresses the question of the impact MuES has on movement behaviour and perception.

## 5.1. Introduction

In this Chapter, the effect of Musical Expectancy Sonification (MuES) on people's movement behaviour and perception is explored. As proposed in the Movement Sonification Expectation Model (MoSEM), in Chapter 4, musical expectation can be used to either promote the conclusion of movement or encourage its continuation. Using the results of the stimuli validation in Section 4.7 and previous work in the implicit understanding of harmonic cadence [Bigand, 1997, Sears et al., 2014], both a perfect cadence and an imperfect cadence to the dominant 7th were chosen to create an instantiation of the MoSEM to investigate how it impacts people's movement behaviour and perceptions. This provides an example instance of MuES, specifically utilising harmonic stability, through which the MoSEM can be evaluated.

To explore the application of musical expectancy in sonification this Chapter examines two movements, the stretch forward and the squat down. These two movements are both used in populations where low self-efficacy may impact physical activity. The stretch forward for people engaged in chronic pain rehabilitation [Singh et al., 2014] and the squat down, for people who struggle with physical activity for general wellbeing [Myer et al., 2014]. Additionally, they both highlight movements with different levels of perceptual cues: the stretch forward being an "open" movement, i.e. has an undefined ending point and the squat down being a "closed" target movement, i.e. has a defined end.

## 5.2. Study 1: Musical expectancy Sonification for the Stretch forward movement

### 5.2.1. Introduction

This study aims to demonstrate how MuES could be used to both encourage changes in movement and reward movements through musical expectation and thus help to validate the predictions of the MoSEM presented in Chapter 4. The MoSEM proposes that the musical expectation created by the sonification will alter people's movement behaviour and perception, dependent on how it aligns with their expected movement. Therefore, it is hypothesised that:

**H1**: Participants will move further and for longer past the target point in unstable conditions.

**H2**: Participants will perceive stable endings as more rewarding .

**H3**: Participants will perceive unstable endings as encouraging continued movement.

### 5.2.2. Participants

A total of 21 healthy paid participants were recruited for the study (age=21-75, 14 female and 7 male). Four participants from the study were discounted from the analysis, three as they failed to reach the final cadence point consistently and one due to exceeding the range of the sensor. Participants were recruited through the UCL psychology subject pool and had not participated in any other studies in this thesis.

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 73.82 (max 107 and min 35), with 13 out of the 17 participants being found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014]. Therefore we assume the effects that may be observed are not due to musical training.

### 5.2.3. Materials

The stretch movement was tracked using a smartphone strapped to the participants' back as illustrated in Figure 5.2. The movement was tracked and the sonification produced as described in Section 3.2.2.

The sonification used two cadence types (stable and unstable) and three lengths shown in Figure 5.2. The different lengths were used to change where the final cadence would be heard, to avoid the participants learning where the end of the sonification would appear. This alteration was achieved by removing one or more chords from before the cadence point, in the positions shown in Figure 5.2. This led to three length conditions: Short which was 9 chords long, Medium which was 10 chords long and Long which was 11 chords long. This meant that in the longest condition, the cadence ended at the set target point, while the shortened conditions ended one and two segments beforehand respectively.

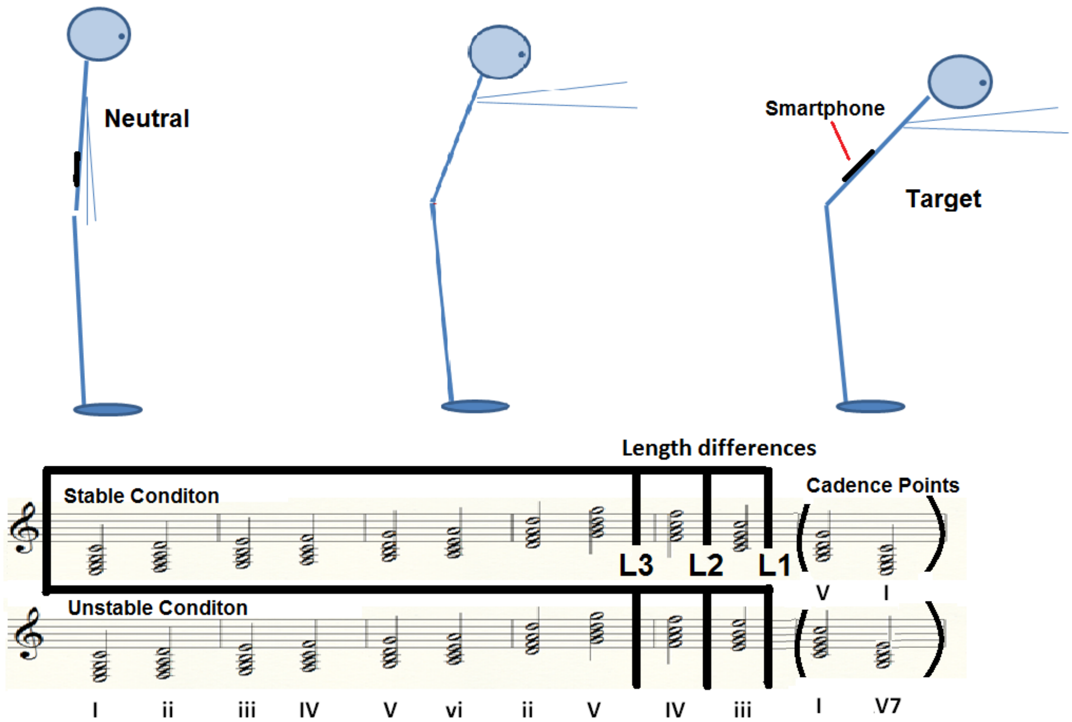



Figure 5.2: The calibration space used in the experiment, from a neutral upright position to a maximum target point, and the stimuli used for the stretch study. This shows the chord used ending in either a stable cadence (perfect cadence) or an unstable cadence (imperfect cadence with a dominant seventh), in addition, it shows how the stimuli were shortened to create the different length with notes being removed at L1, L2 and L3 respectively before the cadence point

### 5.2.4. Experimental design

The study followed a randomised within-subject design using the 12 total conditions based on the independent variables of stability (stable and unstable) and three lengths (Short, Medium and Long) and two repetitions.

The study measured two behavioural and four self-reported measures as the dependent variables. In terms of behavioural data, the average amount of movement beyond the final chord of the sonification **(Additional movement)** and the average time taken between the final chord of the sonification and the maximum amount of movement **(Time of Return)** before returning were measured using the smartphone on the participants lower back, as described in Section 3.2.2.

In terms of **self-reported measures**, perceived stability at the target point, perceived motivation to continue stretching at the target point, the perceived total amount of stretch and perceived amount of reward felt at the target point were all measured using a 7-point Likert scale taken after each condition.

### 5.2.5. Experimental procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the back using a back support and calibrated using a neutral position (standing position) and a maximum comfortable stretch as set by the individual participant.

Participants were instructed to stretch forward at a steady pace allowing each chord to sound so that the feedback could be heard. They were told to use the music produced to inform them of the movement's conclusion and to then return to the neutral position. After each set, they were asked to fill in the questionnaire for the self-reported measures. Finally, after all the conditions were complete, they filled out the GSMI questionnaire.

### 5.2.6. Results

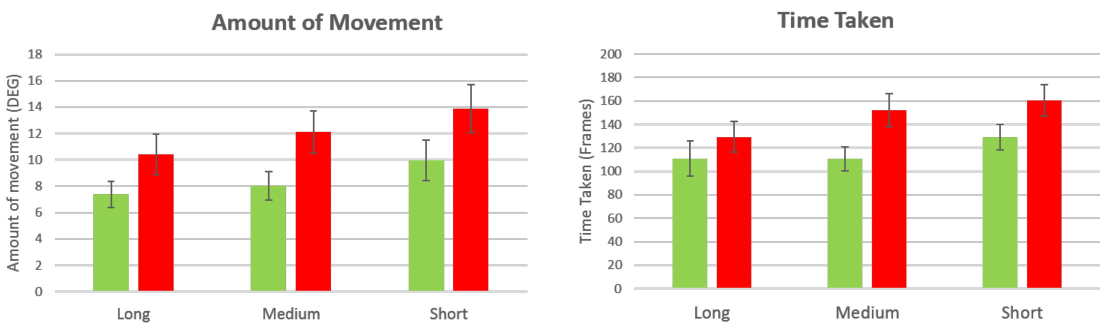



Figure 5.3: Mean (SE) stretch distance & time of return for stable and unstable cadences across different lengths. From this the impact of both the stability and length can be seen

Figure 5.3 shows the mean stretch distance and time of return across the conditions normalised using individual z-scores to meet assumptions of normality. The Figure shows how participants stretched more and for longer in the unstable conditions compared to the stable conditions and in the shorter compared to longer conditions. In

| | Stable Long | Stable Medium | Stable Short | Unstable Long | Unstable Medium | Unstable Short |
|---|---|---|---|---|---|---|
| **Stabilty** | 1(1-6) | 1.5(1-5.5) | 3(1-6.5) | 5(1-7) | 6(1-7) | 5.5(3-7) |
| **Motivation** | 4(1-7) | 5(1-7) | 4.5(1-7) | 2.5(1-6.5) | 3.5(1-7) | 4(1-7) |
| **Reward** | 6(4-7) | 5.5(2-7) | 5(1.5-7) | 5.5(2-7) | 5.5(2.5-7) | 5.5(1-7) |
| **Stretch** | 5.5(4.5-6.5) | 5.5(3.5-6.5) | 5(2.5-6.5) | 4(1-6.5) | 3.5(1.5-6) | 5(1-6) |

Table 5.1: Median (range) values for self-reported data for stable (ST) and unstable (UN) cadences of lengths long, medium and short.

Table 5.1 descriptive statistics from the self-report data can be seen, showing the impact of the different stabilities and length on the perceptions of the movement.

To assess how the stabilities and length impact the behavioural measures the data was submitted to repeated measures analysis of variance (ANOVA) with stability, length and repetition as within-subject factors, followed by Bonferroni-corrected pairwise comparisons.

For **Additional movement** significant effects were found both for stability ($F(1,14) = 25.744, p < .001, \chi^2 = .632$) and length ($F(2,60) = 15.201, p < .001, \chi^2 = .503$), with no significant interaction. No significant effect was seen due to repetition. *Participants moved further past the target point in unstable and shortened conditions*

For **Time of Return** significant effects were found for stability ($F(1,14) = 13.917, p = .002, \chi^2 = .481$) and length ($F(2,60) = 8.000, p = .002, \chi^2 = .348$), with no significant interaction. A significant difference was found between long and short (p = .006). Again, no effect of repetition was found. *Participants responded quicker to stable compared to unstable, and to the longest vs shortest.*

**Self-reported measures:** Self-reported data were analysed with Friedman tests, followed by Bonferroni-corrected Wilcoxon signed rank tests. Repetitions were averaged resulting in six conditions. A series of Friedman tests found significant differences for: perceived stability ($\chi^2(5) = 47.357, p < .001$), perceived stretch ($\chi^2(5) = 12.139, p = .033$) and perceived reward ($\chi^2(5) = 38.180, p < .001$), but not for perceived motivation. Wilcoxon tests showed that:

- For perceived Stability, Stable short was perceived as significantly less stable than Stable long (Z = -2.866, p = .004) and Stable medium (Z = -3.005, p = .003). Stable conditions were significantly more stable than their Unstable counterparts for long (Z = -3.209, p = .001), medium (Z = -3.625, p = .001) and short (Z = -3.423, p =

.001). *Stable conditions were perceived as more stable, while shorter stable cadences were perceived as less stable.*

- For perceived reward, significant differences were found between Stable long and Stable short ($Z = -2.806$, $p = .005$). Stable conditions were found more rewarding than their Unstable counterparts for long ($Z = -3.054$, $p = .002$), medium ($Z = -3.160$, $p = .002$) but not short. *Stable cadences were perceived as more rewarding, though again the shortest stable condition was not.*

Significant effects were not found for perceived stretch.

### 5.2.7. Discussion

From these results, it can be seen that, as hypothesised, a stable cadence used at the target point promoted conclusion, whereas an unstable cadence encouraged additional movement. In the unstable conditions, participants moved significantly further after the cadence point than in the stable conditions and the time of return was significantly shorter in the stable condition, showing participants returned towards the neutral position faster in the stable condition. Stable conditions were also found to be more rewarding than unstable.

However, a significant effect of length was also found for both stretch distance and time of return, with participants moving more and for longer in shorter conditions. It was also shown that, while stable conditions were found to be significantly more stable than unstable conditions, the shortest stable condition was perceived as less stable, and less rewarding, than longer stable conditions.

The results of this study validate some of the predictions from the proposed MoSEM for understanding expectancy-based sonifications. This is seen both in the behavioural measures, showing the immediate **Reaction response** to the sonification, the **Prediction response** in people's rating of the stability of the cadence and in the self-report measures as the **Appraisal response** is formed. It can be seen how stabilities impact people's perception of their movement. That is when the music meets their expectation people feel rewarded as they appraise their movement as "complete". Similarly, the "predication effect" of Huron where the misattribution of the complete cadence to the movement itself makes it feel more pleasurable [Huron, 2006]. While when this expectation is not met, the reaction/prediction response it to continue past the target point in order to achieve completion, reflecting people's feeling of unstable sounds needing to continue on [Huron, 2006] and the feeling of a tipping point at points of instability [Chew, 2016]. The results of this study show how this musical expectation can not only change one's perception of a movement but alter the way people perform the movement, as predicted in the MoSEM in Chapter 4.

The results of this study show how the MoSEM can be used within sonification design to reward movement and alter movement behaviour. Through meeting musical expectation at a given target point, the movement and the sound are appraised together as more rewarding. This is useful for promoting self-efficacy not only in creating attributional feedback [Schunk, 1995] but also in relating the achievement to a "positive" feeling [Bandura, 2000]. Moreover, if there is an implied continuation of the music, people are encouraged to continue their movement as seen through their adapted movement behaviour.

These findings demonstrate how the use of musical expectation within sonification can support self-efficacy by showing how different levels of harmonic stability can create a sense of reward. Previous works in sonification have used musical sonification and harmonic closure to help inform people's movement [Huang et al., 2005, Wallis et al., 2007]. However, it has yet to be demonstrated how different levels of harmonic closure impact both movement behaviours and perceptions. The results of this study show how the implicit understanding of cadential closures, shown in previous works [Sears et al., 2014, Bigand, 1997], and that the impact of meeting or defying people's movement expectancy can be utilised within movement sonification. Similarly, this subconscious impact of music on one's movement has previously been seen both on a large scale, such as impacting the amount exertion exercise one can do [Mohammadzadeh et al., 2008] and movement [Komeilipoor et al., 2015], these results show how it can be used to motivate additional movement through sonification.

These results also build on previous studies on motor-to-sensory transformations showing that sensory feedback received on one's actions can implicitly bias subsequent motor behaviour [Wolpert and Ghahramani, 2000] where only a few studies looking at sound feedback [Tajadura-Jiménez et al., 2015a, Boyer et al., 2013]. In these works, distorted sounds based on those produced by the body were used, however here the implicit associations between body movement and musical sound, which have previously been used for motor-learning [Dyer et al., 2017], are shown to affect the way people move, using people's embodied understanding of music to trigger the conclusion of movement.

However, as well as the stability of the final cadence, the length of the stimulus seems to affect both the perceived stability and the movement behaviour at the target point. This is may be due to the participants' knowledge of their maximum stretch distance, so as they approached the cadence in the longest condition, they were more expectant of the conclusion. This implies that the musical ending does not solely determine the expectation felt in the MoSEM.

## 5.3. Study 2: Musical expectancy Sonification for the squat down movement

### 5.3.1. Introduction

Based on the results of the Study 1 seen in Section 5.2 it can be seen how MuES can be used to impact movement behaviours and perceptions. However, it has yet to be considered how other movements may interact with such a sonification design. If we consider the stretch forward movement, i.e. a forward flexion of the trunk into space, the target point to reach is unclear, and as one stretches into space, there are limited visual cues.

Conversely, the squat movement has a very definite conceptual start and endpoint, standing upright and ending with the persons bent at 90 degrees. The squat movement additionally has relatively high levels of perceptual cues in that one can see themselves approaching the ground. This is also a common movement for general wellbeing, in which both understanding the correct depth of the squat [Myer et al., 2014] and barriers surrounding self-efficacy [Biddle and Mutrie, 2007] can impact people trying to engage in physical activity. Based on the predictions of the MoSEM and the results from the previous study the hypothesises for this study remain:

**H1**: Participants will move further and for longer past the target point in unstable conditions;

**H2**: Participants will perceive stable endings as more rewarding;

**H3**: Participants will perceive unstable endings as encouraging continued movement.

### 5.3.2. Participants

A total of 20 paid participants were recruited for the study (age=19-48 (mean = 28.4), 10 female and 10 male). All participants reported that they did not currently engage in regular physical activity and that they struggled with performing squats. Participants were recruited through the UCL psychology subject pool and prior to the study, the first 18 participants participated in Study 7, an interview study about their relationship with physical activity, the results of which are presented in Chapter 8.

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 64.1 (max 107 and min 39), with 18 out of the 20 participants being found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014]. Therefore we assume the effects that may be observed are not due to musical training.

### 5.3.3. Materials

The squat movement using a smartphone strapped to the upper leg as described in Section 5.4. The movement was tracked and the sonification created as described in Section 3.2.2

However, the sonification was slightly altered to reflect the downward trajectory of the squat movement better and to limit the impact of length from the previous study. While the initial stretch forward study used an ascending then descending scale, as seen in Figure 5.2, based on the work of Singh *et al.*, for this study it was changed to a simple descending scale as the change in the direction of the tones found in the wave formation may more clearly signal that the end of the movement is coming. This is explored in more detail in Chapter 6. In addition, the overall number of chords used in the sonification was shortened, in order to both facilitate a smooth descent for each of the different lengths, i.e. to minimise the difference in pitch between the chords, and to account for the speed of the squat movement compared to the stretch forward, so that the chords are heard as a discrete sequence [Khan et al., 2018]. The chord progressions used can be seen in Figure 5.4.

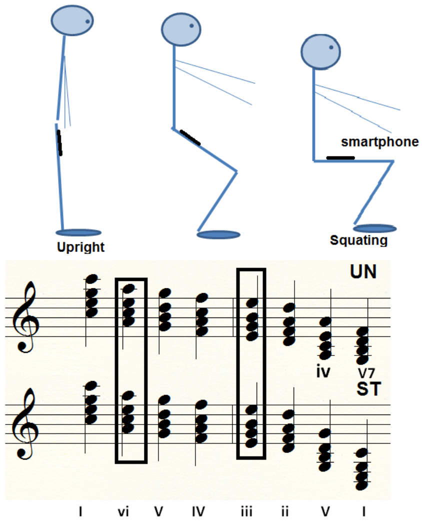



Figure 5.4: The calibration space used in the experiment, from a neutral upright position to a maximum squat, and the stimuli used for the squat study. This shows the chords used ending in either a stable cadence (perfect cadence) or an unstable cadence (imperfect cadence with a dominant seventh); in addition, it shows how the stimuli were shortened. For this study, chords were removed from different sections to minimise chord "jumps". For the longest conditions, all were played and the fifth chord in the sequence and the second were removed respectively to create to the medium and short conditions

### 5.3.4. Experimental design

The study followed a randomised within-subject design using the six total conditions consisting of the two independent variables, stability (stable and unstable endings) and length (long, medium and short). The different lengths were used to change where the final cadence would be heard, to avoid the participants learning where the end of the sonification would appear and was achieved by removing one or more chords from before the cadence point, creating stimuli of 6, 7 and 8 chords. The study's dependent variables consisted of two behavioural and four self-reported measures. In terms of behavioural data, the average amount of movement beyond the target point **(Additional movement)** and the average time taken between the target point and the maximum amount of movement **(Time of Return)** before returning were measured using the smartphone device placed on the upper leg of the participants as described in Section

3.2.2.

In terms of **self-reported measures**, measures of perceived stability of the cadence, perceived motivation to continue and perceived reward at the final chord were taken with 7-point Likert-type response items. The perceived angle of the squat was reported in degrees, 0 degrees being standing and 90 degrees being where the upper leg is parallel to the ground.

### 5.3.5. Experimental Procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the leg using a leg strap and calibrated using a neutral position (upright) and a maximum comfortable squat as shown in Figure 5.4.

Participants were instructed to squat down at a steady pace allowing each chord to sound and to use the music produced to inform them when they had reached the target point (i.e., the end of the feedback). After each squat a questionnaire was used to collect the self-report measures.

### 5.3.6. Results

Descriptive statistics for all measures are summarised in Figure 5.5 and Table 5.2.

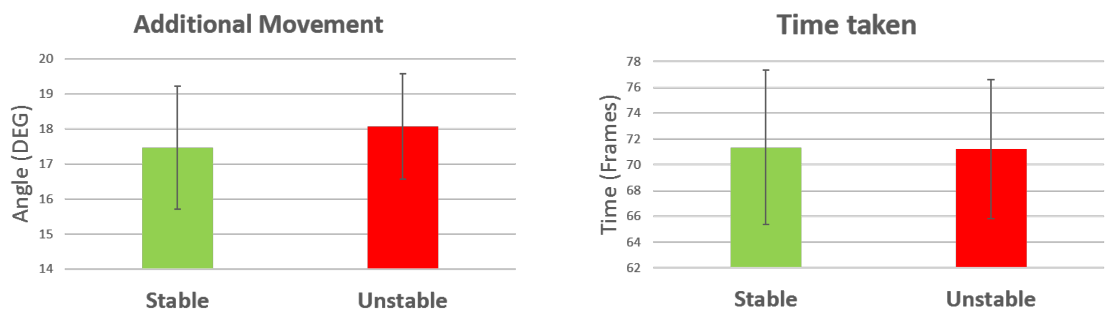



Figure 5.5: Mean (SE) stretch distance & time of return for stable and unstable cadences across different lengths, from this the impact of both the stability and length can be seen.

The behavioural measures were normalised using a square root transformation to meet assumptions of normality and were submitted to repeated measures analysis of variance (ANOVA) followed by Bonferroni-corrected pairwise comparisons. Self-reported data were averaged across lengths and analysed with Wilcoxon signed rank

| | Stable | Unstable |
|---|---|---|
| **Stabilty** | 3(1-7) | 5(1-7) |
| **Motivation** | 3(1-7) | 3.5(1-7) |
| **Reward** | 5(1-7) | 3(1-7) |
| **Squat** | 70(30-90) | 70(30-90) |

Table 5.2: Median (range) values for self-reported data for stable and unstable cadences averaged across the three lengths

tests.

**Additional movement:** No significant effects were found for the amount of squat past the target point across the two stabilities. However, the length condition did have a significant impact on the amount of additional movement ($F(2,38) = 8.14, p = .001, \chi^2 =$ .300). The pairwise comparisons showed a significant difference between the long and short length ($Z$ = .842, $p < .001$) and the middle and short length ($Z$ = .723, $p$ =.001).

**Time of return:** No significant effects were found for the amount of squat past the target point across the two stability levels. However, the length condition did have a significant impact on the time of return ($F(2,38) = 4.74, p = .015, \chi^2 = .200$). The pairwise comparisons showed a significant difference between the long and short length ($Z$ = 21.33, $p < .034$) and the middle and short length ($Z$ = .723, $p$ =.001).

**Self-reported measures:** Initial Friedman tests did not show any significant differences in self-report measures; however, when averaged across the three lengths, Wilcoxon signed tests of the stable versus unstable cadences showed that:

- For perceived Stability, stable cadences were found to be significantly more stable than unstable ones ($Z$ = -2.65, $p$ = .014).
- For perceived motivation to squat past the target point, participants were significantly more motivated in unstable endings ($Z$ = - 2.45, $p$ = .014).
- For perceived depth of the squat, participants felt they squatted significantly more in stable endings than in unstable endings ($Z$ = - 2.36, $p$ = .018).

### 5.3.7. Discussion

It was found that participants perceived that they had squatted deeper in stable conditions, even though no such difference was found in the actual movement. This may be due to the sense of completion leaving participants feeling they have moved further. This feeling of completion from the expectancy created by the cadences, with the unstable being incomplete making people feel like they had completed less movement. Additionally, it demonstrates how unstable endings provide motivation to continue. These results support **H2** and **H3** suggesting that the use of this kind of feedback could improve self-efficacy in people engaging in physical activity; as well as acting as a motivational tool during the movement in addition to stable sonifications being perceived as more rewarding.

However, this study does not find evidence to support **H1** as there is no significant effect on movement behaviours. This reflects on the **Reaction response** portion of our MoSEM, showing no impact of the ending's stability on the movement past the target point. However, the **Prediction response** is demonstrated by the rating of stability of the different sonification endings.This could be related to the use of additional cues by participants to determine the end of the movement.

Relating these findings to our proposed MoSEM, demonstrates the impact different stabilities have on the perception of the movement. The feeling of achievement created by stable conditions can be seen to match up with the **Appraisal response** of the MoSEM in Chapter 4. As people realise their expectation of sound has been met, this is reflected in a feeling as having completed a more "complete" movement. Conversely when the ending was unstable, i.e. the expectation of the music is not met, people felt they had achieved less and felt a motivation to continue on past the target point, as the unfinished nature of the music is reflected on the movement. However, this was not reflected in reaction response, i.e. the behaviour at the cadence point itself.

The results of this study show how the MoSEM can be applied to closed target movements. It shows how musical completion can be used to highlight achievement [Schunk, 1995] and that musical completion can be used within feedback to alter people's perceived movement, as previously shown with false positive feedback [Fitzsimmons et al., 1991, Harvie et al., 2015]. Additionally, while a physical change in the movement behaviour was not seen, the implied continuation of the music does lead to a feeling of motivation and a desire to achieve more.

As in the results of Study 1 in Section 5.2, these results show how MuES can be used to impact one's perception of one's movement, this time for the squat down movement. As previously stated, this is an important movement for general wellbeing and one that many beginners struggle with [Myer et al., 2014]. Previous sonification works have shown how sonification of the squat movement can support the learning and performance of the squat down movement [Khan et al., 2018, Hale et al., ]. However, these works do not explore how these sonifications can be used to motivate and increase one's sense of achievement in the squat movement. This reflects findings in using music to motivate exercise [Karageorghis et al., 2008, Mohammadzadeh et al., 2008] and shows how this may be achieved through sonification.

However, unlike, in the stretch forward movement, there was no significant impact on people's movement behaviour at the target point. Various explanations could be provided for why impacts on movement behaviour were seen in the stretch forward and not the squat down. For instance, one possibility is that all participants completed their squats to the extent they could and could not go down further. However, when examining the differences between these two movements, it is apparent that the level of perceptual cues (visual and proprioceptive) at the target point differ dramatically. The stretch forward movement has no definite conceptual endpoint and has a lack of visual cues to tell the person how far they have stretched. The squat down, on the other hand, has a very definite endpoint (as the person approaches the ground) and clear visual cues. Proprioceptive feedback may also differ given the number of joints involved in the execution of the movement.

The question is, hence, could there be an interaction between the sonification feedback and the visual and proprioceptive feedback that affect the impact of the sound on the behaviour? It has yet to be seen how different levels of perceptual cues may impact the use of musical expectancy within movement sonification. People are primarily visually dominant, i.e. they rely more on visual input than other [Colavita, 1974, Posner et al., 1976]. Petrini *et al.* show that children will even use irrelevant visual cues to help localise sound, showing that learning to ignore these cues can be difficult [Petrini et al., 2015]. These interactions must be considered when design sonifications, especially those that aim to alter people's behaviour. An unexpected interaction between visual and auditory cues may lead to this kind of sonification being ineffective. This also reflects in the findings for the Study 1 shown in Section 5.2, wherein the sonification ended earlier, having not reached the expected endpoint, stable endings were perceived as less stable, as they interact with one's expectation of the movement itself. However, interestingly while participants did not move significantly more in either cadence, they did perceive themselves as having had moved further in stable cadences, implying that while these external cues may impact the individual's expected end-point for the movement, this happens at a subconscious level. While the results of the study do show some of the predictions of the MoSEM shown in Chapter 4, it again raises questions as to other external factors, such as the level of additional cues, that should be considered when designing MuES.

## 5.4. Conclusions

In this Chapter, it can be seen how musically-informed sonification can be used for two different movements, the squat down and the stretch forward. These findings demonstrate how the use of musical expectation within sonification can support self-efficacy by showing how different levels of harmonic stability can create a sense of reward or motivation, while also informing the individual about their own movement.

The studies in this Chapter show the initial evaluation of the MoSEM and its impacts on movement behaviour. However, it also raises some important questions about how these kinds of sonifications may be used. For example, it is seen how in the stretch forward movement, unstable endings encourage movement past a given target point and stable endings promote conclusion. However, for the squat down, the change in movement behaviour is not seen. It was also seen in these studies how the length of the sonification impacted how it was perceived, which the listening test did not show.

The disparities in the two movements imply there are additional factors which impact how a musical-expectation based sonification function. Indeed, the physical properties of the movement, i.e. its length or the movement type, seem to impact the perception of the sonification. This calls for further study of how we build a movement expectation and further integration of the MoSEM to explore how musical expectation can support physical activity.

**Contributions**

∗ Demonstrates stable ending create a sense of reward while unstable endings provide motivation to continue the movement, validating the predictions of the combined appraisal response in the MoSEM

∗ Demonstrates how unstable endings encourage additional movement while stable promote conclusion, in the stretch forward movement but not in the squat down, partly validating the predictions of combined reaction/prediction response in the MoSEM

∗ Demonstrates how applying the MoSEM to movement sonification can support both rewarding movement and encouraging continuation

∗ Leads to emerging questions on how movement expectation interacts with the MoSEM

# 6. Movement Expectancy and its impact on Musical expectancy Sonifications

**In this Chapter:**

*RQ3: Does the expectation of a given movement impact the effect of MoSEM?*

∗ Explore the impact of the length of the sonification compared to the expected length of the movement

∗ Explore how different movement types interact differently with the MoSEM

∗ Extensions to the MoSEM to consider limits based on movement expectation

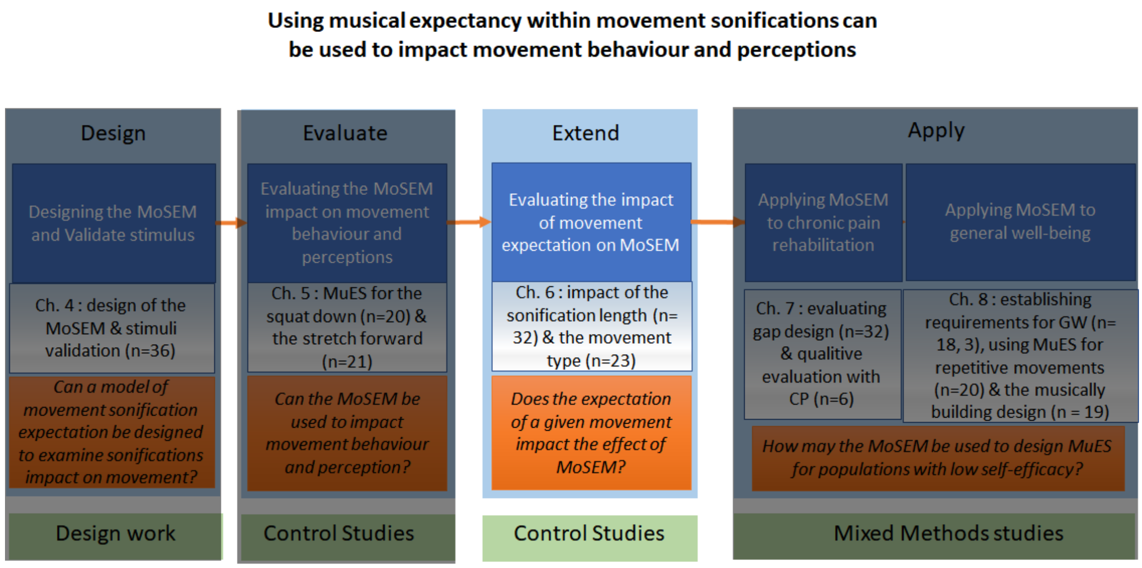



Figure 6.1: This Chapter focuses on extending the MoSEM to consider further the impact one's expectation of one's movement has on the use of MuES. Through two control studies, one exploring the impact of the length of the sonification and one exploring the additional cues available at the end of the movement, this work addresses the question of the limits of the MoSEM in relation to one's expectancy of the movement itself

## 6.1. Introduction

The two studies shown in Chapter 5 demonstrate how MuES impact both movement behaviour and perceptions. However, within those studies, there are still some emerging questions around how the expectation of a movement may impact these effects. The study which examines the stretch forward movement (Study 1 in Section 5.2) shows that when the feedback sounds musically unfinished at the target point (i.e. maximum trunk stretching point to be reached as set by the person), people move further and for longer past said target point and feel less rewarded than when the feedback sounds musically finished. However, it was also found that the length of the sonification, which was included in the study to avoid learning effects, also impacted the movement behaviours and perceptions and even the perceived stability of the cadence. These results seem to contradict the findings of the stimuli validation in Chapter 4, which showed no significant impact of the length of the stimuli on their perceived stability.

Additionally, when that same kind of sonification is used for the squat down movement, while similar impacts on people's motivation and sense of achievement were found, there was no effect seen in the movement behaviour itself. From this disparity, while the way people perceived the sound is unchanged for the two movements, there are different effects on the body movement itself.

This section describes two studies which explore how the expectation of a given movement may impact how the sonification is perceived and interacted with. Specifically, the first study investigates how the length of the sonification, in comparison to the expected length of the movement, impacts the MuES. The second investigates how different levels of additional cues that the ending of the movement is coming impacts the MuES. From this, the MoSEM can be used to better understand the role movement expectation in designing such sonifications.

## 6.2. The Impact of sonification length on expected movement

### 6.2.1. Introduction

In the previous Chapter it was shown that the length of the sonification impacted how MuES were perceived and interacted with. However, in previous studies, it was unclear whether this impact was related to the length of the sonification giving some cue to the end of the movement or related to the amount of movement covered. In this study the stretch forward movement is again used to explore this effect in more detail. By simplifying the sonification and reducing any additional cues from the sound that the end of the movement is coming, the length of the sonification can be investigated. This, in turn, can be used as a first step in re-examining the MoSEM and how one's movement expectation is impacted by one's pre-built expectation of a given movement.

To achieve this the stimulus used in the initial stretch study (Study 1 in Section 5.2) was re-examined in order to take out any additional cues in the sonification that would let participants know they were approaching the end. The strategy for doing this was twofold, 1) removing the ascending/descending pattern and 2) not only removing notes from the end. The ascending/descending pattern, while in the listening experiments shown in Chapter 4 did not impact the perceived stability, when originally presented in the work of Singh *et al.*, was designed to help inform people of different points of the movement [Singh et al., 2014]. In this design, the change from an ascending scale to a descending one was used to inform people they had reached the second section of the movement. It is likely in that case it helps inform participants that they are reaching the end-point of the movement and hence interfering with the desired expectation. If that is the case, it is possible that when the stimuli were longer, there were more notes for the descending half of the sonification, making the longer stimuli feel more complete.

Additionally, to create the shortened stimuli, chords were originally removed from the end of the sonification before the cadence point. This would lead to a greater interval between the shorter stimuli and the final cadence, which could lead to them being perceived as more unstable.

In order to remove these confounds, the stimuli were changed to use a simple descending scale and notes were removed from different points in the chord progression to limit the size of the intervals between chords, as seen in Figure 6.2. This is as seen in Study 2 in Section 5.3 and is used in this study to examine the impact of the length of the sonification, and then later in all subsequent studies. In addition, an additional length of the stimulus was included to explore better how this factor impacts people's expectation of the movement.

Based on the previous findings in Chapter 5 three hypotheses were tested:

**H1:** As in the initial experiment there will be an effect of stability on the additional stretch past the cadence point, the time taken to return and the perceived reward

**H2:** Shorter stimuli will also see a larger stretch distance, slower time of return

**H3:** shorter stimuli will be perceived as less stable than longer stimulus.

For this study participants were recruited as part of an undergraduate project including the length study 7.4 in Chapter 7. The undergraduate student was responsible for recruitment/the data collection and was given the experimental design and procedure including all experimental materials, which were original designs for this thesis. The undergraduate student did some initial data analysis, using the measures designed for this thesis and self-report data, the data was then reanalysed for the purposes of this thesis, which included improvements on the behavioural results analysis and more rigorous analysis. Participants first completed this study then completed the study presented in Section 7.4.

### 6.2.2. Participants

A total of 32 healthy paid participants were recruited for the study (age=19-47 (mean 23.12), 24 female and 8 male). Four participants from the study were discounted from the analysis because they failed to reach the final cadence point consistently. Participants were by an undergraduate student and also participated in the study presented in Section 7.4.

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 72.58 (max 108 and min 40), with 21 out of the 32 participants were found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014], therefore we assume the effects seen are not due to musical training.

### 6.2.3. Materials

The movement was tracked and the sonification produced as described in Section 3.2.2. As described above the chord sequences were simplified to examine the impact of the length of the sonification better(see Figure 6.2. In this version, the stimuli use a simple descending scale, and chords are removed from different points in the sonification, from L2, L3 and finally L4.

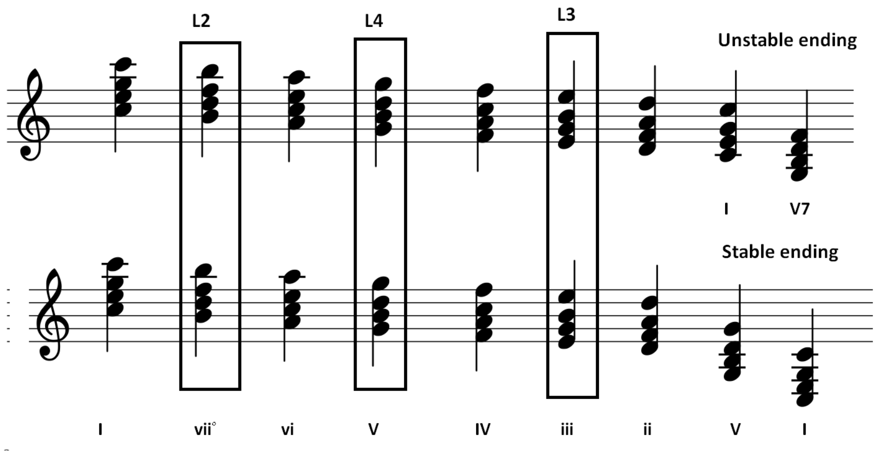



Figure 6.2: Stimuli used for the length experiment, showing how the four lengths of the stimulus were created for stable and unstable endings, by removing chords from different areas of the chord progression the size of the intervals was limited, such that L1 played all chords, then chords were removed at L2, then L3 and for the shortest stimuli at L4

### 6.2.4. Experimental design

The study followed a randomised within-subject design using the eight total conditions based on the independent variables of stability (stable and unstable) and four lengths (L1, L2, L3 and L4). The study measured two behavioural and three self-reported measures as the dependent variables. In terms of behavioural data, the average amount of movement beyond the target point **(Additional movement)** and the average time taken between the target point and the maximum amount of movement **(Time of Return)** before returning were measured.

In terms of **self-reported measures**, perceived stability at the end of the movement perceived motivation to continue stretching at the end of the movement, and perceived amount of reward felt at the end of the movement were all measured using a 7-point Likert scale taken after each condition. Perceived amount of stretch was removed from Study 1 in Section 5.2.

### 6.2.5. Experimental procedure

The procedure followed that of Study 1 in Section 5.2, after an initial introduction and demonstration of the device, the smartphone was placed on the back using a back

| | stable L1 | stable L2 | stable L3 | stable L4 | unstable L1 | unstable L2 | unstable L3 | unstable L4 |
|---|---|---|---|---|---|---|---|---|
| **Stability** | 1(1-6) | 2(1-7) | 1(1-7) | 3(1-7) | 6(1-7) | 6(1-7) | 6(1-7) | 6(1-7) |
| **Motivation** | 5(2-7) | 5(2-7) | 5(3-7) | 5(3-7) | 4(1-7) | 4(1-6) | 4(1-6) | 4(1-7) |
| **Reward** | 5(2-7) | 5(3-7) | 5(1-6) | 4(2-6) | 3(1-6) | 3(1-7) | 3(1-6) | 5(1-5) |

Table 6.1: Median (range) values for self-reported data for stable and unstable cadences across different lengths from L1, the longest, to L4 the shortest.

support and calibrated using a neutral position (upright) and a maximum comfortable stretch.

Participants were instructed to stretch forward at a steady pace allowing each chord to sound so that the feedback could be heard. They were told to use the music produced to inform them of the movement's conclusion and to then return to the neutral position. After each set, they were asked to fill in the questionnaire for the self-reported measures. Finally, after all the conditions were complete, they filled out the GSMI questionnaire.

### 6.2.6. Results

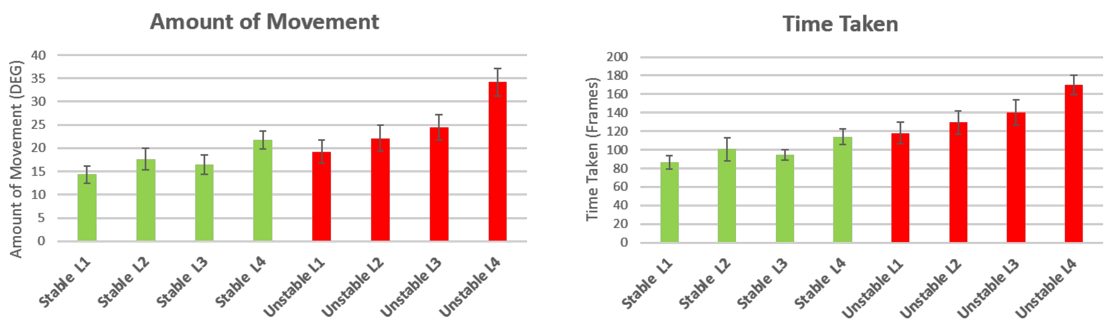



Figure 6.3: Mean (SE) behavioural measures for stable and unstable cadences across the different lengths used. The impact of stability and the length of the sonifications can be seen on the amount of movement past the target point

Behavioural data were normalised using square root transformation to meet assumptions of normality; Figure 6.3 shows the impact of the different stabilities and length on both the amount of movement and the time taken to return. In Table 6.1 descriptive statistics from the self-report data can be seen, showing the impact of the different stabilities and length on the perceptions of the movement.

The trials were submitted to repeated measures analysis of variance (ANOVA) with stability and length as a within-subject factor, followed by Bonferroni-corrected pairwise comparisons to explore the impact they had on the amount of movement and time taken to return.

For **Additional movement** significant effects were found both for stability ($F(1,27) = 24.828, p < .001, \eta^2 = .479$) and length ($F(3,81) = 19.739, p < .001, \eta^2 = .422$), with no significant interaction. Bonferroni-corrected pairwise comparisons showed that people stretched more in L2 than in L1 (p = .029) and significant differences in L4 compared to L1 ($p < .001$), L2 ($p < .001$), and L3 ($p < .001$). *Participants moved further in unstable conditions compared to stable ones and in shorter conditions compared to longer ones.*

For **Time of Return** significant effects were found for stability ($F(1,27) = 28.566, p < .001, \eta^2 = .514$) and length ($F(3,81) = 8.850, p < .001, \eta^2 = .247$), with no significant interaction. A significant difference was found between L4 and L1 ($p < .001$), L2 ($p = .010$) and L3($p = .011$).*Participants took longer to return in unstable conditions compared to stable ones and in shorter conditions compared to longer ones.*

**Self-reported measures:** Self-reported data were analysed with Friedman tests, followed by Bonferroni-corrected Wilcoxon signed rank tests. A series of Friedman tests found significant differences for: perceived stability ($\eta^2(7) = 97.25, p < .001$), perceived motivation ( $\eta^2(7) = 32.54, p < .001$) and perceived reward ( $\eta^2(7) = 86.70, p < .001$). Wilcoxon tests showed that:

- For perceived stability showed that STL4 was significantly less stable than STL1 (Z=-3.22, p=.001), STL2 (Z=-3.00, p=.003). STL3 (Z=-3.46, p=.001). ST conditions were significantly more stable than their UN counter-parts for L1 (Z=-4.11, p<.001), L2 (Z=-4.00, p<.001), L3 (Z=-4.53, p<.001) and L4 (Z=-4.47, p<.001). *stable cadences were found to be more stable than unstable, while shorter stable conditions were perceived as less stable than longer ones.*

- For perceived motivation, significant effects were found for STL3 vs UNL3 (Z=-3.21, p=.001) and STL4 vs UNL4 (Z=-3.14, p=.002). *unstable cadences were found to be more motivating than stable.*

- For perceived reward, ST conditions were found more rewarding than their UN counterparts for L1 (Z=-4.22, p<.001), L2 (Z=-3.98, p<.001), L3 (Z=-4.28, p<.001) and L4 (Z=-4.14, p<.001). *stable cadences were found to be more rewarding than* *unstable.*

### 6.2.7. Discussion

These results support previous findings that stable cadences promote conclusion while unstable ones encourage the continuation of movement. The amount of additional stretch past the cadence point was significantly more in the unstable conditions compared to the stable. Again, stable conditions were found more rewarding and were perceived more stable than unstable conditions, while unstable conditions were found more motivating, further confirming the predictions of the MoSEM as seen in the results from Chapter 5.

This experiment focused on how the length of the stimulus may affect how people respond to them. The shortest stable length L4 was found to be significantly less stable than the other stable conditions, contradicting previous findings from the stimuli preparation studies. In addition, significant differences were found between the L4 conditions and the other lengths for both additional movement and time of return.

The findings from this study help to explain the findings in Study 1 show in Section 5.2 and in addition, show how the MoSEM can be extended to more fully consider non-musical cues' impact on the individual's expectation. These findings suggest that it is not only the musical ending that determines our MoSEM, but people already have a pre-determined expectation of the movement in mind, seen in Figure 6.4. For instance, one might have chosen a specific point to move to and when the sonification ends before that point is reached, it is perceived as defying that expectation. While previous iterations of this model have considered only the musical endings' impact on our expectation of the movement, i.e. whether or not to continue, these results imply that the effect is bi-directional. This length study shows that when the expectation of the movement is not met, i.e. the stimulus is too short, this impacts not only the **Reaction response**, in terms of movement behaviour, but also the **Prediction response** through the change in perceptions of stability.

These findings imply that while in a static listening scenario, in Chapter 4 the length of the stimulus does not significantly affect the perceived stability. However, when the sound is driven by the individual and is specifically designed as an external representation of their movement, stimuli that are too short are perceived as less stable. As

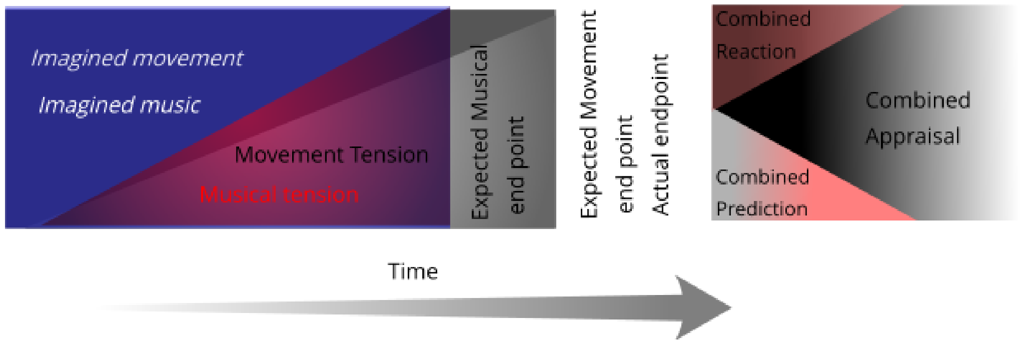



Figure 6.4: How these results impact the proposed MoSEM for different length stimulus. Demonstrating how the individual expectation of the movement itself impacts how they perceived and reacted to the expectation in the sonification. The imagined movement goes past the expected musical endpoint, leading to a continued movement tension. When the expected movement endpoint is reached, there is a combined prediction and reaction response in which the music is appraised as less complete due to the mismatch with the expected movement

participants have certain expectations of how far they will stretch and by proxy how long the sound will go on for, when this expectation is defied, it is perceived as an amount of instability because the sound was expected to continue with their continued desire to move. When considering the use of misattribution seen in Huron's description of "the prediction effect", in which a correct or incorrect prediction of completion may be attributed to an external factor [Huron, 2006], it seems the ending of sonification affects how the ending of the movement is perceived. It seems in cases in which sonifications are too short the failed prediction of the end of the movement is reflected in the perception of the sonification, while the original design of MoSEM aims for the opposite. This points to the interplay between one's movement expectation and the musical expectation, as people seem to rationalise when the completion comes too far from their own expected endpoint, they describe it as less musically stable.

This mirrors previous work in auditory illusions which describe both spatial and temporal limits [Tajadura-Jiménez et al., 2017b], which when passed will break the illusion. For instance, when Tajadura-Jimènez *et al.* demonstrate the alteration of the spatial mapping of finger tapping can give the perception of one's finger being longer when the distance between the altered sound and the expected source of the sound is too great, the illusion fails [Tajadura-Jiménez et al., 2017a]. This is also seen in virtual environments when altered visual and audio feedback is used to alter perceptions of movement and subconsciously alter trajectory; there is a limit to the severity to which people will accept this altered feedback [Serafin et al., 2013, Nogalski and Fohl, 2016]. In this study, it is shown that when the length of the sonification provides a similar breaking point for MuES, as when the sonification reaches musical completion too far from the expected end of the movement, the impact of the musical stability is lessened. This shows a limiting factor for using MoSEM in which it needs to closely mirror the expected movement as while there was a general impact of stability seen in movement behaviour this appears to stronger in the stable case when it matches the individuals' expected movement distance.

As stated by Tajadura-Jimènez *et al.* sonifications which seek to alter bodily representation must respect the thresholds of people's perception[Tajadura-Jiménez et al., 2017b]. There are thresholds to the deviations in movement behaviour that can remain unconscious, and sonifications which try and alter past that point will be disregarded in favour of the individuals own expectation of their movement, based on prior experience and other additional cues of how far through the movement they are. This study demonstrates that this is true not only for sonifications which seek to adapt bodily sounds or augment bodily sensation but for those that use people's embodied sense of music to alter their movement behaviour and perceptions.

Additionally, four participants did not make it to the final cadence point in the unstable conditions as when they reached the tonic chord in the imperfect cadence, participants reported they felt they had reached the end of the music, and before the final chord could be triggered, they returned. To account for this in future studies the tonic chord was replaced with an A minor chord, so participants did not stop at an incorrect endpoint.

## 6.3. Impact of different movement types on expected movement

### 6.3.1. Introduction

While the above study investigated the impact the expected movement has on the MoSEM, this study will explore the influence of external cues on the MoSEM. To investigate the disparity between musical expectancy's effect on movement behaviour seen

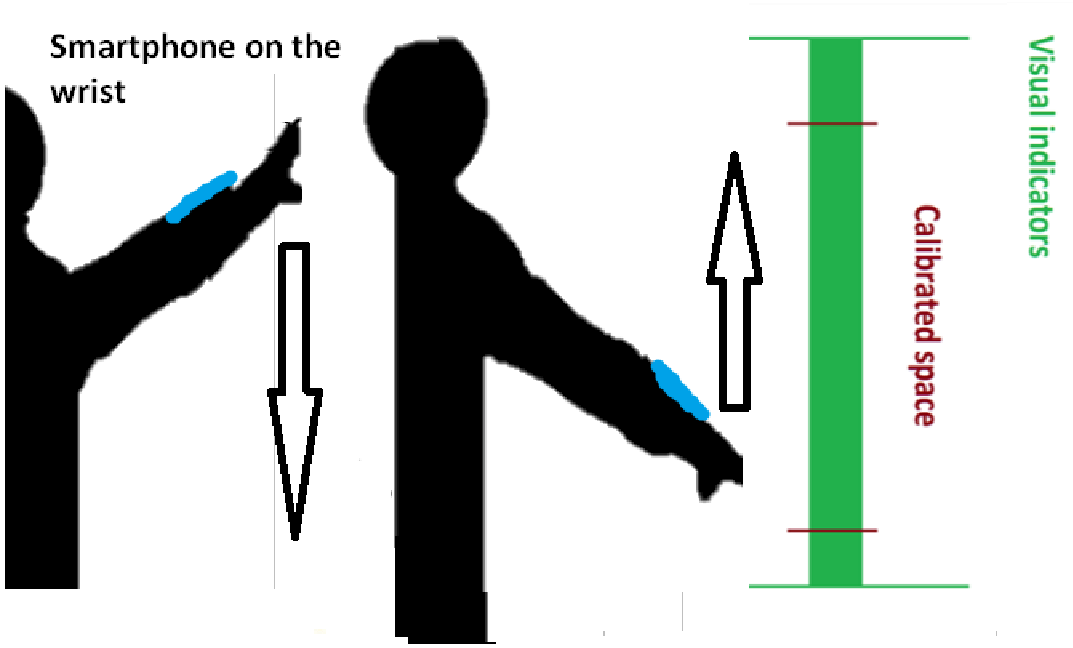



Figure 6.5: The experimental set-up using a simple arm movement: participants move within the calibrated space with the visual markers in front of them (with eyes either open or closed).

in the two studies in Chapter 5, an investigation in which the level of cues could be manipulated was designed. A vertical arm movement was chosen for the study to limit the tactile cues given at the extremes of a movement.

Visual cues were indicated on the wall in front of the participant for closed movement scenarios, and participants were asked to close their eyes to remove the visual reference for open movement scenarios (see Figure 6.5). The aim was to test the hypothesis that the perceptual cues available to an individual at the target point of a movement change the way the musical stability in the sonifications impacts their movement.

Based on the findings from the previous studies in Chapter 5 and the literature on visual dominance it is hypothesised that:

**H1**: Participants will be impacted more by stable and unstable cadences when there are limited additional cues;

**H2**: Participants will be more certain they have reached the endpoint in the stable conditions and when they have additional cues to signal the end.

### 6.3.2. Participants

A total of 23 healthy paid participants were recruited for the study (age = 18 -57 (mean = 27.82), 13 female and 10 male). Participants were recruited through the UCL psychology subject pool and had not participated in any other studies in this thesis.

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 69.34 (max 114 and min 43), with 19 out of the 23 participants were found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014], therefore we assume the effects seen are not due to musical training.

### 6.3.3. Materials

For the movement space, the system was calibrated in the space between the visual indicators, without the knowledge of the participant. The movement space was calibrated to fall within the visual markers, without reaching them, so participants were moving exactly to the extremes of the visual indicator, using it more as a cue than as the target point itself, as shown in Figure 6.5. As the arm moves through the space a series of chords is played, ending in either one that meets musical expectancy (stable) or one that defies it (unstable) (see Figure 6.6).

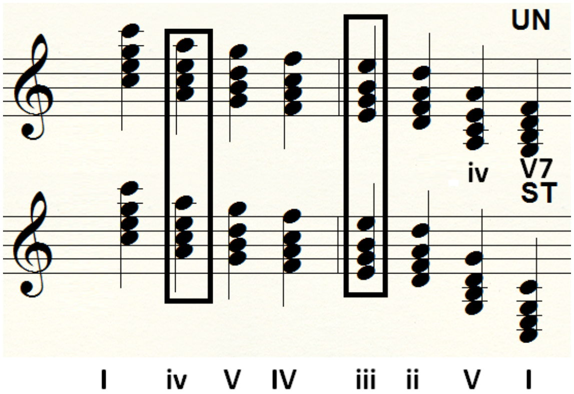



Figure 6.6: Stimuli used for the movement type experiment, showing how the three lengths of the stimulus were created for stable and unstable endings. Again, the different lengths were used to avoid participants learning the endpoint of the movement; this was the same sequence used for Study 2 in Section 5.3

### 6.3.4. Experimental design

A randomised within-subjects design was used for the four trials. There were two independent variables: *harmonic stability* (stable or unstable) and *additional cues* (present or absent). As described above, participants were either given additional visual cues (visual indicators), creating our closed movement, or no additional cues (eyes closed), creating our open movement.

To understand the impact that the different perceptual factors had on the way participants moved at the target point, three behavioural measures were taken from the data:

1. the **Additional movement** made past the target point,

2. the **Time taken** to return to the target point, and

3. the **speed of the movement** to the maximum extension.

The additional movement and time taken were measured as in the previous studies, outline in Chapter 3, while the speed of the movement was taken from dividing the amount of movement by the time taken to return. The speed of the movement was taken into account for this study to gain a better understanding of the different movement types impacted participants expectation of the movement.

In terms of **self-reported measures**, perceived stability at the end of the movement, perceived confidence that they had reached the target point, perceived informativeness of the sound, perceived motivation to continue past the target point and perceived amount of reward were all measured using a seven-point Likert scale taken after each condition, to explore the impact on movement perception.

### 6.3.5. Experimental procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the participant's arm using a phone holder, as in Figure 6.5. Participants were instructed to move their arm to the set target point and back to their neutral position for four repetitions using the music produced to guide them for the four conditions. Specifically, they were told that when they felt they had reached the end of the chord progression, (i.e. the target point at the end of the movement space) they should return.

### 6.3.6. Results

First, behavioural measures were averaged over repetitions, and both behavioural and self-report data were averaged across lengths, to focus on the key variables in this study: the stability and the movement type. Descriptive statistics for all measures are summarised in Figure 6.7 and Table 6.2, which show how the different cadences impact the movement behaviour and perception but with and without additional cues. These results were analysed using Anderson's Information Integration Theory (IIT),

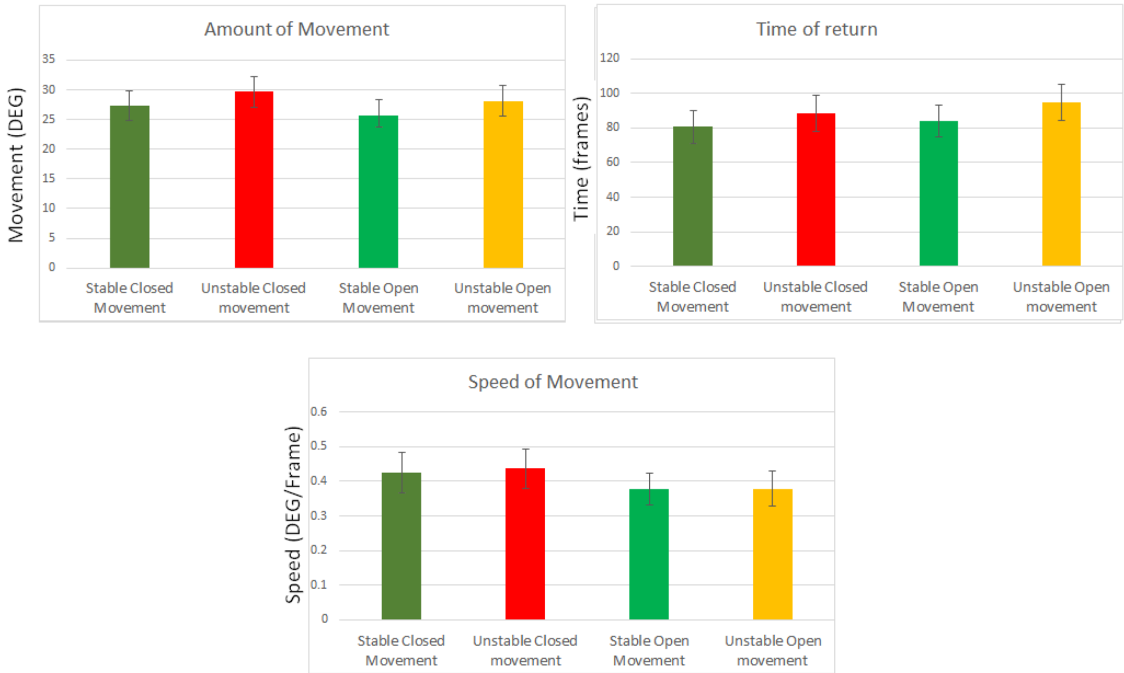



Figure 6.7: Mean (SE) amount of movement, time of return & speed of movement for stable and unstable cadences in both open movements, no additional cues, and closed movement, with additional cues. From this the impact of both the stability and additional cues on the expectation of the movement can be seen.

that can be used to explore how different external stimuli are integrated into peoples' perception to elicit a given response [Anderson, 1982]. By establishing the rules by which people integrate information sources through simple algebraic formulations (defined as *cognitive algebra*), Anderson shows how we can understand how external stimuli are used in conjunction with each other by an individual to establish an internal understanding and perception. The main models considered in IIT are the *additive* model (where there is an impact from both factors), the *multiplicative* model (where one

| | stable Closed Movement | unstable Closed movement | stable Open Movement | unstable Open movement |
|---|---|---|---|---|
| **Stability** | 2.67(1,4.33) | 3.67(1,7) | 2.33(1,3.67) | 4.67(1,7) |
| **Motivation** | 3.33(1,5.33) | 3.67(1,7) | 3(1,5) | 4.33(1.33,7) |
| **Reward** | 4.33(1,6.33) | 3.67(1,5.67) | 4(1,6.67) | 3.67(1,5) |
| **Confidence** | 6.33(4.33,7) | 5(1.67,7) | 6(4,7) | 5(2.67,7) |
| **Informativeness** | 5.67(4,7) | 4.67(2.33,7) | 6(4.67,7) | 4.67(3,7) |

Table 6.2: Median (range) values for self-reported data for stable and unstable cadences for both open, no additional cues and closed, additional visual cues

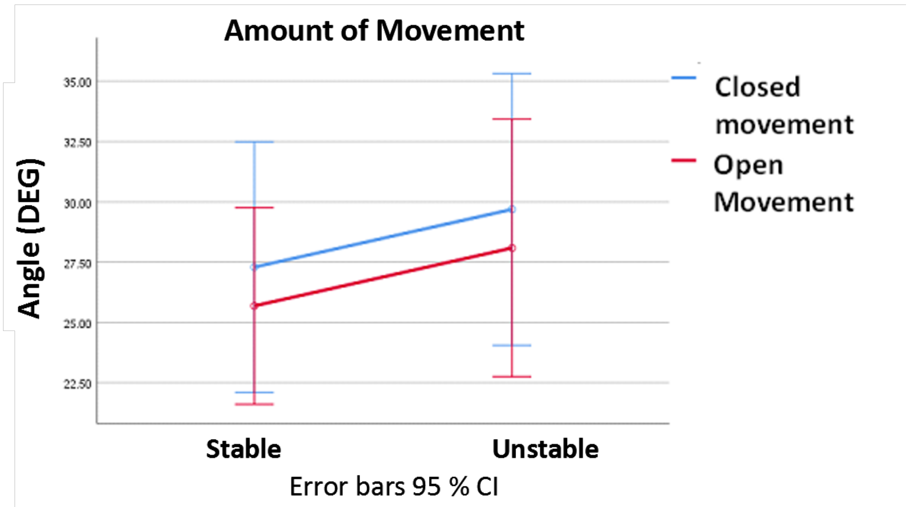
factor multiplies the impact of the other) or the *averaging* model (where the two factors are averaged together to build the individual's perception). While Anderson's work focuses on how this can be used to understand scale ratings of perceptions, previous work has also shown how physical movements can be used similarly, including how different cues impact responses in movement [De Sá Teixeira et al., 2008].

For this study, the IIT is used to explore how the musical stability and visual cues integrated to guide the ending of a movement. Through this method, a better understanding of how the different factors contribute to the changes in people's movement can be explored through the mental model people build for differing stabilities when provided with additional cues.

Following the procedure outlined in previous works for applying IIT to movement data[De Sá Teixeira et al., 2008], firstly, a visual analysis of the factors is done to establish the appropriate type of integration model (additive, multiplicative, averaging). This is then validated by a repeated measures analysis of variance (ANOVA) with stability and visual cues as within-subject factors. From this, the relationship between the two factors can be examined through a functional measurement of the integration, which in this case can be taken using the marginal means for each factor. This was done for all three of our behavioural measures: the amount of movement, the time taken to return, and the speed of the movement.

#### AMOUNT OF MOVEMENT

Visual analysis of the factorial plot for stability and movement type (Figure 6.8) for the amount of movement, show parallelism between the conditions (i.e. the red lines and the blue lines connecting the two points for the stable and unstable conditions are parallel). This is consistent with an additive model for integration, i.e. both factors have an impact on the way people continue moving as they perceive the end of the movement space [Anderson, 1982].



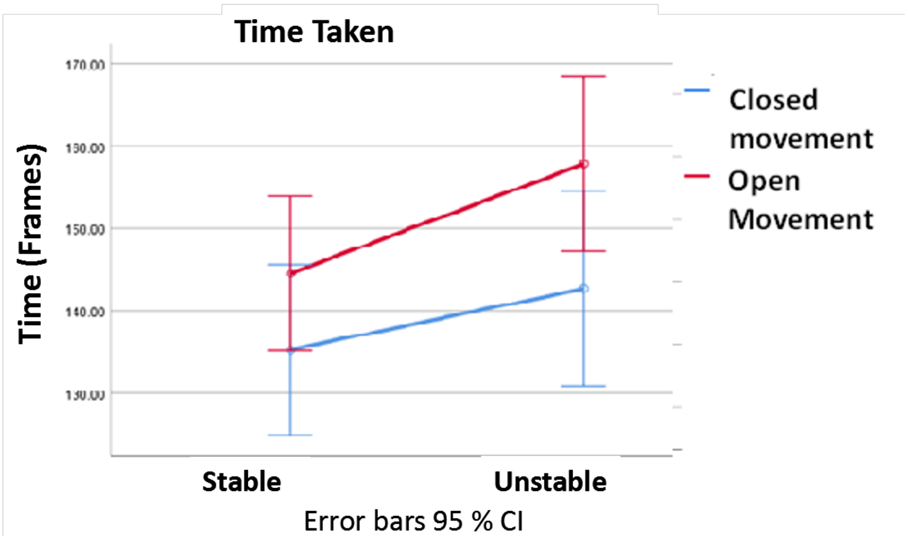

| | Closed | Open | *Marginal mean for stability* |
|---|---|---|---|
| **Stable** | **27.29** | **25.68** | **26.49** |
| **Unstable** | **29.68** | **28.09** | **28.89** |
| *Marginal mean for visual cues* | **28.49** | **26.89** | |

Figure 6.8: Factorial plot and functional measurement marginal mean values for the amount of movement. The parallelism in the factorial plot demonstrates the additive model used for integrating the harmonic stability and the additional cues. The functional measurement shows the marginal means which demonstrates that both the additional cues and the unstable endpoint led to greater movement.

The functional measurement, also shown in Figure 6.8, for the amount of movement shows an increase in the amount of movement both in closed movements and those having an unstable ending. This is reflected in the repeated measure ANOVA showing a significant effect of stability ($F(1,22) = 4.713, p = .041, \chi^2 = .176$), while the effect of perceptual cues (open vs closed) did not reach significance ($F(1,22) = 3.541, p = .073, \chi^2 = .126$). In addition, in support of the additive model of integration emerging from the graph, there was no significant interaction found with the amount of stretch. *Participants stretched longer in unstable conditions (using an additive model of integration).*

### TIME TAKEN

Similarly, a visual analysis was done for the plot, shown in Figure 6.9, for the time taken to return to the end-point of the music. This time the diverging nature of the plot (characterised as a fan shape of the red and blue lines connecting the points for the stable and unstable conditions), suggests a multiplicative model of integration, where the movement type amplifies the effect of the stability [Anderson, 1982].



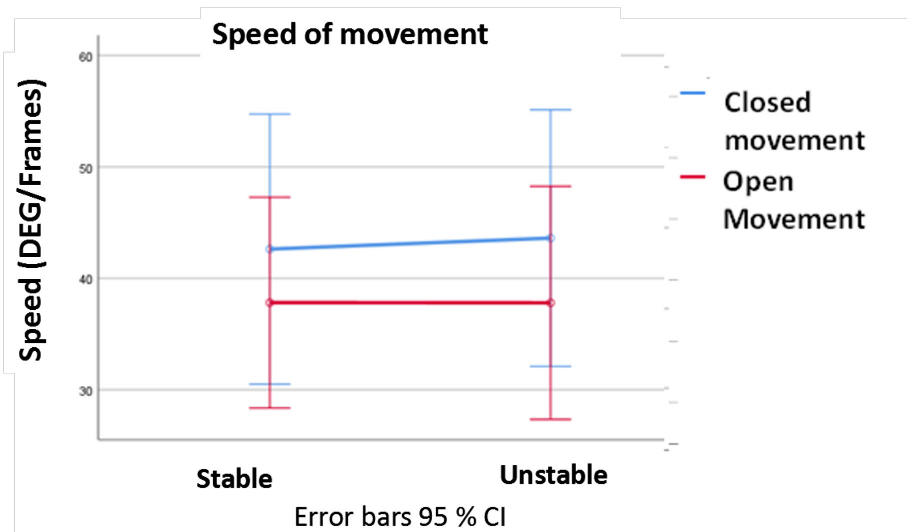

| | Closed | Open | *Marginal mean for stability* |
|---|---|---|---|
| **Stable** | 135.31 | 144.57 | 139.94 |
| **Unstable** | 142.72 | 157.80 | 150.26 |
| *Marginal mean for visual cues* | 139.02 | 151.19 | |

Figure 6.9: Factorial plot and functional measurement marginal mean values for the time taken to return, the divergence in the factorial plot demonstrates the multiplicative model used for integrating the harmonic stability and the additional cues. The functional measurement shows the marginal means which demonstrates that both the additional cues and the stable endpoint led to a shorter time of return.

The functional measurement, also shown in Figure 6.9, for the time taken shows an increase in the time taken to invert the movement due both to having eyes closed and having an unstable ending. Again, the outcomes from the ANOVA support this model. The impact of stability on the time to return to the end-point of the music was found to be significant ($F(1,21) = 7.628$, $p = 0.012$, $\chi^2 = .266$), as was the effect of perceptual cues ($F(1,21) = 15.969$, $p = 0.01$, $\chi^2 = .432$) with no significant interaction. These findings, along with the fanning shape seen in the factorial plot, suggest that the impact of the unstable ending is increased in the open movements. *People took longer in open movements and took longer when their eyes were closed when the music sounded unfinished (using a multiplicative model of integration).*

### Speed of the movement

Finally, a visual analysis of the speed of movement plot, shown in Figure 6.10, indicates that while parallelism is present, there is seemingly no change in speed due to stability. This suggests the movement type was the predominant factor for determining the speed of the movement [Anderson, 1982].




| | Closed | Open | *Marginal mean for stability* |
|---|---|---|---|
| Stable | .4362 | .3782 | .4022 |
| Unstable | .4361 | .3780 | .4070 |
| *Marginal mean for visual cues* | .4312 | .3781 | |

Figure 6.10: Factorial plot and functional measurement marginal mean values for the speed of the movement. The flatness in the factorial plot demonstrates the that the movement type was the main factor used to determine the speed. The functional measurement shows the marginal means which demonstrates that the additional cues led to a faster movement .

The functional measurement for the speed of the movement shows an increase in the speed due to having eyes open, but there was no real impact of the ending, suggesting that only the movement type had an impact on the speed of the movement. The impact of perceptual cues on speed between the end-point of the music and the maximum was found to be significant ($F(1,22) = 10.186, p = .004, \chi^2 = .316$). *However, no significant effect of stability was found nor an interaction between them, implying that only the movement type was used. Participants were faster when the movement was closed.*

**Self-report Data** Self-reported data were analysed with Friedman tests, followed by Bonferroni-corrected Wilcoxon signed rank tests. A series of Friedman tests found significant differences for: perceived stability ($\chi^2(3) = 22.353, p < .001$), confidence ($\chi^2(3) = 21.187, p < 001$), perceived informativeness ($\chi^2(3) = 29.638, p < 001$), perceived motivation ($\chi^2(3) = 8.912, p = .030$), and reward ($\chi^2(3) = 10.064, p = .018$).
Subsequent Wilcoxon tests showed:

- For perceived stability, stable conditions were considered more stable than unstable conditions both with ($Z = -3.631, p < .001$) and without visual cues ($Z = -3.571, p < .002$). *stable conditions were perceived as more stable than unstable conditions*

- For confidence on reaching the target point, the tests showed that participants felt more confident in stable conditions than unstable conditions both in closed (Z = -3.627, p < .001) and open movements ($Z = -2.921, p = .003$). *Participants were more confident they had reached then end point in stable conditions compared to unstable conditions*

- For informativeness, the tests showed that participants felt more informed in stable conditions than unstable conditions both in closed ($Z = -3.211, p = .001$) and open movements ($Z = -3.441, p = .001$). *stable conditions were perceived as more informative than unstable conditions*

- For motivation, results approached significance for stable versus unstable conditions in closed ($Z = -2.077, p = .038$) and open movements ($Z = -2.220, p = .026$), with participants more motivated to go past the target point in unstable conditions. Additionally, they approached significance when comparing unstable conditions in closed and open movements ($Z = -2.184$, $p = .029$), with participants feeling greater motivation in open movements. *unstable conditions were perceived as more motivating than stable conditions, an even more motivating without additional cues*

- For perceived reward, participants found stable conditions more rewarding than unstable conditions in closed movements ($Z = -3.152$, $p = .002$). *stable conditions were perceived as more rewarding than unstable conditions, but only when there were additional cues at the end of the movement.*

### 6.3.7. Qualitative analysis

An analysis of participants' qualitative responses was used to explore further the experience of using the MuES with and without additional cues. The answers given were transcribed from the written descriptions given into *F4 Analyse* and separated by condition for each participant. From this transcription, a deductive analysis was performed to explore the differences felt between the different conditions, the impact of the cadence and visual cues on movement.

These results showed that 13 participants felt they relied on the sound and were "more focused" on the sound in the open movement, while 14 participants reported that they either relied on or were distracted by visual cues (the markers or indeed their own arm) in the closed movement. Additionally, only eight participants reported feeling more confident in their movement in the closed movement as they could see they had reached the end of the movement.

### 6.3.8. Discussion

First, while participants moved more in closed movements, they took longer to return in the open movements. At the same time, both measures were impacted by stability. This difference is also seen in the difference in the speed of the movement, where the impact of stability averages out. In terms of self-report measures, the impact of stability on perceptual measures holds with and without visual cues. Additionally, the qualitative measures demonstrate that while participants were able to concentrate on the sound more in the open movement, in the closed movement, they were able to use visual cues to help guide their movement, though some deemed it a distraction.

These results show how open and closed movements may interact with the MoSEM. What we can see from our analysis is that both the change in stability and movement type affect movement. Interestingly, participants moved more when in the closed movement, suggesting that people were still using the visual markers as strong cues as to where they should move before they are impacted by the stability (reflected in the additive model of integration), this demonstrates the combined **Reaction response** in which the sonification and visual cues are both used to determine the endpoint. Similarly, as shown in the self-report, participants felt more rewarded in stable conditions only in the closed movement, perhaps again, as shown in the qualitative results, they are able to use the visual markers and their own arm as a confirmation that they have completed the movement. However without this confirmation they felt less achievement. Interestingly in the case of closed versus open movements, participants do report that they are movement confident of having reached the endpoint in stable cadences versus unstable in both movement types. This implies that the **Appraisal Response**, in both open and closed movements, relates the cadence heard to whether the end had been reached at least to some degree. Stable cadences were also perceived as more informative than unstable cadence for both cadence types; this reflects the correct **Predication Response** where the complete cadence matches with the perceived end of the movement. However, it was not felt by participants that either sonification was more informative than its counterpart in the open movements versus the closed, despite the additional cues. This is possibly why in the qualitative results participants describe the visual indicators either distracting or used for confirmation.

These results can be used to extend the model for movement expectation (MoSEM) to see how these external cues may interfere with our movement expectancy. As seen in Figure 6.11, the additional cues external to the sonification and proprioceptive feedback can be thought of as an additional cue that the end of the sonification has been reached, hence the change in the prediction/reaction response.

On the other hand, the increased time taken for open movements shows uncertainty in the movement when endings were unstable. The suitability of the multiplicative model for the time taken can be seen as participants being unable to use the visual feedback from their arm for confirmation when their eyes are closed. This is also demonstrated in the greater impact of stability on motivation to continue one's movement

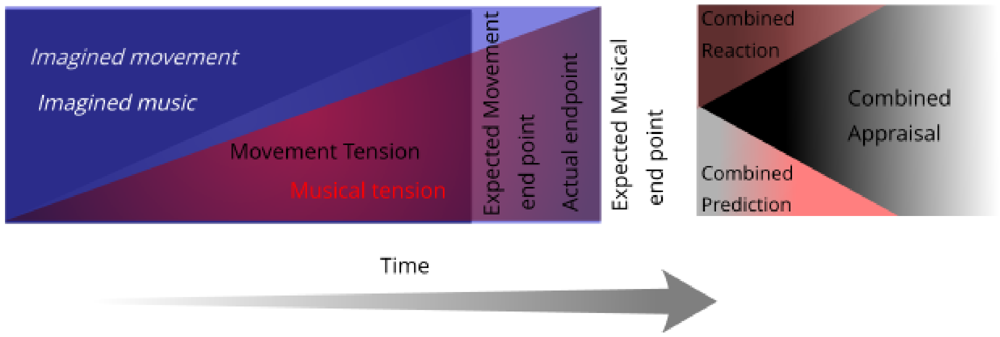



Figure 6.11: The Figure shows how additional cues can impact the use of musical expectancy as an endpoint predictor in a closed movement in the MoSEM; the additional cues to the movement's ending impact the degree to which the movement can be altered by the sonification. While the expected music end goes past the expected end of the movement, the cues to the endpoint, in this case, are so strong that the individual is not as reliant on the sonification, so the expected movement is preferred. However, the movement is still appraised with respect to the musical expectation.

in an open movement over a closed one, with participants more strongly encouraged when there are no overriding cues from the environment. Again, this is reflected in the qualitative findings that they were better able to focus on the sound in the open movement without the visual distractors. The IIT models explored in this study demonstrate how a combination of the cadence type and additional cues are used to signal the end of the movement. As in previous studies shown in Chapter 5, the impacts of MuES on movement behaviour can be seen again in these results. Additionally, these results show how additional cues can impact these effects. For example, the additive model for the amount of movement, suggests that while people were impacted by the stability of the cadence, in closed movements they also used the visual indicators to build their expectation of the movement, and hence moved further when they could see the indicators than when they could not. This is also seen in the time taken, where without the visual markers to confirm the endpoint, participants took longer to return for unstable cadences in open movements. These results are in keeping with those that demonstrate people's preference to other feedback over auditory. As shown by Petrini *et al.*, children will use "irrelevant visual cues" to help will auditory spatialization [Petrini et al., 2015]. Here it is shown how these additional cues may impact the way musical expectation is felt with relation to one's expectation of movement. Since there are fewer additional cues that the movement is ending in the open movement, people are more reliant on the sonification and there entangle their expectation of their own movement with the expectation of the music. However, in the case where there are additional cues to the endpoint of the movement, there is less reliance on the sound and therefore the misattribution of the sounds complete/incompleteness from Huron's work [Huron, 2006] (discussed in Chapter 4 ), is lessened.

Similar to the results for Study 3, seen in Section 6.2, this study highlights a potential breaking point for using MoSEM. The expectancy in movement suggests an adaptation in the individual's movement which goes against their expected endpoint of their movement, in this case, based on the additional cues available to them. The MoSEM proposes, by making the person an active agent in the expectancy, the perceived event onset of the ITPRA response can be manipulated through continued musical tension. While previously the sonification was thought to be the sole impactor on a person's expectation of the movement, the results of this study show other kinds of cue impact people's expectation of the movement. Moreover, the dominance of visual cues over auditory ones will lead to these cues (if present) being used to establish the expected endpoint of the movement and thus create a concrete event onset at which a person will form their prediction and reaction responses.

## 6.4. Conclusions

In this Chapter, it can be seen how people have predetermined expectation of the movement and the use of external cues can change the way a musical expectation based sonification is used and perceived. It was shown how the length of the sonification impact its perceived stability, when it ends short of what the individual expects of their movement it changes the perception of the music. Furthermore, external cues available in different movement types were shown to impact the way musical expectation impacts movement. It was found that in movement types where perceptual cues are high the impact of stable/unstable endings is lessened as there are more cues to build an expectation of the movement outside of the sonification.

These findings show how the expectation of a given movement must be considered when using these musically-informed sonifications, in addition to the musical expectation created by the sound. When applying these musically-informed sonifications to specific movements this expectation of the movement as well as the additional cues available that might impact the way the sonification can be used. For instance, in an open movement, the sonification may be expected to alter movement behaviour and perception when the movement is closed only the perception of the movement can be affected. By leveraging the impact on movement behaviour for open movements, the use of musical tension to encourage movement past a certain target is explored in the context of chronic pain rehabilitation. Additionally, the use of musical expectancy impact on feelings of motivation/reward is used to explore how repetitions of a movement may be encouraged for general wellbeing.

The MoSEM presented in this thesis has been explored in multiple movements. From these explorations, a series of design opportunities and constraints can be seen for different movement contexts. For movements with relatively open target points, i.e. a low level of visual cues and an undefined conceptual endpoint, such as the stretch forward, it was demonstrated how musical expectancy could be used to promote additional movement or encourage movement competition, depending on the musical completion. Conversely, for movements that have a relatively closed target point, i.e. a high level of visual cues and a definite conceptual endpoint, such as the squat down, no impact was seen on movement behaviour, however it was still possible to evoke a sense of motivation to continue the movement/sense of achievement using musical completion.

**Contributions**

∗ Shows the length of the sonification can impact its perceived stability due to the expected continuation of the movements

∗ Shows how different movement types interact with musically-informed sonification

∗ Shows that cues in the environment and the given movement should be considered in applying the MoSEM to movement sonification

# 7. Case Study 1: Chronic pain rehabilitation

**In this Chapter:**

*RQ4: How may the MoSEM be used to design MuES for populations with low self-efficacy?*

∗ How may the MoSEM be used to design for chronic pain rehabilitation?

∗ The gap design to encourage past a certain boundary

∗ How would people with chronic pain utilise MuES in real-life scenarios?

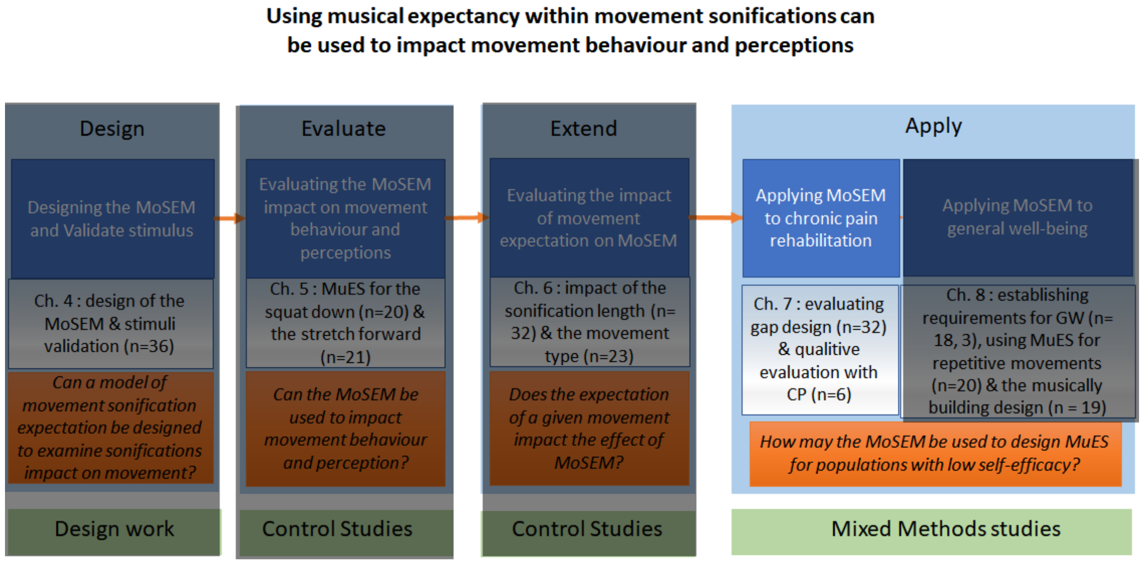



Figure 7.1: This Chapter focuses on exploring the MoSEM in the context of chronic pain rehabilitation. Through two studies, the first exploring a potential MuES design to promote either conclusion or progression of movement within a healthy population. The second, more qualitative, study explores MuES with people with chronic pain, including its potential impact on movement and how it may be applied to real-life scenarios, this work addresses the question how MoSEM may support people with chronic pain.

## 7.1. INTRODUCTION

This Chapter presents the first of two cases studies which seek to better understand the MoSEM through real-life practice with populations with low self-efficacy. This case study focuses on chronic pain (CP) rehabilitation and explores a potential design using the MoSEM in the form of the "gap" design.

The work in Chapter 5, shows how the MoSEM can be used with open target movements, such as the stretch forward. The findings showed that by using a musically complete ending at the end of movement, people are encouraged to complete their movement and feel a sense of reward. Conversely, by using a musically incomplete ending people are driven by the musical tension to continue their movement and feel a sense of motivation to continue towards a potential resolution, as described in the MoSEM shown in Chapter 4.

In this Chapter, a design which uses a combination of these ending types is presented. Through this design people's range of motion may be altered; either through promoting conclusion, when they have reached a desired amount of movement, or encourage people to move past a point, where they may lack confidence. This design may be useful within CP rehabilitation where fear-related boundaries and over-activity can make it difficult to engage in physical activity [Hayden et al., 2005, Leeuw et al., 2007, Singh et al., 2014]. This Chapter explores the impacts of low self-efficacy on physical activity for CP and how the MoSEM may be used to overcome such boundaries. This design is then examined, firstly through an evaluation with healthy participants and then a qualitative evaluation with people with chronic pain to understand both the experience of using these sonifications and how it may be used with chronic pain rehabilitation.

## 7.2. CHRONIC PAIN

According to the 2009 Chief Medical Officer's Report, *"Each year, 5 million people in the United Kingdom develop chronic pain, but only two-thirds will recover"* [Donaldson, 2009]. The sheer numbers of people with CP and the kind of care they require put enormous pressure on the health sector: *"In England, there is currently only one pain specialist for every 32,000 people in pain"* [Donaldson, 2009]. Chronic pain, which is pain which persists after the expected time of healing [Turk and E.Rudy, 1987], can not only be physically debilitating but can also lead to psychological and social problems such as anxiety, depression and social isolation. CP can impair people's ability to engage in and enjoy everyday activities [IASP, 2014]. It can also cause them to withdraw from their family and friends [Snelling, 1994].

Physical activity is important in the management of CP and maintaining everyday functioning [Hayden et al., 2005]. However, it can be difficult in the presence of pain for people to engage in movement, especially that which they believe may cause increased pain or damage [Leeuw et al., 2007]. One of the primary factors that can stop people from engaging in physical activity is fear. This fear of movement is caused *"when stimuli that are related to pain are perceived as the main threat"*[Leeuw et al., 2007]. People with CP may fear those movements and activities that they perceive as being the cause of pain or re-injury, leading to avoidance behaviours and catastrophising thoughts [Vlaeyen and Linton, 2000]. This in turn, can lead to increased fear of movement, causing a vicious cycle where because the feared movement is avoided, those movements become harder and more painful to do; this is known as the fear-avoidance model [Leeuw et al., 2007]. Additionally, the anticipation of these threats can cause people to become hyper-vigilant of movements they perceive as threatening [Leeuw et al., 2007]. Conversely, overactivity due to people's desire or expectancy of being able to do more movement can lead to overexertion and setbacks leaving people unable to engage in more activity for weeks [Singh et al., 2014].

However, as suggested by Bandura [Bandura, 1977], a person with high self-efficacy is more likely to continue in the face of obstacles, in this case, pain. Additionally, it is thought that if a person's self-efficacy is high, then they are less likely to exhibit the avoidance behaviours seen in the fear-avoidance model [Woby et al., 2007]. Therefore, it is important that a person with CP can self-attribute their successes, which leads to a greater belief in their ability and decrease the likelihood of this avoidance behaviour [Turk and Okifuji, 2002]. Singh presents the *go-with-the-flow* framework, a framework for designing technology to support physical activity for people with CP [Singh, 2016]. This framework was built from an extensive literature review and qualitative studies with people with CP and physiotherapists and represented how the barriers faced by people with CP can be overcome. It highlights several important aspects that should be considered: enhancing the perception of movement, encouraging a sense of progress, providing a sense of achievement and reward and avoiding under/over-doing.

From these works, it can be seen how musical expectancy based sonification can be applied to help support people with CP and address some of the barriers demonstrated in the *go-with-the-flow* framework [Singh, 2016]. For the stretch forward movement, common in chronic lower back pain rehabilitation, musically complete endings can be used to reward movement and avoid overactivity, while a musically incomplete ending can be used to encourage additional movement to help people with CP cross fear-related boundaries.

## 7.3. Designing MuES for Chronic pain

Based on the work in Chapters 5 and 6, the impact of MoSEM has on open target movements can be seen. The MoSEM shows how sonification can be used to encourage continued movement using people's desire to reach a musical conclusion. Considering a point where a person may be afraid or anxious about moving past, they may require additional encouragement to continue onward. This could be due to fear of injury or of overdoing or could be down to a preconceived boundary the individual has put on themselves. However, as shown in previous work, the movement should not be punished, even if a given target is passed nor should the progression past a given barrier be strictly enforced [Singh et al., 2014]. The aim is instead to encourage progress but allow the final decision to be that of the individual while supporting low self-efficacy through both rewarding movement and encouraging progress.

To achieve this, a "gap" can be employed within the sonification to allow for this decision to be made. Triggered in the same way as before, with the movement of the individual driving the sound, at this boundary or point where the movement should be encouraged an unstable cadence would be used followed by a gap or break in the sonification where no sound is triggered. This gap allows the individual time to respond to the cadence and internally decide whether or not to continue. Once this gap is bridged, the sonification is triggered again leading to a stable target point as before. By using musical expectancy to encourage movement past certain fear related boundaries, people with chronic pain can better understand how their ability might surpass their expectation and instil a sense of reward when a certain target point is reached,this can be seen in Figure 7.2. This design mirrors the expectation of each individual chord seen Chapter 4, where the unstable ending creates the expectation there is more music to come, and hence movement. If the desire to continue on is strong enough, the gap in the sonification will be crossed, and the sound will continue.

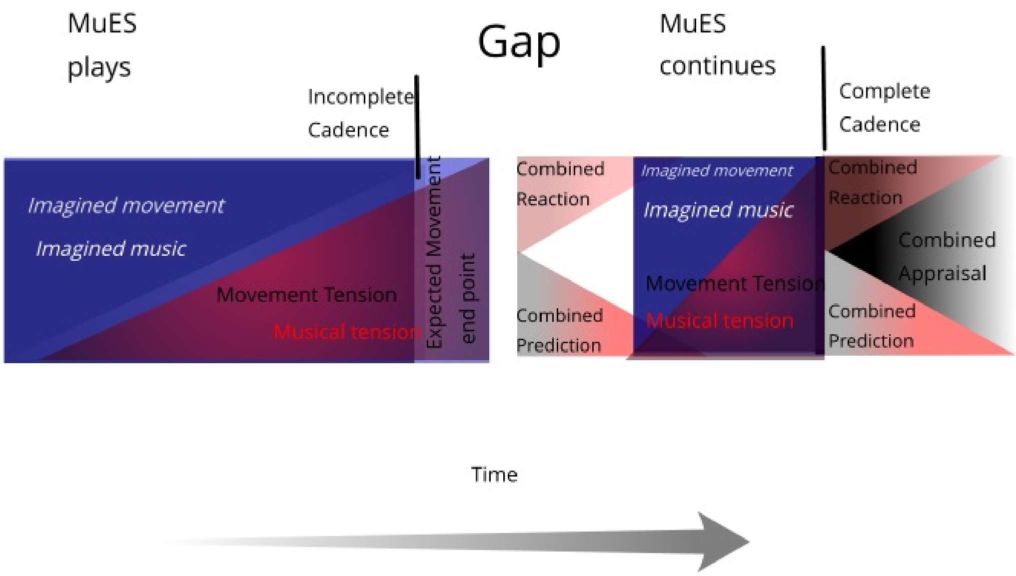



Figure 7.2: MoSEM used to create the gap design. In this design, the use of the unstable cadence is used drive movement past a gap in the sonification, where the expectation of continued music encourages additional movement. This gives the individual a chance to respond and if they desire to continue on they can use such encouragement to drive them across the gap where the sonification continues to a complete cadence.

This design reflects Chew *et al.*'s idea of a cadential "tipping point" which gives the feeling that the sound needs to move forward [Chew, 2016]. By using the MoSEM to place this expectation at the point where the gap starts, the individual is encouraged to cross the gap, or in the case of a stable cadence encouraged to stop, but the gap itself leaves the individual with time to decide if they are able to continue or not.

## 7.4. MUSICAL EXPECTANCY TO EXTEND THE RANGE OF MOVEMENT FOR AN OPEN TARGET MOVEMENT: THE "GAP" SONIFICATION FOR CHRONIC PAIN REHABILITATION

### 7.4.1. INTRODUCTION

To investigate the gap-design, an experiment was designed to see how harmonic stability and the length of a gap in the sonification effect movement behaviour. Firstly, the design was explored with healthy participants to understand its impact on movement behaviour before examining its impact and potential use for people with chronic pain. The reason to first explore these designs within healthy populations is twofold: firstly difficulties in recruiting people within chronic pain, who suffer from limited mobility, stigma related to their condition and, as shown by Singh, can show distrust to researchers [Singh, 2016]. This means that it is more beneficial to spend the time with CP participants with a later stage design, after using previous work in the literature to establish the needs of the users, such as work in pain psychology [Woby et al., 2007, Turk and Okifuji, 2002] and the qualitative explorations of Singh *et al.* [Singh et al., 2016]. Secondly, there is an ethical need to fully explore the impact of a potentially movement altering design before introducing it to a population where these changes in movement may be harmful to their on-going wellbeing.

Based on the findings of the previous studies and the MoSEM used to develop the gap design it is hypothesised that:

**H1**: People will move further in unstable conditions as seen in previous studies;

**H2**: People are more likely to first cross the gap in an unstable condition, as the MuES encourages additional movement;

**H3**: People will not cross the gap if it is too long as the movement will be appraised as complete as seen in Study 3 presented in section 6.2.

For this study participants were recruited as part of an undergraduate project including Study 3 in Section 6.2. The undergraduate student was responsible for recruitment/the data collection and was given the experimental design and procedure including all experimental materials, which were original designs for this thesis. The undergraduate student did some initial data analysis, using the measures designed for this thesis and self-report data, the data was then re-processed and reanalysed for the purposes of this thesis, which included improvements on the behavioural results analysis and more rigorous analysis.

### 7.4.2. Participants

A total of 30 healthy unpaid participants were recruited for the study (age=19-47, 22 female and 7 male). These participants were recruited as part of an undergraduate project including the Study 3 in Section 6.2 (the first two participants completed a pilot version of this study and were discounted).

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 73.61 (max 108 and min 40), with 16 out of the 30 participants were found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014], therefore we assume any effects seen are not due to musical training.

### 7.4.3. Materials

The design of the stimulus for the gap trials follows on from that of Study 3 seen in Section 6.2. Each of the four stimuli starts with the same chords of the L3 conditions ending on either a stable or unstable cadence, for both the four stable (using stable L3 from Study 3) and the four unstable (using unstable L3 from Study 3). Each one is then followed by a gap in the chord progression of four different lengths (described above) and then a final two chords to provide a final stable cadence, as seen in Figure 7.3. The gap lengths used were L1 = 2 segments, L2 = 2.5 segments, L3 = 3 segments, L4 = 4 segments. These lengths were based on results from pilot experimentation.

### 7.4.4. Experimental design

A within-subjects design was used for the eight trials, for the independent variables stability and gap-length. For these two variables, there were two stabilities and four different gap lengths based on how many segments where a note wasn't triggered.

Both behavioural and self-reported measures were taken to determine the dependent variables. For behavioural measurement, additional movement and the time of return were taken as described in Chapter 3.2.2. In addition, whether they did or did not cross the gap was recorded.

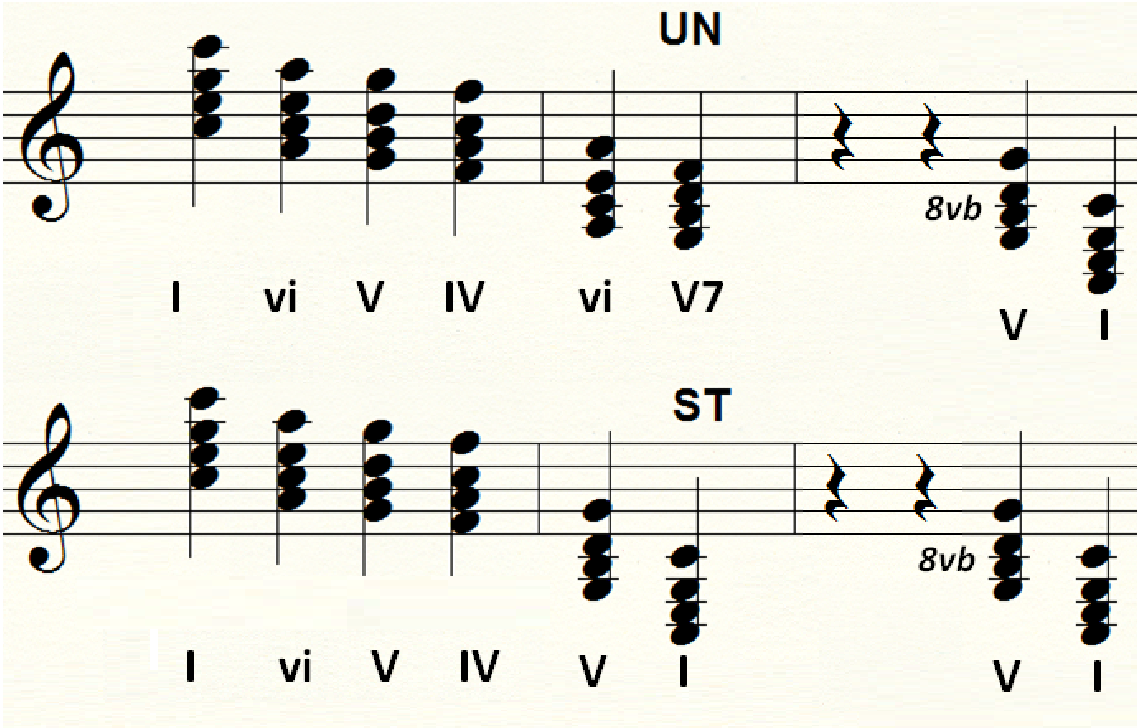



Figure 7.3: Stimuli used in the gap experiment, showing the two cadences used, where the length of the silence is altered depending on the gaps size. After the gap, both sonifications end in a stable cadence.

In terms of self-reported measures, perceived stability at the end of the movement, perceived motivation to continue stretching at the end of the movement, the perceived total amount of stretch and perceived amount of reward felt at the end of the movement were all measured using a 7-point Likert scale taken after each condition.

### 7.4.5. Experimental procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the back using a back support and calibrated using a neutral position (upright) and a maximum comfortable stretch as in Chapter 5.

Participants were instructed to stretch forward at a steady pace allowing each chord to sound so that the feedback could be heard. They were told to use the music produced to inform them of the movement's conclusion and to then return to the neutral position. After each set, they were asked to fill in the questionnaire for the self-reported measures. Finally, after all the conditions were complete, they filled out the GSMI questionnaire.

The stimuli were presented in length order so that the longest gap stimuli were first and the shortest last. This was done as it was found in pilot studies that once the gap had been bridged once and the participants were made aware of the additional sound, they would continue to cross the gap from then on. By presenting the stimulus in length order, the threshold for crossing the gap can be found. The order of the stability was randomised across the lengths.

### 7.4.6. Results

Six participants were excluded from analysis due to either incomplete data or having not made it to the gap before returning. Figure 7.4 shows the mean stretch distance and time of return across the conditions. The Figure shows how participants stretched more and for a longer in the unstable conditions compared to the stable conditions. In addition, it shows how as the gap gets shorter, more people crossed the gap and hence moved more.

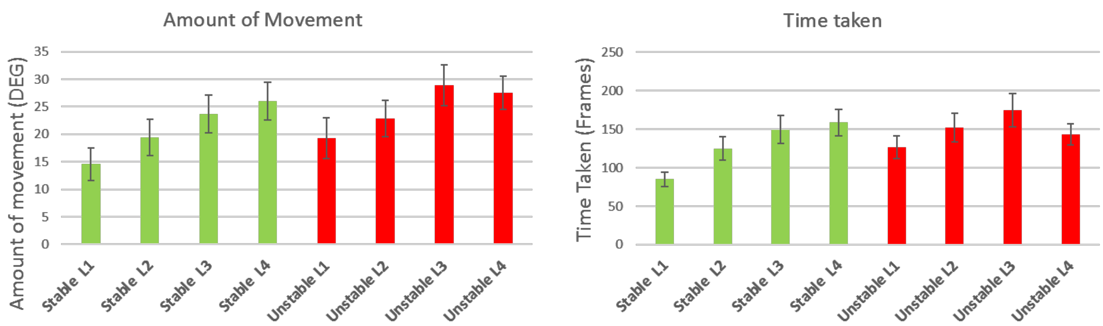



Figure 7.4: Mean (SE) values for behavioural measures for stable (ST) and unstable (UN) cadences of gap-lengths longest, L1, to shortest, L4

Table 7.1 shows that the self-report measures and Figure 7.5 the number of times and the first time crossing the gap occurred in each condition, showing more people crossed for the first time in unstable conditions.

While assumptions of normality were not met for behavioural measures, likely due to the variance between cases where the gap was crossed or not, the repeated measures ANOVA has been shown to robust to non-normal data [McDonald, 2014]. Data was submitted to a Levene test, to test for variations in homogeneity and no significant results were found, $(F(1,150) = 0.346, p = .448)$ for additional movement and

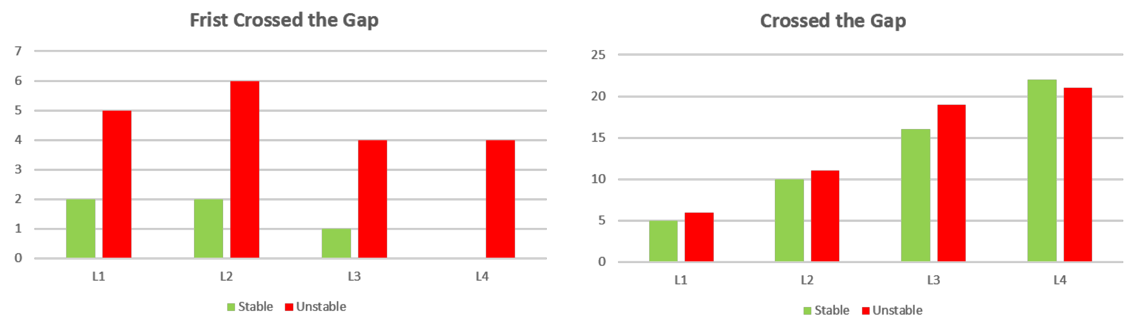



Figure 7.5: Shows the number of instances in which the gap is crossed, and in which condition the gap is crossed first for stable (ST) and unstable (UN) cadences of gap-lengths longest, L1, to shortest, L4

| | Stable Gap L1 | Stable Gap L2 | Stable Gap L3 | Stable Gap L4 | Unstable Gap L1 | Unstable Gap L2 | Unstable Gap L3 | Unstable Gap L4 |
|---|---|---|---|---|---|---|---|---|
| **Stability** | 1(1,6) | 1(1,7) | 1(1,6) | 1(1,7) | 6(1,7) | 6(1,7) | 3(1,7) | 1(1,7) |
| **Motivation** | 5(2,7) | 5(1,7) | 5(2,7) | 5(1,7) | 4(1,7) | 4(1,7) | 5(1,7) | 4(2,7) |
| **Reward** | 5(3,6) | 5(3,7) | 5(1,6) | 5(1,7) | 3(1,6) | 3(1,7) | 4(1,7) | 5(2,7) |

Table 7.1: Median (range) values for self-reported data for stable (ST) and unstable (UN) cadences of lengths of Gap L1 the longest to L4 the shortest

($F(1,150) = 0.913, p = .341$) for time of return, therefore, homoscedasticity can be assumed [Field, 2013]. Therefore, the amount of movement over the gap and the time taken from the gap to the maximum were submitted to repeated measures analysis of variance (ANOVA) with stability and gap-length as within-subjects factors, followed by Bonferroni-corrected pairwise comparisons.

For **Additional movement** significant effects were found both for stability ($F(1,23) = 11.910, p < .002, \chi^2 = .341$) and length ($F(3,21) = 4.093, p < .020, \chi^2 = .369$), with no significant interaction. Pairwise comparisons found significant differences between L1 and L3, L4 (p= .005, .007) *Participants moved more in unstable cadences and in shorter gap conditions.*

For **Time of Return** significant effects were found for stability ($F(1,23) = 8.674, p = .007, \chi^2 = .274$) and length ($F(3,21) = 5.904, p = .004, \chi^2 = .458$), with no significant interaction. Pairwise comparisons found significant differences between L1 and L3, L4 (p= .018, p = .008). *Participants took longer in unstable cadences and in shorter gap conditions.*

In terms of **crossing the gap** the number of times the gap was crossed was recorded for stable versus unstable conditions and across the four the lengths of gap. For gap-length, Friedman test showed significant differences across the lengths ($\chi^2(3) = 36.349, p < .001$). Follow up Wilcoxon signed rank tests, with a Bonferroni correction for multiple comparisons, showed significant differences between: L1 and L2($Z = -2.667, p = .008$), L3($Z = -3.509, p < .001$), and L4($Z = -3.827, p < .001$), as well as L2 and L4 ($Z = -3.017, p < .001$), Wilcoxon signed rank test showed no significant different between the two stabilities. *Participants were more likely to cross the gap in the shorter gap conditions than in the longer conditions.*

However, in terms of the conditions in which participants first crossed the gap, Friedman tests showed no significant effect for gap length, while a Wilcoxon signed rank test showed a significant difference between stable and unstable conditions ($Z = -2.711, p < .007$). *Participants were more likely to cross the gap for the first time in unstable conditions.*

For **Self-reported measures**, Friedman tests found significant difference for stability ($\chi^2(7) = 51.207, p < .001$), perceived motivation ($\chi^2(7) = 23.09, p = .002$,) and perceived reward ($\chi^2(7) = 32.08, p < .001$). Wilcoxon tests showed that:

- For perceived stability significant differences were found between stable and unstable conditions for gap lengths: L1($Z = -3.917, p < .001$), L2 ($Z = -3.525, p < .001$) and L3 ($Z = -2.759, p = .006$) though not for L4. *Stable endings were perceived as more stable than unstable, expect for in the shortest gap length.*

- For perceived reward, significant differences were found between L1 ($Z = -2.767, p = .002$). *Stable endings were perceived as more rewarding than unstable.*

- For perceived motivation significant differences were found between stable and unstable conditions for gap length only L2 ($Z = -3.303, p = .001$). *Unstable endings were perceived as more motivating than stable, but only in the initial gap lengths.*

### 7.4.7. Discussion

From these results, it can be seen how the gap may be utilised to encourage change in a person's range of movement. As seen in Figure 7.5, participants are more likely to cross the gap when the cadence is unstable, which is also reflected in the amount of stretch and time taken. Additionally, as predicted, the length of the gap impacts whether it is crossed or not; if the gap is too short, it will be crossed regardless of the cadence stability, but if it is too long people will feel they have reached the expected endpoint, as seen in previous studies in Chapter 6. This means that the calibration of the gap's length is important, so that it matches the individual's range of movement and how easy the gap should be to cross. However, it has yet to be explored how this may affect long term use of the sonifications, if once participants have knowledge that there is more sound to come, it is unknown how would that impact the expectation of the sonification itself.

For self-report results, we see that the perceived stability is found to match the condition across the lengths, bar L4, where the majority of participants had crossed the gap in both conditions. Additionally, the feeling of motivation and reward are also consistent with previous results for the MuES, in Chapter 5.

These findings support the predictions of this design that the unmet musical expectation drives participants to cross the gap. This "tipping point"[Chew, 2016] encourages the individual to explore further and reach the expected resolution. Additionally, it shows that as in previous Chapters stable endings encourage the conclusion of the movement and create a sense of reward while also avoiding overactivity, both of which are important to CP rehabilitation [Singh, 2016].

The results show how the use of a gap-based design can allow for flexibility in MuES, using stable endings to encourage conclusion and hence avoid overactivity or unstable endings to encourage movement past it as described in Figure 7.2. It should be noted that in both these cases the final decision is that of the individual, with the music only providing encouragement towards the desired behaviour rather than signalling a wrong or incorrect amount of movement. From this evaluation of the gap design, it can now be explored with people with chronic pain to explore how it may be utilised.

## 7.5. Evaluating musical expectancy sonification with people with Chronic Pain

### 7.5.1. Introduction

The previous study shows how the gap sonification design can be used to encourage progress and avoid overactivity. In this study, a mixed method approach is taken with people with CP to investigate not only the efficacy of musical expectancy sonification to support CP but also to highlight how it may be adopted within chronic pain rehabilitation and potential future avenues for the application of MuES.

The focus of this study was to gain some initial understanding of how MuES may be used within CP rehabilitation. However as previously stated recruitment of people with CP can be difficult due to mobility issues, stigma related to the condition and distrust of researchers [Singh, 2016]. As such this study gives a larger focus to exploring the potential for MuES within CP rehabilitation and uses a smaller, more qualitative study to generate rich understand of the experience of individual participants [Braun and Clarke, 2013].

The first stage of the study involves an open-ended exploration with the original MuES stimuli used in Chapter 5, i.e. the stable and unstable endings. This exploration allows participants to think aloud to discuss different aspects of the feedback. The second stage reiterated the protocol in the gap design study, in that participants did a single reach forward with gaps of decreasing length, with a randomised order of stable and unstable endings. This was then followed with a general discussion of how such sonifications may be used in real-life scenarios as well as any general thoughts on the sonification and potential improvements.

### 7.5.2. Participants

Six people with chronic low back pain (5 female) were recruited for the study; four were recruited through an NHS pain group, two were recruited from local advertisements of the study. Participants were recruited based on having had persistent back pain for a period of longer than three months. The average age was 52.1 (20-79) and participants had pain for an average of 10.6 years (0.5-32). Of the data collected, one interview was lost to data corruption (p1), one set of movements was lost due to errors in the recording (p3), and one participant was unable to complete the gap section due to an increase in pain.

The mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index was 66.16 (max 100 and min 42), with 5 out of the six participants were found to be below the mean score the general population (81.58) [Müllensiefen et al., 2014], therefore we assume the effects that may be observed are not due to musical training. P6 was the only participant to score over the general population mean, with a GMSI score of 100.

#### 7.5.3. Materials

For the initial exploration the stable and unstable sequences from Study 3 in Section 6.2. The second stage used the same stimuli seen in the gap study.

For qualitative responses, a semi-structured interview method was utilised, as outlined in Chapter 3. The general areas covered included: perceptions of the sonification, impressions of how it impacted participants movement and potential for its use in real-life scenarios. The responses were recorded through both paper notes taken during the study and through an audio recording of the session.

#### 7.5.4. Experimental design

Participants first explored the MuES with the stable and unstable sonifications, for which the order was counterbalanced. They were encouraged to think aloud during this time, about their thoughts of the sound and how it impacted their movement and how they felt during the movement. Behavioural measures were taken in the form of the amount of movement and time taken. For self-report participants were asked to rate each condition on perceived stability, motivation to continue past the target point, perceived reward, and informativeness on a 7-point Likert scale, as well as their current pain out of ten and the maximum angle they felt they had reached. For the second stage of the study the gap trials followed the same design as in Section 7.4, participants were given both stable and unstable endings before the gap, and the length of the gap was reduced such that the first trial had the longest gap and the final trials had the shortest. For this study, the same measures were taken, with expectation of perceived informativeness, which was removed to simplify the questionnaire.

#### 7.5.5. Experimental procedure

First, participants were introduced to the study and the activity involved. Then they answered a series of demographic questions and questions related to their pain and experience, after this, the mobile device and the first set of stimuli were introduced.

| | General | | Stable | Unstable |
|---|---|---|---|---|
| **Confidence** | 4.5(3-7) | **Stabilty** | 1.5(1-6) | 1.5(1-6) |
| **Anxiousness** | 2.5(1-4) | **Motivation** | 1.5(1-7) | 2(1-7) |
| **Usual pain** | 6(3-8) | **Informativeness** | 4.5(4-6) | 4(1-6) |
| **Current pain** | 5(1-5) | **Reward** | 4.5(1-7) | 1.5(1-7) |
| | | **Pain** | 4.5(2-7) | 5(2-6) |
| | | **Max** | 57.5(25-90) | 60(20-85) |

Table 7.2: Median (range) for self-report data for initial demographic data and self-report data for the initial exploration of the two cadences.

Once the device was calibrated to a comfortable movement space for the individual, they were asked to explore the first stable and unstable sounds while "thinking-aloud" and giving their impressions on the feedback after each sound participants were asked the self-report questions and any further reflections on the sound.

Participants then experienced the gap sonification design in the same manner as 7.4 and answered self-report questions after each condition. After the final condition, the goal of the sonification was explained to participants, and they were asked how they may deploy such a sonification in real scenarios and any final positives/limitations of the current design.

### 7.5.6. RESULTS

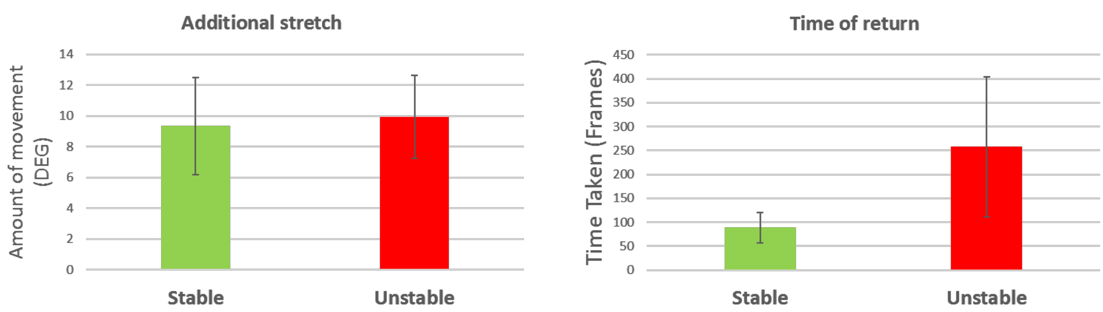



Figure 7.6: Mean (SE) values for behavioural data during the initial exploration of the two cadences, for stable and unstable showing the additional stretch past the cadence point and the time taken to return.

In Figure 7.6 and Table 7.2 an overview of the quantitive measures taken from the initial exploration can be seen. Behavioural measures were submitted to a paired t test; however, no significant differences were found. This is likely because the sample number is too small, and the trends in the data suggest that participants moved slightly more and for longer in unstable conditions compared to stable.

For self-report measures, responses were submitted to Wilcoxon signed rank test, though again no significant differences were found.

Due to the nature of the study, the mobility of participants and the set length of the gap, participants only crossed the gap 10 times (out of 30 trials). Of the five participants who trialled the gaps design two never crossed the gap, two crossed the gap twice, and one participant crossed the gap every time. An overview of the quantitive results can be seen in Figures 7.7 and 7.8, while the self-report results can be seen in Table 7.3.

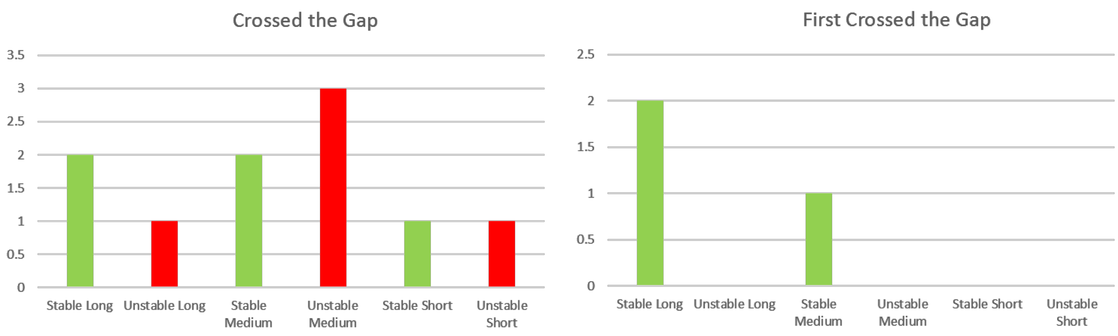



Figure 7.7: Shows the number of times the gap was crossed in each condition and the conditions in which the gap was first crossed.

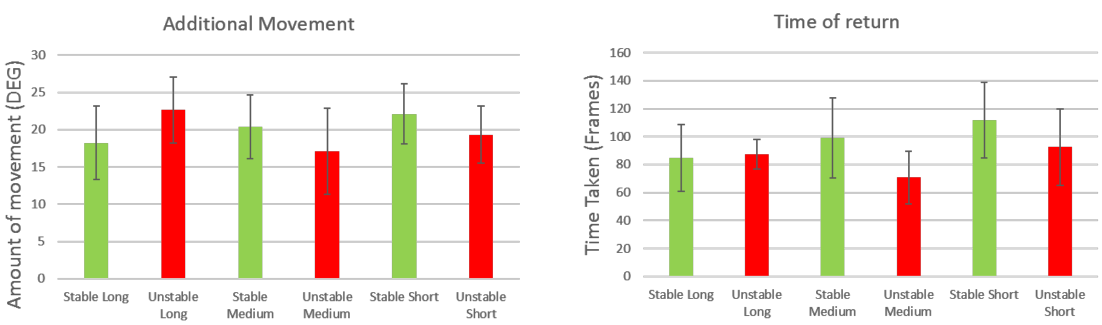



Figure 7.8: Mean (SE) values for behavioural data during the gap trials of the two cadences, for stable and unstable and different gap lengths showing the additional stretch past the cadence point and the time taken to return.

| | Stable | Unstable |
|---|---|---|
| **Stabilty** | 1(1-1.33) | 1(1-5.67) |
| **Motivation** | 2.33(1.33-7) | 1.67(1.33-7) |
| **Reward** | 5.67(1-7) | 4(1.33-7) |
| **Pain** | 4(1.33-5) | 4.33(1.67-5) |
| **Max** | 73.33(30-90) | 76.67(31.67-90) |

Table 7.3: Median (range) for self-report data for the gap design with people with chronic pain

For the gap design behavioural measures were submitted to a repeated measures ANOVA; however, no significant differences or interactions were found.

For self-report measures, responses were submitted to a Wilcoxon signed rank test, though again no significant differences were found. While few conclusions can be drawn from these measures, the responses given can be used to explore the qualitative responses provided by participants.

### 7.5.7. Qualitative Data Analysis

The qualitative data was first transcribed in *F4 Transkript* from the audio recording, with the support of written notes. The data was not transcribed verbatim, with false starts and filler words omitted from the transcript. The focus of the transcription was maintaining the full responses while making the transcript understandable for coding the data. After rereading and familiarisation with the dataset, responses were selectively coded according to areas of interest, and from these codes, initial themes were developed *F4 Analyse*, where an inductive approach to developing themes was taken [Braun and Clarke, 2013]. These were then reviewed, revised and organised into higher level themes and subthemes; these were then grouped into how they relate to three topics: specific comparisons between the two cadences, people's general impressions of the sonification and how MuES may be used with chronic pain rehabilitation. Firstly, an overview of the identified themes and their meaning within the context of the study is given, with some representative quotes from participants, then the themes are explored in terms of related work and how it informs the use MuES for chronic pain.

### 7.5.8. Impact of MuES

When comparing stable and unstable cadences participants highlighted aspects of both that contributed to informing movement, encouraging movement and also leading to uncertainty of the movement, some of which aligned with previous findings from the MoSEM as well as providing some new insights.

#### **Informing**

Participants highlighted different ways the stable and unstable cadences inform them of the endpoint. One participant highlighted that the stable cadence was a clearer signal that they had reached the endpoint than the unstable cadence. This implies that the conclusion of the music helps confirm that the end of movement has been reached, relating the prediction of the musical conclusion to the movement as suggested in Chapter 4. This also highlights how the use of musical structure can be used to support the representation of sonified data [Vickers et al., 2017], since, due to the associations with music, the ending of the movement is more identifiable.

> *"it's [stable cadence] more recognisable" (P6)*

However, one participant also highlighted how they could use the unstable ending as an indicator of the endpoint due to the lower pitch of the chord. In order to create an unstable ending, the music actually goes to a lower pitch. This change in the sound was enough to use it to signal the end of the movement, and after initial explorations past the target point, it was learnt that the lower note indicated the end-point.

> *"the first time I kind of knew I was going that far and I had kind of got it in my head that is the endpoint. because there was quite a low sound, so in my head, I knew that was the end, I tried to do a little bit more, and there was no sound, so I was like ok that is the point." (P5)*

#### Encouraging

In terms of encouragement, participants felt differences in the way the two endings encouraged their movement behaviour both at the endpoint and in the pacing of the movement. Due to the music created by the sonification participants were encouraged to change the way they moved and changed the way they feel about it.

Participants mentioned the stable cadence encouraged them to stop when they reached the cadence point, equating the conclusion of the music with the need to conclude their movement, as described in the MoSEM.

> *"but it motivated me to keep going within the movement while the music was playing and as soon as it stopped that makes you want to stop" (P3)*

Participants also noted a sense of reward from the stable cadence, compared to sonification that ended in an incomplete cadence.

> *"the ending is better …it's more rewarding" (P6)*

However, other participants mentioned that they didn't feel a particular impact on their feelings of reward because the movement in itself wasn't rewarding to them. This suggests that participants may have different views on what constitutes a "reward" in the movement

> *"I think if you said were you satisfied then I would say yeah, but the reward it makes me feel, but I guess it is the same as satisfied, I don't know, but I didn't feel rewarded, but I was satisfied with it." (P5)*

Additionally, participants highlighted feeling more encouraged when the ending was incomplete.

> *"in a way it was sort of more encouraging" (P3)*

Participants also highlighted how this motivation encouraged them to move more, to reach the expected ending of the music.

> *"I think the music makes you want to go a little bit more" (P6)*

One participant likened the incomplete cadence to listening to music which hadn't reached the end, which left them expecting more. However, since the individual is the driving force behind the sound, this desire for completion is what causes the feeling of wanting to go on.

> *" no, it doesn't sound finished, it's like you listen to the opera and they finished there "* (P4)

However, one participant mentioned that they started to learn where the end point of sonification was, which impacted how much they were willing to continue on afterwards. Furthermore, one participant also found the unstable endings unpleasant, and they felt that the incomplete cadence signalled they had performed the movement incorrectly. This highlights how alterations in the sonification design may impact the underlying representation of the data [Vickers et al., 2017, Scaletti, 2018]

> *"it makes you feel like you are doing something wrong, when you go like *stretches forward to incomplete cadence* it's like 'what are you doing' ...it's like you shouldn't go any further" (P6)*

In addition to finding the sound generally useful to track the pacing of the movement, participants mentioned that the felt the pacing of the music changed across the different cadences, with three participants feeling faster in the unstable and one in the stable.

> *"it [unstable sonification] feels to me that it's faster, so it is making me inclined to move more quickly ... it gets faster as it moves on I think, it feels that way. The end of it feels faster than the beginning bit. So it is almost as if it is pushing you on a bit further possibly" (P3)*

> *" it's [stable sonification] quicker? or maybe because I am moving quicker or differently?" (P4)*

While participants felt the speed of the sound changed across conditions, the speed of the sound was entirely driven by the participant's movement. This suggests that the sonification itself may affect the perception of the pace of the movement.

### 7.5.9. General Impression of the sonification

In addition to the difference between the sonifications, participants gave a series of positive and negative impressions of the use of sonification related to how it informs their movement, sound as a distraction, how it relates to the physical barriers they face, and their desire for more music.

#### Sound informing movement

Participants generally found that the sound helps to inform them of their movement just through having the sonification. By sonifying, the movement participants were able to keep track of how far they had gone, where they were in the movement as well as the pacing of the movement. This was found to be a useful tool during physical activity, as it can be hard to monitor one's own movement without feedback. This reflects the main use of movement sonification as highlighted in Section 2.3 and previous reviews of the use of sound feedback in physical activity [Sigrist et al., 2013]

> *"it informs you that you are not going too far, with the sound of the music you can control the movement and everything, it's helping" (P4)*

Furthermore, participants found the sonification helped guide them in the movement, with the specific design of the descending scale maps to their sense of the movement going downward. This mirrors the findings of Roddy and Furlong on people's embodied understanding of pitch direction to different data types [Roddy and Furlong, 2015] because the movement "goes down" the pitch should "go down"[Zbikowski, 2009].

*"I think the fact that it's a scale that goes up and down that kind of correlates with what you are doing with the up and down, so as you are going down it is going lower on the scale, and as you are coming up it's going higher on the scale" (P5)*

Participants also highlighted the agency and sense of control over the sound, leading to them feel like they are the "musician" playing the music created by the sonification.

*"it is like when you are doing the music when you play, you try to follow the music like, I don't know if I try to explain right. Like the musician, you try to play the music, and you are going down like the musician play, you do the same" (P4)*

#### SOUND AS A DISTRACTION

Participants made several comments with regards to the sound acting as a distraction. For one participant this was a benefit, relieving the anxiety related to the movement through the use of music and being able to focus on the external representation of the movement over the movement itself. Moreover, they found that the having the sonification during the movement was relaxing and allowed them to shift focus away from their pain, this reflects previous work where sound has been used to help pain relief [Cepeda et al., 2006].

*" actually [my pain was] not so bad, let's say about four [out of ten] because you forget a bit the pain...*
*"...yes, so I am fibromyalgia, so I have the pain 24 hours all the time, and I try everything even the painkillers and everything and nothing stops. And sometimes you need something like"*
*"Researcher: a bit of a fun distraction?"*
*"p4: yeah" (P4)*

In addition, other participants mentioned the sound was *"pleasant"* (P2), *"chirpy"* (P3) and *"nice"* (P5). Participants found the sound pleasant to listen to, and in many cases, the novelty of having the sound made the activity of moving more enjoyable.

> *"the sound it was nice to have. I think about if I use music when I am moving, I mentioned before I use it for pace. Generally, I use more upbeat music something I might know" (P5)*

However, participants also highlight how the sound being a distraction may have negative impacts on their movement. For instance, through focusing on the sound, they may ignore some of the signals from their body of what movement they should or shouldn't do.

> *"as in like I think the music distract you from feeling your movement, so let's say you are doing a deadlift or something and let's say you have the music. If the music kind of makes you mitigate what you feel from the deadlift because usually what you should do is see what you feel to distinguish what you are doing and now there is the music which is giving another impression of what you should be doing" (P6)*

Moreover, there were some cases where participants were unable to focus on the sound, due to either anxiety or increased pain.

> *"*laughs* I was trying to focus, but I was beginning to feel very uncomfortable … I was probably getting a bit anxious" (P2)*

#### Physical barriers

Leading on from participants being distracted from the sound entirely, there were also several reported instances of participants coming across physical barriers which changed the way they interacted with the sound. Firstly, participants used what felt like their physical limit to inform them when they stopped stretching.

> *" no I felt that that was my limit" (P2)*

Similarly, participants would use their sensations of pain or expectation of pain to inform their return point. This reflects the impact of fear and anxiety on movement avoidance [Woby et al., 2007], which is to be expected when working with people with chronic pain [Leeuw et al., 2007].

> *"I guess that would be highly influenced by your level of pain at the time because I think in a painful scenario that first thing to stop and you wouldn't carry, so you wouldn't carry on there you would stop" (P3)*

#### DESIRE FOR ADDITIONAL MUSIC

Finally, participants noted that they would prefer more varied and personalised music due to the repetitive nature of the exercise and to make it more enjoyable to listen to. By varying the music created the sound would be more engaging, while if it is always the same, it may get boring.

> *"If it could change and not always be the same and I am sure it varies from one person to another we all like different things. " (P2)*

### 7.5.10. SCENARIOS FOR USE

In terms of scenarios in which MuES would be useful for people with chronic pain, participants highlighted a variety of benefits where having something that informs and encourages could be beneficial. Firstly, the informative nature of the sonification was seen to be useful in providing ongoing feedback on one's movement capabilities.

*"if you get that as a constant feedback to yourself then I am sure it is going to have a knock-on effect" (P3)*

Additionally, the sound feedback was found beneficial for improving technique as people could use the notes to ensure they were performing correct movements with proper technique. In particular, stable endings could be used to inform people when they should conclude movement so as to avoid unsafe movement.

*"to signal what I am doing is right or not, so if you are stretching in a certain way like getting to this angle or this point is good for the muscles or whatnot." (P5)*

Conversely, the use of the musical endings to encourage movement was seen to be useful in scenarios where pain or fear of movement might cause people to avoid certain movements.

*"... because you end up doing nothing at all for fear that it is going to hurt " (P5)*

#### IMPRESSIONS ON THE GAP DESIGN

Due to the low sample size in the study and the limited number of participants who crossed the gap, it is difficult to gain many insights from the quantitive data. However, once the trials were complete, each participant had the gap design explained and demonstrated to them in order to elicit feedback on the designs used for chronic pain rehabilitation. While participants felt that there was potential in the design, to help cross potential boundaries and "push yourself a bit more". They had concerns surrounding the uncertainty that it may cause and felt that the design in its current format might cause hesitancy because during the gap there is no feedback on one's technique.

*" the thing with the gap, when you don't know what is happening you don't know what is coming next. So, with the first gap, you sort of think well has*

*it finished or is it just a little tiny gap, and it is going to carry on again. But when you know what it is doing well you know... because if you hesitate because there's a gap, then you may have lost your momentum, so you don't carry on. Or it is harder for you to pick up so then you don't do anything because you have lost that momentum of the movement. So personally, I would say the gap is not very helpful" (P3)*

Additionally, it was felt that because the gap ends with a continuation of the musical phrase, this may push people past what they should do and that there would be a need for a physiotherapist to set up what would be the safe bounds for the movement.

*"but this think you know how you get to that complete note then after that you get to a, so if you go past it, then you get another incomplete note then a complete note. If the complete note was meant to stop someone from doing something past that point the ones after that should be the same note with a chord or something, because if you go past it an get to an incomplete note you might go a little further, which was the point if you wanted someone to stop there" (P6)*

### 7.5.11. Discussion

The results of this study show how MuES may be beneficial to chronic pain rehabilitation and offer several insights into how it can be used in future designs. This study confirms what previous works exploring sonification for rehabilitation have found, in that patients find sonification helpful for informing about their movement and that the use of sound in exercises is enjoyable [Singh et al., 2016, Vogt et al., 2009].

Additionally, participants do add some confirmation for the proposed MoSEM in that they felt stable endings encouraged the conclusion of their movement and a feeling of reward. Conversely, unstable endings encouraged the continuation of movement and left them wanting more. This was also seen in the trends of the behavioural measures, with participants moving more in unstable cadences, though no significant differences were seen. It was also seen how the sonification might be used as a distraction from pain and from fearful movements as they can instead focus on the sound as an external representation of the movement. This follows on from previous work which has used sound and music to address pain and anxiety within chronic pain directly [Singh et al., 2014, Cepeda et al., 2006, Nazemi et al., 2013]. Moreover, some participants highlighted that the music allowed them some relief, or at least distraction from their pain, making it easier to perform the movement. This reflects the use of music in the past for pain relief/management [Cepeda et al., 2006]

This exploration of musical expectancy as a design concept also highlighted some additional insights surrounding its use in chronic pain rehabilitation and the experience of using such sonifications. Firstly, it was found how pain and lack of mobility may impact measures of MoSEM, with people often preferring the signals from their body than that of the sound. This shows the potential advantages of MuES over traditional movement sonifications, which often highlight erroneous movement with some alarm-based or unpleasant sound [Huang et al., 2005, Vogt et al., 2009]. By using musical expectation, people do not feel punished for not reaching a certain point and hence are not encouraged to perform painful/detrimental movements. However, some participants did feel that incompletion signalled they had completed the movement incorrectly and the unstable cadence caused them to feel less sure about the endpoint. This implies some limit to the use of MuES to alter perceptions of movement, without failing as representation of the data itself [Vickers, 2017, Scaletti, 2018]. Participants also highlighted the issue of trust in the sonification, suggesting it would be useful if there were some way for it to "know" what a safe and injury-free movement, would be either through automatic recognition [Olugbade et al., 2014, Olugbade, 2015] or through use with a physiotherapist. This reflects the need for trust when being persuaded to build self-efficacy, as stated by Bandura if the individual does not believe the persuader is sufficiently knowledgeable or trustworthy they will not be persuaded to continue past perceived obstacles [Bandura, 2000].

This reflects findings from the studies in Chapter 6, showing how external factors may impact the MoSEM. However, in this case, it is not the expectation of one's movement which impacts the MoSEM, rather a reluctance to use the sonification as an extension of the sensory feedback. Without established trust and correct calibration of the system participants were wary of using only the sound feedback as their means for performing the movement. In addition, this is the first time the alteration in the musical expectation in the MoSEM has been seen to sufficiently disrupt the representation of the movement to be perceived as incorrect. These findings highlight the need for a balance within the design of MuES, to allow for the encouragement felt from the desire for music resolution, without implying incorrect movement or uncertainty in the movement itself.

In terms of scenarios for using MoSEM, participants again highlight its use to both inform and encourage movement. They described how the sound could be used to inform on their movement not only ensuring safe movement but also allowing them to track their progress through the movement and better understand the pacing of their movement. Additionally, the encouraging aspects of the sound would be useful in situations where they needed to push that little bit further to reach a certain goal, or past a certain boundary. This may be especially useful in situations where pain or anxiety may be limiting their movement and in scenarios where they would want a complete cadence to signal endpoint and promote the conclusion of their movement.

In terms of the development of the MoSEM, the findings from this study offer some new insights. The responses from participants do show that the different musical endings did support either a feeling of completion or encouragement, depending on their musical resolution. However, participants also highlighted some potential limitations for the current design for using MuES in chronic pain rehabilitation shown in Figure 7.2. One key insight is how such a sonification would need to adapt to the changing needs and capabilities of some on living with pain, in terms of where to encourage or conclude a movement. An individual's current pain, confidence/anxiety and the potential for movement to be harmful are all keys to where the expectation created by the feedback should lead. This reflects on-going work exploring automatic recognition of pain and pain-related emotional states using movement sensing [Olugbade et al., 2014, Olugbade, 2015]. Specific to the proposed gap design, participants were concerned with the uncertainty the gap may cause. With the brief removal of any feedback (during the gap) and then the abrupt continuation could lead to both hesitation in the movement and an uncertainty if the movement was still safe. Despite this, participants seem to feel a different implementation of the gap design would be beneficial. For example, P3 described a similar design before taking part in the gap trials, using the two cadences together with "some kind of window", but felt the current gap left them unsure of what to do in the space with no feedback. P6 suggested that rather than a continuation of the musical phrase, after the gap there should be increasing more stable notes, so as to not push movement past what the individual is comfortable to do. Additionally, participants noted that considering the repetitive nature of the task, they might prefer some variability in the music or for it to better suit their personal taste. This reflects previous work in using musical sound for such tasks, where using self-selected music promotes better engagement [Cepeda et al., 2006, Karageorghis et al., 2008].

These findings demonstrate the potential for using the MoSEM in chronic pain rehabilitation and offer several potential avenues for future designs of MuES within chronic pain to explore further iterations of the gap-based design, the use the MoSEM within more adaptive feedback and the inclusion of more musical variety.

## 7.6. Conclusions

In this Chapter, the first of two case studies explores the use of the MoSEM to design sonification for populations with low self-efficacy. This first design explores how the MoSEM can be used within chronic pain rehabilitation to address barriers of movement past a feared boundary and the risk of setbacks caused by overdoing. To address this, the MoSEM is used to design a gap-based sonification, in which the individual is encouraged, through the use of an unstable cadence, to continue on and then encouraged to conclude the movement, through the use of a stable cadence. This design focused on the idea that the decision to continue or not should be left to the individual and that all movement should be rewarded. Through the use of musical expectancy, this design can still encourage a certain amount of movement, but not punish, i.e. through use of an alarm or unpleasant sound, if such a target is not met.

The initial study with this design demonstrates how it can be used to push past a boundary or encourage conclusion. In a study with healthy participants, it was found that participants were more likely to continue past the gap when they hear an incomplete cadence, as predicted by the MoSEM. However, once the gap had been found, people would more consistently cross and the length of the gap in which people would cross for the first time varied.

Next, musical expectancy sonifications and the gap design were explored with people with chronic pain, through a largely qualitative approach in order to gather insights on the design's potential in real life scenarios. It was found that while MuES was viewed as being useful for both informing and encouraging movement, the current implementation of the gap design was thought to cause uncertainty and hesitation when the gap was reached. In addition, it was highlighted by participants that such a system would need to be adaptive to their pain and mobility. The findings from these studies show both the potential advantages of designing sonifications with musical expectancy and also the considerations that must be made in order to maintain the balance between leveraging musical structure in sonification and the integrity of the data it is meant to represent. While musical expectancy can be a useful tool in movement sonification, it is important that such sonifications are designed with the target population to understand how best the MoSEM can be utilised to overcome their specific barriers. The next case study, in Chapter 8, explores these ideas within the context of general wellbeing.

**Contributions**

∗ Shows how a gap-based design can be used to promote conclusion or continuation movement past a target point

∗ Shows how MuES can benefit people with chronic pain

∗ Shows how the use of musical sonifications must be considered within different contexts

# 8. Case study 2: General wellbeing

**In this Chapter:**

*RQ4: How may the MoSEM be used to design MuES for populations with low self-efficacy?*

Exploring how the specific barriers people who struggle with low self-efficacy can be addressed with MoSEM

Using the MoSEM to support on-going repetitions of the squat down movement

Incorporating musical building into the MoSEM for ongoing repetitions

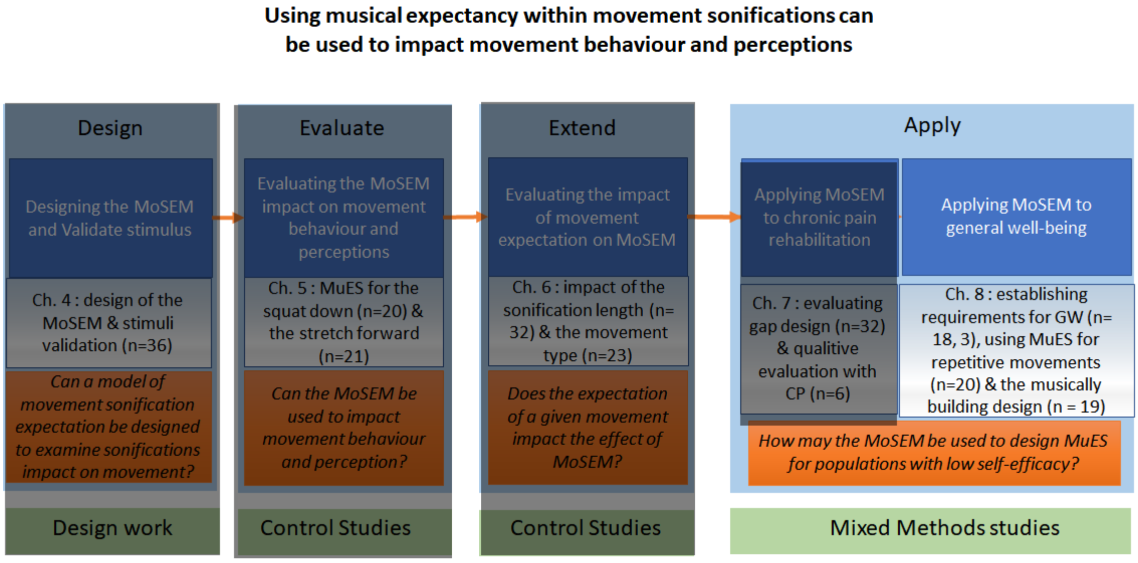



Figure 8.1: This Chapter focuses on exploring the MoSEM in the context of general well-being. First, an interview study is used to establish how MuES may address the needs of people who struggle with physical activity. Then two studies explore how MoSEM may support repetitions of a movement. The first explores MuES in comparison with a non-musical sonification of movement and no sound. The second then explores how a MuES may build in musical tension throughout an exercise to support ongoing encouragement. This work addresses the question of how MoSEM may support general wellbeing

## 8.1. Introduction

This Chapter presents the second of the two case studies which seek to better understand MuES through their application in real-populations with low self-efficacy, this time focusing on people who struggle with physical activity for general wellbeing. While within chronic pain there was already existing work to form a starting point for applying the MoSEM [Singh et al., 2016, Woby et al., 2007], this work forms a more exploratory user-centred approach. It starts with establishing some of the needs within general wellbeing which can be addressed through the MoSEM and leads to the design of a MuES which aims to encourage additional repetitions of a movement.

Through a series of interviews with people who struggle and with personal trainers, the issues faced by people who struggle and methods used to overcome these barriers are explored. These interviews showed that people who struggle need support in increasing their awareness of their body and in encouraging themselves in progressing towards goals.

While previous studies in Chapters 5 and 6 show how for closed target movements musical tension/resolution have limited impact on people's movement, people still feel a sense of motivation/achievement in their appraisal of their movement. While for this kind of movement, musical expectation may not alter people's movement directly, the sense of reward and motivation they provide can still be used to help people overcome barriers to physical activity. If not encouraging movement past a given target point, then perhaps musical tension/resolution can be used to encourage further repetitions of a closed target movement and reward the completion of a set. This design is explored in this Chapter and could be useful for people who struggle with physical activity for general wellbeing where adherence to a routine is low.

From this some initial studies explore how MuES impacts people who struggle doing repetitions of the squat down movement, comparing both stable and unstable endings as well as a non-musical sonification and no sound. However, while this study did show an increase in encouragement from the MuES compared to the other conditions, the difference in stability was not perceived, perhaps due to the repetitive nature of the movement. To explore this further, musical building was incorporated into the design of MuES to increase the musical tension as the repetitions went on. The results from these studies were used to explore potential scenarios for using MuES and potential limitations of the MoSEM.

## 8.2. General wellbeing

It is essential to healthy living that people maintain good levels of physical activity. Physical activity has a large impact on many health-related issues[Allender et al., 2007, Warburton et al., 2006, Metcalf et al., 2008]. While people cite a variety of reasons for engaging in physical activity, such as weight loss and health and wellbeing [Hoare et al., 2017], adherence to physical activity is incredibly low. There have been many previous works that explore social, economic and environmental factors that attribute to this [Giles-Corti and Donovan, 2002]. However, perhaps more important is the impact self-efficacy has on one's participation in regular physical activity [Biddle and Mutrie, 2007]

It has been discussed how Sonstroem and Morgan's model of self-efficacy may impact people's engagement in physical activity [Sonstroem and Morgan, 1989], showing how the higher one's belief in oneself, the more likely one is to continue on. In addition, other works have shown how people perceived ability might impact their continued adherence to a physical activity routine [Shieh et al., 2015].

Standage et al. explore what specific motivations are effective in secondary school physical education [Standage et al., 2003]. They assessed 328 students' motivational responses using a model of motivation to predict students' intention in taking part in extracurricular physical activity. Their model included aspects of self-determination theory, the degree of internal motivation and achievement goal theory, related to the "mastery" of a task. They found a series of social factors and the promotion of self-determined motivation to be main indicators. Frederick and Ryan demonstrate the relations of motivation to participation and mental health [Frederick and Ryan, 1993]. Across 376 adult participants, they explored interest/enjoyment, competence and body-related motives as motivating factors. The measure was taken by questionnaire and motivations for participation in physical activity were taken via a 23-item questionnaire; the level of participation was measured via a four-item questionnaire as well as questionnaires for self-esteem and depression. They found that all three motivational factors affected participation in fitness-based activity. However, only body-related motivations indicated a change in participation for sport-based activities, both interest and enjoyment were related to the number of hours spent doing the activity.

Previous works in music have found that during repetitive exertion exercise motivational music can be used to increase endurance and motivation[Karageorghis et al., 2008, Mohammadzadeh et al., 2008]. Patel and O'Kane, highlight how the ability to track repetitions through technology may be desirable for people engaging anaerobic exercise [Patel and O'Kane, 2015]. Gammage et al., show how people often use self-talk to motivate them through their movement repetitions, for instances telling themselves 'just two more reps' until they reach a specific goal [Gammage et al., 2001]. Using musical expectancy based sonification, these three aspects could be combined, providing motivation and reward through musical completion, tracking the number of repetitions through the progression of the music and motivating people toward a certain goal.

This work demonstrates a need for not only an approach that helps inform people about their movement quality, that is have they successfully completed the movement but also a need for more affirmative feedback which encourages and rewards the completion of multiple repetitions of a movement. To explore how these MuES can be used to overcome these barriers, first a better understanding of how they may manifest for people who struggle with physical activity is needed. To achieve this, an interview study was designed to get a better understanding of how these self-efficacy related issues are currently addressed for people who struggle with physical activity.

## 8.3. Design requirements for musical expectancy sonification for general wellbeing

### 8.3.1. Introduction

To better explore how to design MuES to overcome these psychological barriers to physical activity, a series of interviews with both people who struggle to maintain regular physical activity as well as personal trainers who regularly work with people who struggle was conducted. The goal of these interview studies was to develop a better understanding of how people with low self-efficacy currently struggle with physical activity, the aspects are most important for overcoming these barriers and how they are currently addressed by trainers who specialise in people who are trying to get started with a physical activity routine. The aim of this study was to explore the specific opportunities for using MoSEM within a general wellbeing context. While many of the underlying motivators and detriments for people who struggle with physical activity have been explored [Biddle and Mutrie, 2007, Shieh et al., 2015], specific barriers which may overcome through the use of MuES have yet to be identified.

From this, a series of design requirements can be developed to explore how the MoSEM can be applied to general wellbeing to support people with low self-efficacy.

### 8.3.2. Participants

Three personal trainers were recruited from local gyms, as well as 20 healthy participants who identified themselves as struggling with physical activity, who then participated in Study 2 presented in Section5.3. The personal trainers (PT) had been training for 10 months, 3.5 years and 6 years. All were fully qualified personal trainers with experience working with beginners. Of the people who struggle with physical activity (PwS), 15 were female and 5 male (age=20-62 (mean = 26.5). 13 participants reported in engaging in zero hours of physical activity per week, five engaged under an hour, one reported between one to three hours and one between three and seven.

### 8.3.3. Data collection and analysis

The interviews were semi-structured to ensure that the same areas were covered while allowing for the exploration of new areas that arose during the interview process. They lasted for approximately 45 minutes for the PT and 10 minutes for PwS. For the PTs, interviews covered the trainer's background, the issues people face in the gym and how these are addressed. PwS were asked questions surrounding the areas they struggle with, times they have tried to start a new exercise routine, why they stopped and any technology they had used in the past. Two PT interviews were conducted at the gym and one in a meeting room at UCL, while all interviews with PwS were done on UCL premise. All PT interviews were completed before the PwS, and the PwS were recruited as part of the squat study presented in Chapter 5 which took place after the interviews.

Data was collected through audio recording and written notes. Later, all interviews were transcribed in *F4 Transkript*. The data was not transcribed verbatim, with false starts and filler words omitted from the transcript, the focus of the transcription was maintaining full participant responses while making the transcript understandable for coding the data. After familiarisation with the datasets, they were iteratively analysed in *F4 Analyse*, first using an inductive selective coding scheme [Braun and Clarke, 2013] and then iterating on those to generate themes focusing on self-efficacy related issues surrounding physical activity and how they may be overcome. PT and PwS were analysed separately, and the themes then discussed and compared in relation to previous work in designing technology to support physical activity.

### 8.3.4. Personal Trainers

#### Motivations

Trainers mentioned a variety of motivations for beginners starting an exercise routine such as weight-loss, building muscle and fitness.

> *"Weight loss, most frequent. GP recommend or people unhappy with the way they look. The main reason is weight loss fitness, and wellbeing is secondary" (PT1)*

However, one trainer pointed out that the kind of motivation people bring to sessions, impacts whether or not they will stick out their routine.

> *And sometimes you have the ones who are a bit lazy, and they sort of complain a lot. I probably just have to remind them why they are there. The ones that leave, I don't know if they are keeping up with their exercise or not, but what I try to promote is not just like a diet or something you don't enjoy, I try to promote something that is obtainable so like a lifestyle" (PT2)*

#### Difficulties

In terms of difficulties faced, that lead to people either giving up or struggling to maintain physical activity trainers highlighted a mixture of physical barriers as well as lack of knowledge and awareness. In terms of physical barriers, trainers pointed to a lack of flexibility leading to difficulty in completing some movements. Additionally, poor technique is a major concern for trainers whose aim to get people moving safely.

> *"I've got to find out what's causing this stuff, is it tightness, is it weakness, is it technique and they just don't know how to do the movement. It's going to be one of those three." (P3)*

As well as physical issues and learning new movements, trainers point out that these problems stem from lack of awareness or knowledge of the body. Whether it be through lack of knowledge of a specific movement or poor proprioception, trainers point to this being their priority with new trainees, in order to have safe movements and avoid injury.

> *"in any exercise you do, my job is firstly to make sure what they're doing is safe" (PT2)*

In terms of specific movements, all three trainers pointed towards the squat movement and related movements, such as the deadlift, being one that beginners struggle with. Whether due to flexibility, poor posture or general lack of knowledge of the movement, trainers are careful to correct the movement to ensure a safe movement to avoid either people falling or injuries in the back or knee. Trainers also identify some external factors which impact people dropping out such as moving, illness or financial reasons, as shown in previous work in this area [Giles-Corti and Donovan, 2002].

#### SOLUTIONS

Trainers also highlighted different strategies they use to motivate people to continue on with their exercise routine. The main solutions cover correcting movement through feedback and giving efficient workouts, and encouragement through setting goals, building up and social motivators. By building on movements people struggle with, training can help improve posture and push for a safe and optimal technique. Occasionally, they would break movements into simpler versions to ensure the fundamentals are understood.

> *"Optimal movement is most important, push for the one good movement, but five not so good movements to get there" (PT1)*

Additionally, trainers spoke about getting people to use efficient exercise in their movement, as a way to improve performance and progression.

> *"they come to the gym, they sit on the treadmill or bike for an hour and go home. Now I find that's not going to get you results at all and it's really boring. If you are going to a gym and you are not enjoying it, and nothing's happening no one's going to come." (PT3)*

In addition to improving technique, trainers also outlined methods they used to keep up motivation and ensure people maintained their exercise routine. As trainers cited lack of motivation or laziness as key factors for dropping out, maintaining that motivation is key to keeping people engaged in physical activity. Social motivators were used to get people to return to the gym, whether that be through introducing them to people at the gym and encourage participating in classes (PT1) or through encouraging groups to come together (P3). By mixing the motivation to go to the gym with a social atmosphere, trainers hope to increase the regularity people come to the gym, which would allow for greater progress.

During training, one of the most common strategies trainers used was goal setting, as *"Without goals people lose motivation" (PT1)*. Depending on people's overall goals (their motivation for coming to the gym) trainers would work to set intermediate and measurable goals. Trainers often would get people to set their own goals, in order to highlight achievement and progress. However, this varies from individual based on not only their goals but also what motivates them. The specifics of what the trainer does with the individual based on their level, needs and personality.

> *"I think the reward comes in the work they do themselves. So, when they are able to form a pull or do dips, which requires quite a lot of strength and dealing with their own body weight (. . .) most of it probably comes for what*

*they do themselves, and the fact they can see their own progression is what keeps them coming back." (PT2)*

This leads to the idea of trainers slowly building up exercises, increasing the difficulty once the fundamentals are understood and the movement is safe.

#### 8.3.5. People who struggle with Physical activity

For the people who struggle to maintain regular activity, 16/17 interviewees report currently engaging in no physical activity, with one interviewee reporting they do *"a little bit when I am free. Maybe just yoga on the weekend and sometimes I just go for mild exercise like jogging." (P6)*. However, of those 16 people, 15 reported having previously tried to engage in regular physical activity including: running (6), sports activities (6), gym-based exercise (6) swimming (4), yoga(3), walking(4), cycling(3), and at home exercises (2). One participant report having never attempted any regular physical activity.

**Motivations**

People reported two main reasons for their motivation: recreation or for a healthy lifestyle. Those who report recreation-based motivations reported physical activity as a social activity or that they wanted to try something new.

*"oh it was generally just a social activity, that's why I went" (PwS15)*

However, most commonly people stated health reasons for them having originally taken up physical activity (13), primarily to do with weight (weight loss (8), weight gain (1). Some interviewees additionally stated just healthy living and keeping fit as their motivations. The motivations mirror findings in previous works of why people take up an exercise routine [Hoare et al., 2017].

*"I wanted to live a healthy and balanced lifestyle" (PwS7)*

#### Difficulties

In terms of barriers faced when trying to engage in regular physical activity, people gave a series of environmental, physical and social concerns. In terms of environmental reasons people often cited time pressure (12) as their reasoning for discontinuing their physical activity. As well as moving away, illness or the cost.

> *"I was always hard-pressed for time, which why I think is the main reason I didn't find time to fit my gym slot into my term schedule" (PwS12)*

Interviewees also gave a series of physical concerns related to why they discontinued their physical activity. Some mentioned being unsure of technique or if they were performing exercises properly, while many (6) mentioned the physical discomfort that came from exercise drove them to stop. This highlights the impact of negative feelings on building one's self-efficacy [Bandura, 2000]

> *"then also just the pain. I don't like pain" (PwS10)*

However, only four people said they had ever considered the safety of their movement, whereas 11 people said they had never considered the safety of their movement. Finally, there were some social/emotional factors mentioned such as feeling embarrassed performing exercises in front of people or simply not finding enjoyment in exercising. Several people (9) also self-identified themselves as being lazy when giving reasons for why they gave up exercise.

#### Solutions

People reported two main methods for supporting their physical activity, either to support motivation or to track progress. Interviewees had a few different methods they would use to try and motivate themselves to engage in physical activity. To help support them starting an activity they would schedule when they were going to do their physical activity, and some would use food-based rewards for having completed their physical activity, as seen in previous works [Khot et al., 2015]. However, one participant mentioned they would avoid food-based rewards as it would negate the benefits of their exercise.

> *"I know myself, if I give myself a reward it is going to be a very big reward which is going to counteract me going jogging" (PwS17)*

In addition, several people mentioned using music when they were engaged in physical activity to motivate them during exercise.

> *"it [music] just keeps you going" (PwS3)*

In terms of tracking, participants used a variety of methods for tracking their progress either through making a mental record, pen and paper, activity tracking or timing. In addition, people cited seeing progress as being motivational in itself.

> *"it [seeing progress] gives me a sense of accomplishment. Yes, it's a motivation" (PwS6)*

Several people (10) said if they had seen more progress towards their goals, they might have been more likely to continue.

> *"if I had more progress I would have kept going" (PwS7)*

#### 8.3.6. Discussion

From the two sets of interviews, several similarities and differences in people's focus can be seen, which highlights some of the needs and requirements of technology to support wellbeing. Both PTand PwS gave similar motivations for starting a physical activity routine, with weight loss and health concerns being the main factors. This matches previous work in their area of physical activity [Allender et al., 2007] in addition to environmental and social factors mentioned as reasons from discontinuing [Giles-Corti and Donovan, 2002].

Further, both groups cited lack of motivation and laziness as the main psychological reason for people dropping out; this follows what is seen in work that shows how people with higher self-efficacy and internal motivation are more likely to continue on in the face of obstacles[Markland, 1999, Shieh et al., 2015]. Trainers also mention goal-setting and feedback as key solutions to overcoming these barriers, which have been successful in previous uses of technology for physical activity [Munson and Consolvo, 2012]. As well as PwS highlighting the benefit of music [Karageorghis et al., 2008] and rewards [Khot et al., 2015, Patel et al., 2016] for motivating physical activity.

However, some of the key differences in the responses were the emphasis of trainers on having safe and efficient technique, whereas for PwS neither was considered as important as motivation and seeing progress. Safe and efficient movements are important not only to avoid injury but also to ensure progress is made towards goals; many PwS reported not seeing enough progress. However, the PwS who primarily did activities without an external trainer, lacked both the feedback on their form and technique, as well as the encouragement from having the trainer there to support them building towards their goals. This dual need reflects that which is seen in the self-efficacy literature around giving both performance feedback, on what one is doing, and affirmational feedback on what one has achieved being key for promoting increased self-efficacy and hence in the continuation of exercise [Schunk, 1995].

Through these interviews, the squat down movement can also be identified as a movement in which beginners often struggle with, as well as PwS use of music to help encourage them during physical activity. The results of this study point to some specific issues which can be addressed by MuES to support ongoing physical activity when a trainer is not available or financially viable. The two groups highlight the dual needs that people struggling with physical activity face that need to be addressed: learning safe and efficient technique and the need for encouragement to continue on towards their goals. Previous works have demonstrated how technology can be used to track safe and proper technique [O'Reilly et al., 2015, Whelan et al., 2015], to inform and optimise movement [Hale et al., , Yang and Hunt, 2014] and for goal setting and tracking [Munson and Consolvo, 2012]. However, there is little exploration of how it can be combined with the encouragement provided by music to keep going [Karageorghis et al., 2008]. This leads to the two ways in which MuES can be designed to support this kind of physical activity:

1. **Inform on technique** PTs and PwS highlight the need for teaching proper technique, which can be difficult for beginners with limited awareness of their movement. Through informing on the movement itself people can also track and better understand their progress.

2. **Encourage toward goals** In addition to informing on movement, it is necessary for people to be encouraged to continue on. The key factor that both PTs and PwS highlighted was the need to motivate progression towards goals as a way to encourage continuation.

## 8.4. Musical expectancy sonification for a set of squats: initial experimentation

### 8.4.1. Introduction

Based on the findings from the previous qualitative study with trainers and people who struggle with physical activity, the impact MuES has on continued encouragement towards goals in the squat down movement is explored. In this study, stable and unstable endings are compared to a non-musical sonification and no sound, to explore how MuES may facilitate continued motivation and awareness of technique. Based on the previous findings of the MuES and previous findings in using music for exertion exercise [Mohammadzadeh et al., 2008], it is hypothesised:

**H1**: MuES will encourage more movement than having a non-musical sonification or no sound;

**H2**: MuES will be reported more rewarding and motivating than having a non-musical sonification or no sound but will be found less exerting;

**H3**: Unstable endings will encourage more than stable endings whereas stable endings will be more rewarding.

### 8.4.2. Participants

A total of 20 paid participants were recruited for the study (age=20-62 (mean = 26.5), 15 female and 5 male). Participants were recruited through the UCL psychology subject pool and had not participated in any other studies in this thesis. All participants reported that they did consider themselves as "engaging in regular physical activity" in pre-screening. 12 participants reported an average of zero hours per week, five reported zero to one hour per week, one participant reported one to three and one hours per week reported three to seven hours per week. Participants reported activities such as walking or jogging and the participant who reported the most activity (three to seven hours) reported visiting a gym to use the exercise bike.

18/20 participants were found to be below the mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index in the general population (81.58) (mean =66.75, range = 50-99) [Müllensiefen et al., 2014]. Therefore, it is assumed the effects that may be observed are not due to musical training.

### 8.4.3. Materials

The squat movement was tracked as in Study 2 in Section 5.3 and using the same stability stimulus, though only the full-length sonifications. Four sonification conditions are defined: two creating expectations of musical ending (Stable, Unstable) and two that create no musical ending expectation (noise as sound and no-sound condition). These are described below:

1. Stable and Unstable sonifications: as in the previous squat study in Chapter 5

2. Noise or also defined hereafter as non-musical sonification: white-noise was used so as to convey no musical expectation. The white noise sounded during the movement and reaching the target point was signified by the noise stopping. This sonification was used to compare these musical sonifications to one that is purely informative; as such participants would still know when the target point was reached, but there would be no prior musical expectation of its ending.

3. No-sound condition (NS): this condition was considered to compare these sounds to how a squat would be performed unaided.

### 8.4.4. Experimental design

The study followed a randomised within-subject design using the four independent variables described above. The study's dependent variables were by measured three behavioural and seven self-reported measures. In terms of behavioural data, the average amount of movement beyond the target point **(Additional Squat)** and the average time taken between the target point and the maximum amount of movement **(Time of Return)** before returning were measured using the smartphone device placed on the upper leg of the participants. In addition, the number of repetitions was measured, to explore how the different sound encouraged participants to do more squats. For **self-reported measures**, perceived motivation to continue after the target point, motivation to continue the set and perceived reward at the target point was taken with 7-point Likert-type response items. The perceived angle of the final squat was reported in degrees, 0 degrees being standing and 90 degrees being the upper leg is parallel to the ground. Exertion was measured using the Borg exertion scale [Borg, 1998]. For the three sound conditions participants were asked how informative the sound was and for the two musical conditions, perceived stability was also measured.

### 8.4.5. Experimental Procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the leg using a leg band and calibrated using a neutral position (upright) and a maximum comfortable squat as shown in Chapter 5. For each condition participants were asked to set a goal of how many squats they would aim to do. This was done so as to give each participant a practical and safe goal to aim for; however, they were informed that they could stop the set before reaching the goal if the wished and to use the goal as a ballpark number to aim toward.

They were instructed to squat down at a steady pace allowing each sound to play and to use the music/sound produced to inform them when they had reached the target point (i.e., the end of the feedback). In the no sound condition they were told to go until they felt they had reached the target point. After each set of squats, a questionnaire was used to collect the self-report measures. Finally, after all the conditions were complete, they filled out the GSMI questionnaire.

| | Stable | Unstable | Non-stable | No sound |
|---|---|---|---|---|
| **Stability** | 2.5(1-5) | 2(1-7) | n/a | n/a |
| **Informative** | 4.5(3-7) | 5(1-7) | 5(1-7) | n/a |
| **Motivation to continue movement** | 5(1-7) | 5.5(1-7) | 4(1-7) | 2(1-4) |
| **Motivation to continue set** | 4(1-7) | 4(1-7) | 4(1-7) | 4(1-6) |
| **Reward** | 5(1-7) | 5.5(1-7) | 5(2-7) | 4(1-7) |
| **Angle** | 72.5(40-100) | 75(45-95) | 80(35-95) | 77.5(35-105) |

Table 8.1: Median (range) for self-report data for stable/unstable as well as the non-musical sonification and no sound conditions.

### 8.4.6. Results

An overview of the behavioural can be found in Figure 8.2 and self-report data in Table 8.1 Behavioural measures met assumptions of normality under the Shapiro-Wilk test

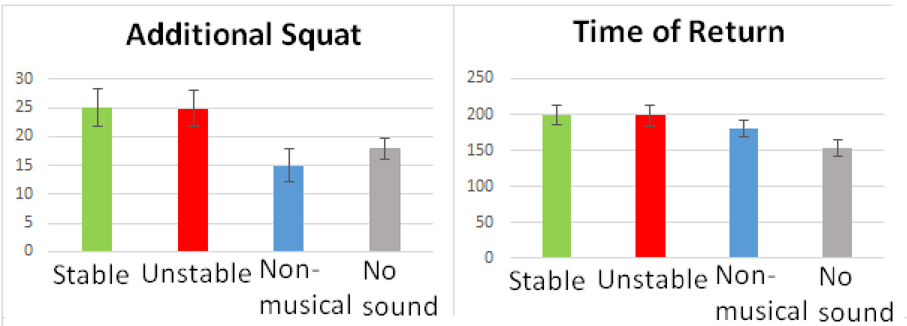



Figure 8.2: Mean (SE) for behavioural measures of additional movement and time of return for stable, unstable, non-stability and no sound.

and were submitted to a repeated measures ANOVA to analyse the differences between the different conditions.

**Additional Squat:** Significant effects were found for the amount of squat past the target point ($F(3,48) = 5.36, p = .003, \chi^2 = .251$). Participants moved significantly more in both musical conditions than in the non-musical conditions: significant differences were found between stable and both non-musical sonification and no sound (*p*=.022 & *p*=.047), as well as between unstable and both non-musical sonification and no sound

($p$=.014 & $p$=.029). *Participants moved more in musical conditions compared to no musical conditions.*

However, no differences were found between the two expectancy conditions (i.e., ST vs UN) and between the two non-expectancy conditions (NM vs NS).

**Time of return:** Significant effects were found across conditions ($F(3,48) = 10.23, p < .001, \chi^2 = .390$). Significant differences were found between stable and no sound ($p$=.004) as well as between unstable and both non-musical sonification ($p$=.005) and no sound ($p < .001$), as well as between non-musical sonification and no sound($p$= .018) with people taking longer to start the return in the NM condition. *People took longer to start the return to a standing position with the cadence sonifications. However, while the stable condition had an effect only compared to the no-sound condition, the unstable ending did have an effect with respect to noise.*

This suggests that the musicality of the sonification encourage movement in itself beyond the target point in comparison to no-sound or noise. Still, it appears that even with simple noise feedback people show a slower time of return.

**Self-reported measures:** A series of Friedman tests found significant differences for: perceived motivation to continue the set ($\chi^2$ (3) = 11.354, $p$ = .010) and perceived reward ($\chi^2$ (3) = 22.288, $p$ < .001). Subsequent Wilcoxon tests (the adjusted significance level was at $p$ = 0.008) showed that:

- For perceived motivation to continue the set: unstable and no sound ($Z$ = -2.815, $p$ = .005)
- For perceived reward both stable and no sound ($Z$ = -3.35, $p$ = .001) as well as unstable and no sound ($Z$ = -3.42, $p$ = .001).

It should be noted that the two musical conditions (ST and UN) were not found to be significantly different in terms of perceived stability, ($Z$= -.144, $p$=.886).

### 8.4.7. Discussion

The results show some effects in movement behaviour when comparing musical cadences with non-musical feedback/no sound at all. In fact, less movement past the target point and a faster return were found for both the non-musical sonifications and no sound conditions. However, no differences were found between the two levels of stability in terms of behaviour, contrary to **H3**.

For the self-reported measures, there was also a limited impact of the different stabilities. However, the unstable cadence was found to motivate participants to do more squats than the no-sound condition. In addition, both musical sonifications were found more rewarding than the no-sound condition. This aligns with previous studies on music for physical activity [Karageorghis et al., 2008] and previous results for MuES.

The shorter movement and quicker return time found in the non-musical sonification and no sound conditions suggest that upon reaching the target point participants began standing back up from the squat. This may suggest that the stopping point (either because of abrupt stopping of the sound or because of proprioceptive feedback) is much clearer in these conditions, leading to an immediate return. Conversely, in the musical conditions this ending is perhaps less clear cut, meaning the return takes longer to come about and while this does lead to more movement, it also gives a smoother turning point. The stability of both stable and unstable condition was quite low. Indeed, people reported being more motivated to continue the movement beyond the target point in the musical condition rather than in the non-expectation.

What is not so clear is why people did not perceive differences in stability levels between stable and unstable conditions. This is reminiscent of the effect of repetition in musical listening, where hearing the same musical stimuli repeatedly leads to an increased acceptance of the sound because the prediction of the endpoint becomes easier, i.e. making it feel more stable [Huron, 2006]. It may be related to the fact that as the participants executed a sequence of squats rather than just one, the music melody was perceived as continuing from one squat to the other leading to a smoother transition between squats. This is supported by the fact that the unstable ending was perceived as most motivating to continue the set, participants being motivated by the perceived continuation of the music. As noted above, there was a difference in the way participants perceived the sonifications when doing a single squat versus the full set. Most notably it seems the difference in the two stabilities was not perceived by participants during the sets of squats. This finding disagrees with previous research on how people perceive harmonic stability [Bigand, 1997, Sears et al., 2014]. However, in the single squat study (Study 2 in Section 5.3), the difference in stability was perceived.

While this may come from the impact of the non-musical stimulus affecting participants' perception of the musical sonifications, it could be that the repetition of the movement impacted how the stability of the music was heard; musically this is understandable as the phrase would no longer be heard in isolation but would be heard as a single longer piece of music comprising phrases in a sequence. This may be also what caused the unstable conditions in Study 2 in Section 5.3 to have the greatest impact on motivation to continue the set, due to the feeling of musical continuation.

In addition, while no differences were identified between conditions in terms of information carried (see Table 8.1), both musical conditions had a greater impact on the motivation and reward, as hypothesised in **H2**. These results show how these musical sonifications can motivate people during physical activity and how musical sonification can be seen as a reward for completed music. From these results, we can see the impact of musical expectancy when compared to purely informative sonification. However, further work is needed to explore how MuES can be leveraged to support repetitive movements. As stated above, the repetitive nature of the movement used in this study may have altered people's perception of the ending of the sonification and therefore the perceived stability. As demonstrated in the first section of this thesis, musical expectancy in movement sonification can be used to encourage continued movement and reward completed movement. Though the impact on movement behaviour is limited for closed movements such as the squat down, MuES can still be used to provide a sense of motivation and reward. By applying our MoSEM to a repeated movement, the potential for ongoing support can be seen. As shown in figure 8.3, the sonification is driven by the movement as seen in previous studies, but when considering each movement as one repetition, the incomplete cadence no longer motivates the continued movement past the target point but instead encourages the next repetition of the movement. This is reminiscent to the initial design for musical expectancy presented in Chapter 4 where the expectation of each given chord invites the continuation of the movement. In this case however, each musical sequence creates an expectation for the next repetition of the movement. Considering each repetition as individual musical phrases in order to create the on-going encouragement through the repetitions, this design focuses on the idea of musical building, to increase the tension throughout the repetitions. By adding musical building, the sonification can help build not only a maintained feeling of instability, but it can use the increased musical tension to increase motivation throughout the set further. Through using this change in the musical progression, the musical tension increases and as the set continues and gets harder, the motivation to continue on increases.

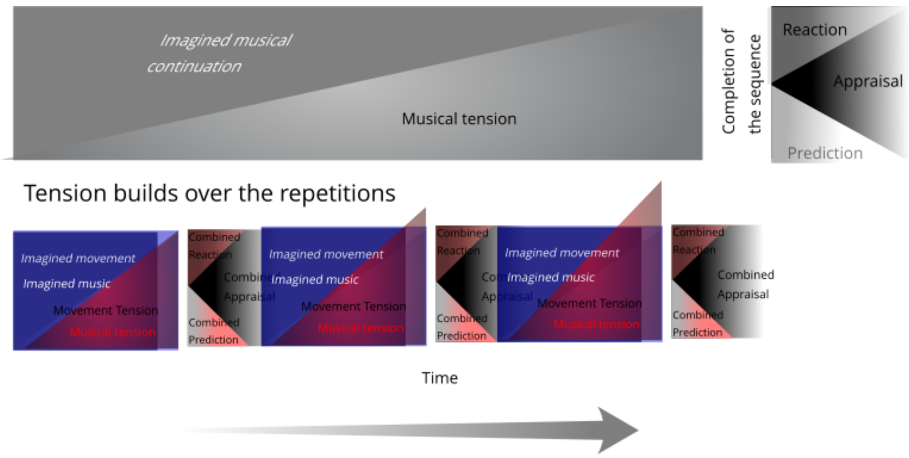



Figure 8.3: Repetition design using the MoSEM, after each repetition of the squat movement. The endings at the top of the squat increases in tension to create an increase in the movement expectation and hence a greater feeling of encouragement to the end and eventual reward at the end of the set. This design uses the change in perception of the movement to encourage the continuation of the set and to announce progress, where the expectancy is linked to the continuation past a target but into continuing the next repetition

## 8.5. Musical expectancy sonification for a set of squats: building musical expectation

### 8.5.1. Introduction

Previous studies have shown how musically informed sonification can be used to support both motivation and increase the feeling of reward by MuES. However, these works explore simple single movements while in practice most exercises for general wellbeing are done in sets of repetitions. While reaching the appropriate depth in a squat is one of the main aspects people struggle within the squat movement, study 8.4 found that just providing sound feedback was enough to encourage participants to reach their maximum depth. Based on the findings showing how musical expectancy can be used for closed target movements, this study investigates placing the cadence point not at the bottom of the squat, but at the top of the squat to encourage the continuation of the set as shown in 8.3. This study again aims for a mixed methods approach, to both explore the impact of MuES on movement behaviour and perceptions as well as a more qualitative evaluation of how they are experienced and what lessons can be learned for designing MuES. Based on the previous findings for MuES and the introduction of the increase in tension through musical building it is hypothesised that:

**H1**: Unstable cadences will give more motivation to continue the set of squats, due to a desire to continue to musical conclusion;

**H2**: Stable target points will encourage a longer time at the top of the squat, due to the feeling of "home" from the stable sound [Huron, 2006];

**H3**: The Musically building unstable sonifications will encourage additional squats as the building tension will increase the impact of the desire to continue;

### 8.5.2. Participants

A total of 19 healthy paid participants who struggle with physical activity were recruited for the study (age=19-67, 13 female and 6 male). Participants were recruited through the UCL psychology subject pool and had not participated in any other studies in this thesis. 14 out 19 participants reported engaging in no regular physical activity, three reported engaging in some mild physical activity (1-3 hours a week and 3-7 hours a week), and two reported engaging in some moderate physical activity (under 1 hour per week and 1-3 hours per week).

15/19 participants were found to be below the mean score for General Musical Sophistication subscale of the Goldsmith musical sophistication index in the general population (81.58) (mean =71.26, range = 48-111) [Müllensiefen et al., 2014], therefore we assume the effects that may be observed are not due to musical training.

### 8.5.3. Materials

The experiment used the same smartphone based as in Study 2 in Section 5.3, as presented in Chapter 3. Each squat is registered by the app, and the sequence changes accordingly. Each sequence was designed so that the chord at the top of the squat was changed for each squat (depending on the condition) ending after the fourth squat with a stable ending. This was done to lead to a heightened sense of reward when a greater expectation was created, i.e. in unstable and building conditions.

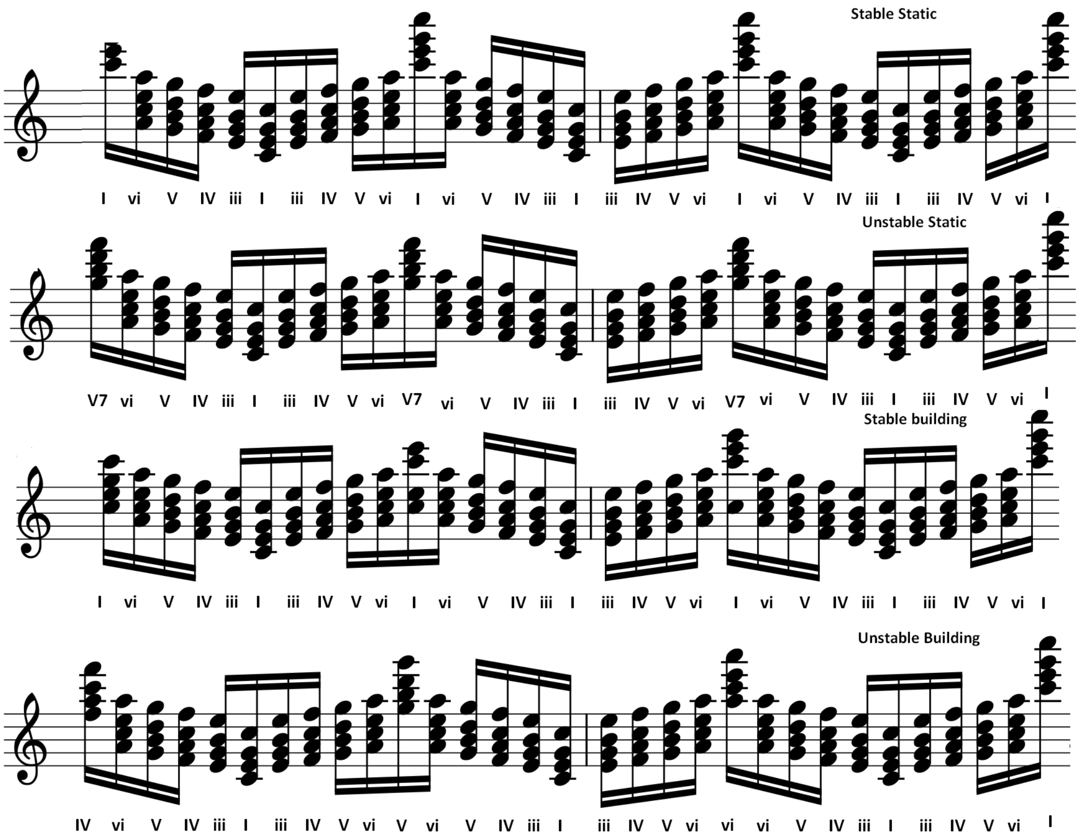



Figure 8.4: Stimuli used for each condition, for the stable and unstable static condition, the same cadence is always the same at the top of the squat either stable or unstable. The musical building conditions the sequence changes after each squat. Either increasing in instability, with IV, V, ii chords or in the stable building condition with the use of tonic chord inversion was used to create a sense of building while maintaining stability. After the fourth repetition, all the stimuli end on a stable chord. It should be noted that while the score shows the use of 16th notes, this is simply for the display of the stimulus and the participant's movement controlled the rhythm and pace of the notes.

Figure 8.4 shows that stable conditions had a musical resolution at the top of the squat, whereas unstable conditions had musical tensions. Static conditions always had the same chord at the top, while for building conditions the chord changed each squat, ascending in pitch. For unstable building, the chords progressed from IV, V, ii and for stable building, inversions of the tonic were used to create the tension of musical progression while remaining harmonically stable. After three repetitions, all conditions ended in a stable chord.

### 8.5.4. Experimental design

A randomised within-subjects design was used for the four trials. There were two independent variables: stability (stable/unstable), musical building (building/static).

A series of behavioural and self-report measures were used for dependent variables to investigate the effect of the different stimulus. For behavioural measures, both the behaviour at the top of the squat and the overall movement was measured. For the top of the squat the amount of movement past the final chord and the time taken to reach the maximum were measured. Additionally, the number of repetitions and the overall time taken per squat) were measured to assess the impact on the overall performance of the movement. This was measured by diving the time taken between the first and last squat, by the total number of squats performed.

In terms of self-reported measures, perceived stability at the end of the set, perceived overall stability, perceived motivation for each squat, perceived motivation to continue the set, perceived amount of reward felt at the end of the set and the perceived quality of the squat were all measured using a 7-point Likert scale taken after each condition. Additionally, participants were asked to rate whether they felt, light/heavy, quick/slow, strong/weak and hunched/straight on a 7-point Likert scale. The Borg exertion scale was used to measure perceived exertion for each condition [Borg, 1998]. A measurement for self-efficacy was based on that of Bandura ( see figure 8.5 [Bandura, 2006]) and affect was measured using the Self-Assessment Manikin (SAM) [Bradley and Lang, 1994].

In addition, qualitative responses were collected from participants after each condition about how they felt about the sound, how they felt it impacted their movement and how it might be useful for engaging in physical activity.

Participants used the General musical sophistication subscale of the Gold-MSI to assess their musical experience, to establish that music experience was not a factor in how much perceived stability's effect on movement.

### 8.5.5. Experimental procedure

After an initial introduction and demonstration of the device, the smartphone was placed on the participant's leg and calibrated between their neutral position (upright) and a maximum squat as in previous squat studies. Participants were instructed to squat at a steady pace allowing each chord to sound so that the feedback could be heard.

If you were asked to do a certain number of squats **RIGHT NOW**, how certain are you that you complete each set lift described below?

Rate your degree of confidence by recording a number from 0 to 100 using the scale given below. You can write any number from 0 to 100 (e.g. 42).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

| | | |
|---|---|---|
| **Cannot do at all** | **Moderately can do** | **Highly certain can do** |

| Squats | Confidence (0-100) |
|---|---|
| A set of 5 squats | |
| A set of 10 squats | |
| A set of 15 squats | |
| A set of 20 squats | |
| A set of 30 squats | |
| A set of 50 squats | |
| A set of 80 squats | |
| A set of 100 squats | |

Figure 8.5: Perceived self-efficacy after each condition was measured using this scale based on guidelines from Bandura.

They were told to use the music produced to inform them about their movement and when they had reached the bottom and top of the squat. The number of squats done was left up to the participants, but they were asked to make their sets a multiple of four (so as to end the set on the stable ending). After each set, they were asked to fill in the questionnaires for the self-reported measures. Finally, after all the conditions were complete, they filled out the GMSI questionnaire.

### 8.5.6. Results

Descriptive statistics for all measures are summarised in Figures 8.6 and 8.7 and Table 8.2.

The behavioural measures met assumptions of normality under the Shapiro-Wilk test and were submitted to repeated measures analysis of variance (ANOVA) with stability and building as within-subjects factors, followed by Bonferroni-corrected pairwise comparisons.

| | Stable No building | Unstable No building | Stable building | Unstable building |
|---|---|---|---|---|
| **Stability at the end** | 2(1,6) | 2(1,7) | 2(1,6) | 2(1,7) |
| **Stability during** | 2(1,6) | 3(1,7) | 2(1,6) | 4(1,7) |
| **Motivation to continue set** | 5(2,7) | 6(3,7) | 6(3,7) | 6(3,7) |
| **Motivation past target** | 5(1,7) | 6(4,7) | 6(2,7) | 6(2,7) |
| **Informativeness** | 6(3,7) | 5(1,7) | 6(2,7) | 5(2,7) |
| **Reward** | 4(1,7) | 4(1,7) | 4(1,7) | 5(2,7) |
| **Squat quality** | 4(1,7) | 4(2,7) | 4(3,6) | 5(2,7) |
| **Exertion** | 12(0,17) | 11(7,15) | 12(0,17) | 11(7,17) |
| **Pace** | 4(1,7) | 4(1,6) | 3(2,6) | 3(2,7) |
| **Heaviness** | 4(1,6) | 2(1,7) | 4(2,7) | 4(2,6) |
| **Strength** | 5(3,6) | 5(2,6) | 5(3,6) | 5(3,7) |
| **Posture** | 5(3,6) | 5(2,6) | 5(1,6) | 5(3,7) |
| **Positive Affect** | 6(4,8) | 7(3,9) | 7(4,9) | 7(4,9) |
| **Arousal** | 5(2,7) | 6(2,8) | 5(2,8) | 5(2,9) |
| **Dominance** | 5(4,9) | 6(4,9) | 5(5,8) | 5(4,9) |
| **Self-efficacy (mean)** | 55(32.5,79.75) | 61.875(30,86.5) | 56.25(32.5,93.75) | 53.125(30,83.125) |

Table 8.2: Median (range) for self-report data for stable/unstable and static/building conditions

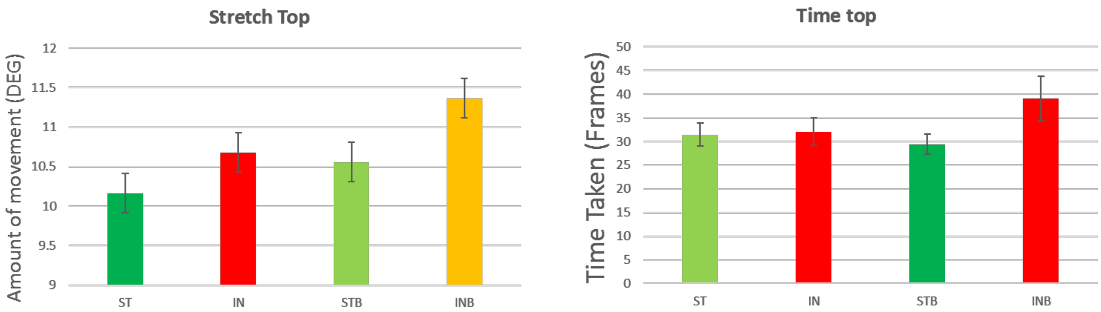



Figure 8.6: Mean (SE) for behavioural measures of additional movement and time of return during the different stabilities, stable and unstable (ST/IN) and musical building(STB/IN)

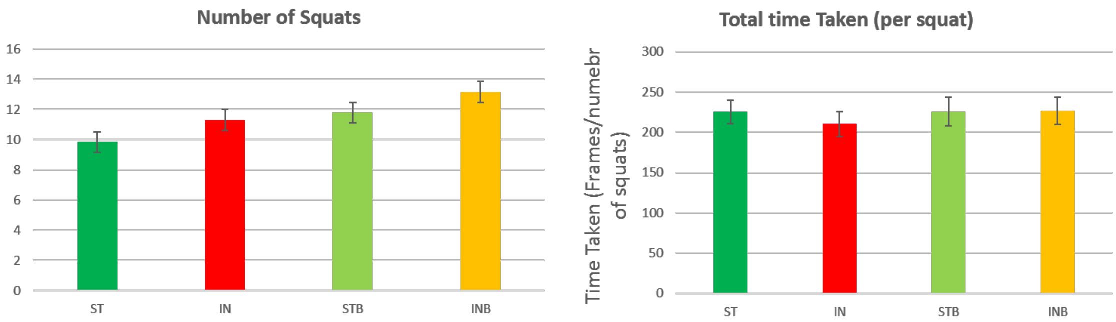



Figure 8.7: Mean (SE) for behavioural measures of the number of reps and the time taken per squat during the different stabilities, stable and unstable (ST/IN) and musical building(STB/IN)

No significant differences were found for either the amount of movement, the time taken, in the number of squats or in the overall time taken per squat. However, the interaction between musical building and stability for the time taken at the top of the squat was significant ($F(1,18) = 4.48, p = .048, \chi^2 = .199$). Follow up T-tests were not significant, though trends show participants took longer to return at the top of the squat in the unstable building condition compared to the stable building condition, (t = -2.005, p = 0.031), but less time in the unstable versus the stable, (t = 1.037, p = 0.096). *Participants took longer at the top of the squat in at the top of the squat during the unstable building condition compared to the stable building, but took less time at the top of the squat in the unstable static condition compared to the stable static*

**Self-reported measures:** Self-reported data were analysed with Friedman tests, followed by Bonferroni-corrected Wilcoxon signed rank tests. A series of Friedman tests found significant differences for: perceived lightness ($\chi^2(3) = 12.795$, $p = .005$). No other measures were found to be significant. Wilcoxon tests showed that:

- For musically building conditions participants report feeling lighter compared to unstable static vs unstable building (Z = -2.743, p = .006) *People felt lighter for unstable static compared to unstable building.*

### 8.5.7. Qualitive results

After each condition, participants were asked a set of open questions surround their experience of the sound and its impact on their movement. They were asked to describe any differences they felt between the sound and how they think it either benefited or negatively impacted them doing the squats. Responses were gathered through written notes by the experimenter which were later transcribed from paper form into *F4 Analyse*, where they were then organised by participant and sound condition. After familiarisation with the dataset and the generation of potential themes, an inductive and complete coding of responses was completed [Braun and Clarke, 2013]. From these codes themes were generated and reviewed and finally organised into themes relating to the differences between the sound designs and general comments about the use of musical sonification. These themes are presented below and then discussed in relation to both quantitive measures and related literature.

#### Impact of MuES designs

Participants mentioned having a greater feeling of completion when reaching a stable cadence. Some also felt the changes in the musical building sonification made the final stable cadence feel more complete than in other conditions. People also felt motivated to keep going by the incomplete cadences because they wanted to hear the continuation of the music, which pushed them to continue on and to do more squats. However, some participants disliked the feeling of incompletion because it sounded unpleasant, which they viewed as not encouraging.

In addition to the feeling of completion/incompletion changing people perceptions of the movement, people also mentioned changes due to the musical building. As mentioned above, some people felt the musical building led to a greater sense of completion in the final cadence, while others enjoyed the musical variation, and some mentioned changing the way they moved (either more movement or slower) to hear more of the music. However, several participants (7) mentioned the changes in the sound were off-putting, making them feel as if they had performed the movement incorrectly or that it made the ending point less clear.

#### General impressions

General comments about having the feedback were positive with participants saying it made doing the squats more enjoyable in comparison to doing them without. One participant compared it to "playing a piano" with their squats and found the process of making music with the squats motivating. Participants also noted that having the feedback made them feel more confident, the sonification helped them to concentrate on the activity and increased their feeling of control.

Participants also mentioned how the sonifications could be used to inform them about their movement. The most common aspects mentioned were the pacing of the movement, being able to speed up or slow the pace of the squats, the smoothness and keeping in rhythm, and the depth of the squats ensure that they went low enough in the movement. Some also mentioned that the changes in the sonification made it easier to keep count of their total squats. Conversely, one participant felt that clearer information on how many had been completed or hold long one should hold the squat would be more beneficial than the current design.

### 8.5.8. Discussion

In this study there were limited effects of the different sonifications on the behavioural and self-report measures. This may be linked to both the way the musical building conditions were perceived differently by participants and the impact of closed movement on the impact of MuES, as shown in Chapter 6. The lack of impact on perceived stability may be linked by the changing the cadence to be at the top of the movement where the target point is even more defined, i.e. the standing position. However, the qualitative responses from participants do provide valuable insights into how the MoSEM can be used to design sonifications for general wellbeing. However, participants also reported feeling heavier in the unstable building sonification condition. This may stem from this feeling of uncertainty may have benefits in promoting feelings of having worked harder based on one's own body perceptions [Tajadura-Jiménez et al., 2019]. Similar to study 8.4 the use of musical sound seems to be generally encouraging as can be seen in the previous use of music in physical activity [Karageorghis et al., 2008, Mohammadzadeh et al., 2008]. This study confirms other works which show how sonification can be used to inform movement [Cesarini et al., 2014, Vogt et al., 2009] and even with the squat down movement [Hale et al., , Khan et al., 2018].

In addition to informing about the technique and the depth of the squat, participants also highlight how the sound could be useful to inform them about the pacing and rhythm of the movement. This finding also correlates with previous work looking at repetitive movements, e.g. rowing [Schaffert et al., 2011]. However, participants also highlighted how the changes in the movement could also help them keep track of how many squats they had performed. This would be important for tracking and achieving goals as discussed in the design interviews with trainers.

There were also perceived benefits to the use of the musical sonification in terms of both making the squatting exercise more enjoyable and in providing motivation to continue on, similar to findings using music during exertion exercise. These findings again offer some confirmations for the MoSEM, in terms of stable endings giving a sense of completion with unstable endings push one to do more. However, the musical building design seems to have some issues surrounding it.

While some participants in this study (as well as participants from previous studies in Chapter 7) thought that the variety in sound made it more musical and hence easier to listen to, for the majority of people the change in the sound obfuscates the information the sound is meant to provide and for some even implies they have performed the movement incorrectly. This demonstrates the problems in making sonifications overly musical as highlighted by Vickers *et al.* [Vickers et al., 2017]. With the addition of the musical variation the underlying representation of the sonification is disrupted, and while in previous studies of these MuES this has been shown to alter movement behaviour and perceptions implicitly, this design demonstrates a breaking point for the use of musical structure within sonification. However, participants also highlight aspects of the sonification which would be beneficial for overcoming barriers to general activity.

It is true that some participants do report enjoying the variation in the sound and that a desire to hear more of the music encouraged them to continue their repetitions. However, others found it unclear as to whether they had correctly performed the movement. This leads to some open questions surrounding the MoSEM design shown in figure 8.3, into how to design anexpectation of continued repetitions. If, as in study 8.4 people struggle to perceive static instability due to the repeated nature of the exercise, in order to achieve instability, there must be some alteration of the sound to stop it from becoming the expected ending. However, as seen in the results from this study, these alterations can cause the representative nature of the sonification to break down, meaning the design presented in figure 8.3 would not, in fact, encourage additional squats but may be detrimental for supporting low self-efficacy if this incorrect performance feedback is not corrected for.

## 8.6. Conclusions

This Chapter shows the second case study of using the MoSEM to support populations with low self-efficacy, in this case, people who struggle with physical activity for general wellbeing. Previous work shows how low self-efficacy can negatively impact people's ability to maintain physical activity and through a series of interviews with both personal trainers and people who struggle with physical activity the potential for MuES can be seen. These interviews help identify a potential use case for the MoSEM for people who struggle with physical activity: used to inform and encourage repetitions of the squat down movement.

Based on this, two studies are presented exploring squat repititions and MuES. The first aimed to examine how MuES compared to doing squat repetitions with a purely informative sonification or with no feedback at all. From this initial study the benefits of the musical sonifications can be seen in people's sense of achievement and their motivation to continue on. However, during the repetitive movement, the difference between the two stabilities was less pronounced than in previous studies. This led to the second MuES design which utilised musical building to increase the feeling of encouragement as the repetitions went on in turn to motivate continuation of the repetitions.

Through exploring this design with people who struggle with physical activity valuable insights can be gained into the use of MuES to overcome low self-efficacy. While as shown previously participants felt the sonification helped inform them better about their movement and helped to encourage them to continue on, the variation in the musical building design led people to believe they had performed the movement incorrectly; this again highlights the balance that must be struck between using musical expectancy to encourage changes in movement behaviour and perceptions and the sonification as a representation of the movement itself. Through gathering feedback with the target population, insights into the current design and potential future avenues of research can be highlighted. For instance, the need to explore how such a design may be utilised over time to support on-going physical activity.

**Contributions**

Shows how the MoSEM may be used to address barriers to physical activity in general wellbeing

Shows how musical building can be applied to a repetitive movement to encourage repetitions

Shows the need to balance the use of musical sonifications with the sound as a representation of the movement

# 9. General Discussion

**In this Chapter:**

∗ Summary of findings in this thesis

∗ Contributions to knowledge in sonification design, body-centred feedback and technology for low self-efficacy

∗ Future avenues of research

## 9.1. Summary of Research Findings

This thesis's main hypothesis is: *"Using musical expectancy within movement sonifications can be used to impact movement behaviour and perceptions for people with low self-efficacy"*. This concept is explored through the design of a Movement Sonification Expectation Model (MoSEM), which seeks to explore the interplay between one's expectation of one's own movement and the expectation created by the sonification. By exploring literature related to movement sonification, the impact of implicit and embodied music understanding on movement behaviour and the use of auditory feedback to alter one's body representation; the potential for leveraging this musical understanding within sonification to alter one's perception of one's movement it can be seen (see Chapter 2).

The MoSEM is developed and presented in Chapter 4, building on previous frameworks of musical expectation [Huron, 2006] and movement [Wolpert and Ghahramani, 2000]. It presents a series of predictions for how Musical Expectancy Sonifications (MuES) will impact movement behaviour and perceptions. The MoSEM posits how sonifications that end with musical expectation being met (harmonically stable) create a feeling of completion which is transferred to the person's feeling about their movement, leading to a conclusion of the movement and a feeling of achievement. However, when this musical expectation is defied (harmonically unstable), the person will feel in turn that their movement is unfinished, leading to the continuation of the movement and a feeling of encouragement to continue.

To evaluate the MoSEM and its predictions a series of control studies are presented to compare stable and unstable endings, presented in Chapter 5. MuES were explored in two movements, the stretch forward and the squat down, two movements common in populations with low self-efficacy, but different in the level of additional cues at the end of the movement. The findings from both of these studies help validate the predictions of the MoSEM and show that MuES can impact movement behaviour and perceptions. However, in these studies, there also appeared to be an impact of external factors on the effect the MuES had on the movement.

In Study 1 in Section 5.2, it was hypothesised that for the stretch forward movement participants will move further in unstable conditions as well as feeling more motivated to continue on and will move less in stable endings but feel a greater sense of reward. The results validate these hypotheses, in that participants moved more and for longer in musically unstable endings. Though they did not consciously feel more motivated to do so, they did feel a sense of reward from the stable endings. However, there was also an impact of the length of the sonification, a control parameter in the study to avoid learning effects, on the movement behaviour and perceptions of the sound. These results, while confirming some of the predictions of the MoSEM, imply there are additional factors at play.

In Study 2 in Section 5.3, the same design was investigated with the squat down movement, a movement with more additional cues that the ending is coming and one that beginners commonly struggle with. It was expected that the same impacts would be seen, in terms of movement behaviour and perceptions. However, while participants did report feeling more motivated to continue their movement in unstable endings and felt they had achieved more in the stable ending, there were no significant effects on the movement behaviours, differing from the results of Study 1 in Section 5.2. This again implies there are factors outside that of the musical expectation that impact the movement behaviours and perceptions.

This led to two studies (presented in Chapter 6) further exploring how an individual's movement expectation may change the way the MuES are perceived. In the first, Study 3 in Section 6.2, the impact of the length of the sonification was explored. Here the musical phrasing in the sonification was altered to limit the musical cues that the end of the sonification was approaching and an additional length added. The study hypothesised that again that MuES would impact movement behaviour but, when sonifications were too short, the impact of stable endings would be lessened, and they would be perceived as less stable. This was reflected in the results and demonstrates that when the sonification breaks the limits of the expected movement; it may be less effective in altering movement behaviour and perceptions.

In Study 4 in Section 6.3, the impact of different movement types was explored in depth. Two movement types were defined as 1) open movements, where limited additional cues indicate the end of the movement and 2) closed movement where strong additional cues indicate the end of the movement. It was hypothesised that the presence of these cues would limit the impact of MuES on movement behaviour, as people are more reliant on the additional cues. Again, the results show how people use a combination of the musical expectation and additional cues to signal the end of their movement and that movements with strong cues at the end of the movement may be less affected. However, it showed that stable endings were perceived as more informative but less motivating than unstable regardless of the additional cues, implying stability still impacts perceptions of closed movements even if the behavioural impact is limited. These studies show the way the expectation of one's movements impact how MuES can be used to alter one's movement, either when it does not match the expected movement, or it disagrees with external cues to the end of the movement. From these observations, an extension of MoSEM was used to consider the impact of movement expectation.

From this understanding of MoSEM, two case studies with low self-efficacy populations were completed to extend the understanding of MoSEM through real-life practice. These case studies used a user-centred methodology to explore how MoSEM may be utilised by specific populations to understand better how MoSEM may be used in sonification design and outlines factors which impact the MoSEM. These studies take a more qualitative and exploratory view, to examine what can be learnt about MuES from these reallife contexts.

The first explored how MoSEM may be used to support chronic pain rehabilitation. The MoSEM was used to design a MuES to either promote movement past a feared boundary or encourage the conclusion of movement, seen in Chapter 7. Based on previous works establishing needs of people with chronic pain during physical rehabilitation [Singh et al., 2014, Woby et al., 2007], the design was first validated with healthy participants (Study 5 in Section 7.4) and then used with people with chronic pain to explore the potential of the design and MuES more generally with chronic pain (Study 6 in Section

7.5. The results from this study demonstrate that while this kind of sonification may beneficial, both for encouraging and informing one's movement, there may be some limits to using musical structure within sonification. The use of musical expectancy to alter the representation of movement in some cases may be perceived as incorrect or cause hesitation in the movement.

The second case study explored how MuES could be designed for general wellbeing. In this study, the specific needs for people struggling to maintain regular physical activity are explored and used to develop a MuES design to encourage continued repetitions towards an individual's goals (seen in Chapter 8). First, an interview study with people who struggle with physical activity and personal trainers was used to gain some specific needs which could be addressed using MuES (Study 7 in Section 8.3. This led to two studies that explored encouraging repetitions of the squat down movement. The first, Study 8 in Section 8.4, compared the MuES to a non-musical sonification and a no sound condition. While it was found as hypothesised that the MuES were more encouraging (both in terms of movement behaviour and perceptions) when compared to the other conditions, there were no significant differences between stable and unstable endings. This could be because of the repetitions of the movement; the stable and unstable endings were not perceived as such since the music was repeated. This led to the design of a musically building sonification which heightened the tension/expectation overtime, this time at the top of the movement, after each repetition to encourage the continuation of the set, explored in Study 9 in Section 8.5. It was hypothesised that musically building sonifications would encourage people to spend less time at the top and feel like they could do more squats. However, this was not reflected in the results, and qualitative findings suggested that participants perceived the changes in the sound from the musical building as signalling incorrect movement and making the endings unclear. From these case studies it can be seen, not only how MuES may be designed to support populations with low self-efficacy, but also highlights some additional considerations for designing MuES and present some open questions on how to extend the MoSEM.

The remaining sections are dedicated to exploring the MoSEM as a conceptual model, the findings of this thesis in relation to the domains of sonification design, body centred feedback and technology to support low self-efficacy and open questions for future work.

## 9.2. Contributions to knowledge

### 9.2.1. The movement sonification expectation model

In order to explore the use of musical expectation within movement sonification, this thesis introduced the movement sonification expectation model (MoSEM) as a lens to explore how the expectation of one's movement may be altered by the musical expectation created by a sonification. This thesis combines three approaches seen in the literature, as reviewed in Chapter 2, the use of sonification to inform on movement, the use of music to encourage movement and the use of auditory illusions to adapt one's bodily representation. This method allows for an in-depth exploration of how sonification can be used to support physical activity through providing both performance feedback, but also attributional feedback to better support the needs of populations with low self-efficacy [Schunk, 1995].

To explore and evaluate musical expectation as a sonification parameter the MoSEM was developed to examine its impact on one's movement. This model provides a lens for understanding how these kinds of sonifications are experienced. Previous works have developed frameworks for understanding sonification design and evaluation. For example, Singh presents the *go-with-the-flow* framework for designing sonifications for chronic pain rehabilitation [Singh, 2016]. This framework is used for designing sonification to overcome barriers to physical activity for chronic pain; it shows how sonification may be used to enhance awareness and support ongoing movement but does not consider the how specific sound designs can be used to alter the movement itself or change the way it is appraised. In Roddy's work for embodied sonification, this impact is further considered through the lens of embodied cognition [Roddy, 2016]. The Embodied Sonification Listening Model is used as a way to understand how people's embodied cognition of sound impacts how sonifications are perceived and the conceptual metaphors that are used when extracting meaning from them. However, this model has yet to fully explore the impact the use of these metaphors has on the behaviour of the listener. Specific to real-time sonification, it does not propose how one may measure the impact of different mappings of how the sonification is interacted with. Degara *et al.* present SONEX as a framework for evaluating and creating reproducible sonifications. This framework calls for standardisation across the field for the methods and evaluations of sonifications and again highlights the need for comparison between different design choices. This framework aims to provide more rigorous and consistent evaluations for effective sonification design, therefore it is focused on the quantitative measures of sonification without consideration of the experience of the sonification itself.

The MoSEM, therefore, captures the benefits of all these approaches, with an understanding of the user needs, how the sonification is perceived and how it can be used for evaluation of sonification design choices. To develop an in-depth understanding of how the use of musical structure within sonification impacts its use, it focuses on musical expectation. Through the understanding of how real-time feedback can impact one's experience of one's own movement and people's implicit and embodied understanding of musical expectation, the MoSEM is used to both examine how such sonifications are experienced and to develop a series of predictions for how they will impact movement behaviour and perceptions. This addresses some important issues within sonic interaction design such as how sonifications can be developed through theoretically grounded frameworks [Rocchesso et al., 2008] and evaluated not only in terms of their effectiveness and usability but also how they change the interaction [Serafin et al., 2011]. By basing these designs within the theory of embodied sonification cognition [Roddy and Furlong, 2015], sensory integration [Wolpert and Ghahramani, 2000] and musical expectation [Huron, 2006], an understanding of how one may interact with such sonifications can be gained and a series of testable predictions made. From this, the MoSEM can then be evaluated in terms of how MuES impact people's movement behaviour and perception, extending the knowledge of how musical structure within sonification can be used to impact people's interactions with it.

This allows for the building of understanding of how these kinds of sonifications are understood, which is important for creating effective sonifications [Serafin et al., 2011, Vickers, 2017, Roddy and Bridges, 2018]. Understanding the impact these sound design choices have on how sonifications are perceived is especially important when considering real-time applications such as movement sonifications, in which the individual who is perceiving the sonification also retains agency and control over the sound in turn. This understanding not only gives more aspects of sonification which can be used to alter the experience of one's own movement, but also provides a basis to better balance the aesthetics and clarity of sonifications [Vickers et al., 2017]. Through this understanding of how musical expectancy may impact people's perceptions of a sonification, it can be better utilised within sonic interaction design so that designers can be more certain that their sonifications have the desired outcome.

This understanding is explored through a series of MoSEM design using chord progression based sonifications and harmonic cadence. However, the instantiation of the MoSEM explored in this thesis leaves other aspects of musical expectancy currently unconsidered, for example, different levels of harmonic stability, rhythmic stability and melodic leading [Bigand and Poulin-Charronnat, 2006, Farbood, 2012]. This shows how the instances of the MoSEM in this thesis may not fully encapsulate the impact of musical expectation and may require additional study. Previous works have demonstrated that more continuous sonifications may be perceived differently [Khan et al., 2018] and while rhythm has been explored within sonic interaction in terms of sensorimotor synchronisation [Repp, 2005], rhythmic stability specifically has not been evaluated. It has yet to be seen how these design choices may impact the MoSEM.

Moreover, the current model only considers the expectation created by music within sonification. While this may be a good starting point, it may also be extended to non-musical sound. As previously stated, people have a possibilty for hearing all sonifications musically [Vickers et al., 2017]. This could mean that a musical expectation is created even when not leveraged as in this thesis. Therefore, the impacts of perceived resolution/tension of a sonification should be considered in the design of all sonification, as it will impact people's perceptions and interactions with the sound. Even outside of perceived musical expectation, there are expectations created through the use of sound feedback based on people's embodied understanding of the sound created [Roddy and Bridges, 2018], for example, the expectation of one's body weight through the use of different frequency footstep sounds [Tajadura-Jiménez et al., 2019], which the current iteration of the MoSEM has yet to consider.

Furthermore, the MoSEM relies heavily on both an applied approach and also on an embodied cognition perspective for leveraging people's embodied experience of sonification in the design of MuES [Roddy and Furlong, 2015]. Rather than focusing on extending or validating the way people understand music and their body, this thesis instead explores how such concepts can be used to build a sonification design method and evaluate its impact on people's experience of the sound. Additionally, current works seek to explore the way people build an understanding of sonification through their interpretation of the sound and the conceptual metaphors attributed to it [Vickers et al., 2017, Roddy and Bridges, 2018]. The MoSEM instead seeks to explore this relationship through how people interact with the sound and does not consider how this could extend the understanding of embodied cognition or how it may relate to or contrast other theories of cognition.

However, the MoSEM does allow for the formation of clear and testable predictions for exploring MuES and through the use of experimentation within real-life populations, and the inclusion of qualitative methods aspects of this model can provide a lens to understand these sonifications, and new avenues of research generated. This MoSEM also offers a model for sonification designers to create MuES, showing harmonic stability as an empirically tested design concept and providing a framework from which it can be applied. The findings of the MoSEM can be used to develop such sonifications with an understanding of how it may impact movement behaviour and perceptions as well as the constraints to designing MuES depending on the movement itself. Additionally, it demonstrates how designers must consider the resolution of their sonifications to ensure the impact of the expectation created does not negatively impact the efficacy of their design; the MoSEM provides an understanding of how expectation within sonification may impact people's perceptions and interactions.

### 9.2.2. Designing Musical sonifications

Outside of the use of the MoSEM, this thesis presents an empirically tested design method for the use of musical sound in sonification. There have been many previous works which utilise musical sound to improve the listenability of sonifications and to improve the effectiveness of them for informing users (see Section 2.3 for an overview). In addition, people's understanding of music is intrinsically linked to the way sonifications are listened to [Vickers et al., 2017, Roddy and Furlong, 2015]. However, there has been little work exploring how the inclusion of musical structure impacts people's movement behaviour and perceptions, and there is a need to understand the impact such design decisions have on how people interact with the sonification [Rocchesso et al., 2008, Serafin et al., 2011].

When considering musical sonifications, the prior discussion in the field has focused on defining boundaries between music and sonification [Scaletti, 2018], the use of musical sound within sonification to improve aesthetics [Vickers et al., 2017] and create more effective conceptual metaphors [Roddy and Furlong, 2015]. However, ways of using this embodied understanding of music and sonification together to create sonifications that can be used to implicitly alter movement behaviours and perceptions has yet to be explored. Vicker's *et al.*, highlight the potential for the use of musical structures in sonification to disrupt the representation of the underlying data [Vickers et al., 2017]. However, this thesis offers not only a lens to better understand how musical sound may alter this representation of data, but also shows how this can be leveraged to alter perceptions of one's own movement deliberately. Though this was demonstrated to be useful in implicitly altering movement behaviour and perceptions, there were also instances where the limits of this use of harmonic structure were found, where an unexpected ending led to uncertainty and feeling of incorrect movement, confirming the importance of considering the use of such structures with sonification.

Few works to have explicitly investigated how expectation may be used within movement sonifications [Dubus and Bresin, 2013] and while some works show how it can be used to signal deviations in trajectory and signal an endpoint [Huang et al., 2005, Wallis et al., 2007], its intrinsic impact on movement behaviour and perception is currently under-examined. In this thesis, the focus is on using harmonic structures to alter this musical expectation. Harmony has benefits of being easily manipulated at specific points in the sonification, in order to generate comparable sonifications and in turn measuring their impacts on behavioural and self-report measures. This work begins to develop an understanding of the impact the use of musical structure within sonification has on not only how they are interpreted or understood, but how it impacts the interaction itself.

Moreover, this work responds to the call for critical and empirical evaluation within sonifications [Dubus and Bresin, 2013, Degara et al., 2013]. Through the series of control studies within this thesis, the impact of different design choices in relation to harmonic stability within movement sonification can be seen across several movements and applications. However, in addition to understanding the impact of sonification design choices on people's behaviour and perceptions, there is a need to understand the experience of interacting with the sonification and how it may integrate into everyday life [Serafin et al., 2011].

This calls for the use of both quantitative methods, to understand the behavioural and perceptual impacts of MuES, and qualitative methods to understand not only the experience of the sonification but also future scenarios. This demonstrates the benefits of user-centred design philosophy and methodology for developing sonification methods. As previously highlighted by Barrass and Vickers [Barrass and Vickers, 2011], the user-centred design allows for a better understanding of the impact of these sonifications. This design approach allows for the consideration of the user experience and how they can be designed specifically to a given populations needs and goals.

The work in this thesis highlights the benefit of exploring beyond the effectiveness and usability of sonifications but also the advantages of exploring behavioural changes and the real-life experience of using sonification through more qualitative evaluation. This allows for an understanding and evaluation of the application of the theoretical approaches used to build the MoSEM while at the same time developing an understanding of the experience of interacting with a musical sonification within the context of real-life problems surrounding populations with low self-efficacy. This in turn can begin to address issues surrounding self-efficacy and open up new potential avenues for research. As sonification and sonic interaction design outline the benefits of developing objective measures and understanding of how sonifications are perceived, the benefits of using qualitative methods to understand people's interaction with technology should not be forgotten [Preece et al., 2005].

### 9.2.3. Body-centred feedback

In addition to sonification and sonic interaction design, this work has ramifications for the field of body centred feedback [Tajadura-Jiménez et al., 2017b] and the development of movement altering feedback. First, this thesis demonstrates how changes in movement behaviour can be achieved not only through altered body movement sound [Tajadura-Jiménez et al., 2015a] or abstract sonification [Boyer et al., 2013, Tajadura-Jiménez et al., 2017a] but also through the use of implicitly and embodied structures in music [Polotti and Rocchesso, 2008, Leman, 2008]. From the behavioural and self-report measures reported across the studies in this thesis (see Chapters 5, 6, 7 and 8) the understanding provided by the MoSEM can be seen in action, in the changes in the way people moved and perceived their movement based on the different musical endings used within the sonification. However, the work in this thesis also demonstrates the breaking point for these alterations. As in previous work demonstrating the impact of spatial and temporal mismatches between the event and sound feedback on the efficacy of auditory illusions [Tajadura-Jiménez et al., 2017b, Tajadura-Jiménez et al., 2017a], this thesis also demonstrates the impact of one's expected movement on the change in movement behaviour.

In Chapter 6, it was demonstrated that when one expects a certain movement end-point, the efficacy of a MuES to alter the behaviour at that end-point is impacted both by the distance from it and the additional cues available to signal the endpoint. This is also reflected in the use of both sensory integration [Botvinick et al., , Anderson, 1982] and the dominance of visual cues [Colavita, 1974]. The impacts of these extra-modal cues should be considered when designing this kind of feedback as a constraint of both the amount of alteration possible and the differing effects dependent on movement type.

This is demonstrated in the two case studies, in which the MoSEM is used differently to design sonifications for different movement types. However, these investigations also highlighted other extra-modal cues that should be considered, such as learnt end-points for the movement, in which people may learn to use unintended cues in the sound, such as the low pitch of the unstable chord to signal to end, as well as the use of one's feeling of pain/discomfort (see in Chapter 7). These findings demonstrate how the extent to which people's movement behaviour and perceptions can be altered must be considered in the design of body-centred feedback [Tajadura-Jiménez et al., 2017b]. In addition to the need to feel sufficient agency over the sound produced [Tajadura-Jiménez et al., 2017a], this work demonstrates how too extreme a difference in the expectation set by the feedback and one's own expectation can limit the impacts of such feedback.

Additionally, within the two case studies, the use of MoSEM to create MuES designs demonstrates more as yet unforeseen impacts of the use of expectancy within movement sonifications. Within the chronic pain rehabilitation case study in Chapter 7, further physical limits on the movement, e.g. fear of pain or reinjury [Leeuw et al., 2007] were also seen to impact the effect of musical expectancy to some degree, and in those situation where there was uncertainty in the movement and musical tension was seen to lead to hesitancy and potentially to signal incorrect movement. Likewise, in the general wellbeing case study 8, repetitions of the squat were seen to impact on the perception of the stability and the use of changing stability was also seen to create uncertainty and potentially signal incorrect movement. These findings demonstrate a currently unexplored limitation of this kind of sonification: the breaking point of the MoSEM where the sonification itself is perceived as incorrect rather than incomplete. Additionally, in both case studies, participants also noted a perceived change in the pacing of their movement. While this reflects previous findings surrounding the perception of pacing in musical sonification [Schaffert et al., 2011] and in synchronisation with musically stable/unstable sounds [Komeilipoor et al., 2015], these aspects are currently unexplored in terms of the MoSEM.

The findings in these studies demonstrate the need to consider individual factors impact on how this kind of sonifications are experienced. As demonstrated by [Tajadura-Jiménez et al., 2015a], individual factors such as body weight and perceived masculinity, change they way sonification may be embodied. For example, a lower pitch sound may be perceived as being associated with a heavier or stronger body, depending on the individual's perception of themselves. Similarly, this is true of how people interact with the MoSEM, depending on not only the sonification, but their perception of the movement, the external cues and more personal factors such as pain or the anticipation of it [Leeuw et al., 2007].

### 9.2.4. Considerations for low self-efficacy

This work also raises some ongoing issues in designing technology to support physical activity for such populations. Low self-efficacy has been demonstrated as a major barrier to engaging in physical activity [Biddle and Mutrie, 2007, Shieh et al., 2015]. However, few sonifications have explored how a combination of performance and attributional feedback [Schunk, 1995] can be utilised with some implicit encouragement of movement behaviour past boundaries to support physical activity.

Within chronic pain rehabilitation, a series of barriers surrounding self-efficacy has been highlighted [Singh et al., 2014, Woby et al., 2007]. The work in this thesis shows how MuES may be used to address some of these through promoting progression while avoiding overdoing. From the responses from participants in Chapter 7, the potential for such feedback can be seen in terms of informing people with chronic pain about their movement, providing encouragement when mobility and intrinsic motivation is low, as well as offering some form of distraction/relief from their pain [Cepeda et al., 2006]. However, there are several aspects which are currently unaddressed. For example, the use of such feedback in functional activity, such as everyday movements [Singh et al., 2017], how long-term use of MuES may be used to support on-going rehabilitation [Singh et al., 2016] and the potential to support mindfulness [Nazemi et al., 2013]. Additionally, participants highlighted potential issues surrounding the MuES use in chronic pain, which could potentially increase anxiety. For instance, the current implementation of the MuES was done on a single calibration, whereas previous works have demonstrated how such calibrations may change day to day and are dependent on activity [Singh et al., 2017]. Participants also noted how they would want to be sure the movement they were doing was safe and effective, either through use with a physiotherapist or through some automated tracking of what movement would be recommended based on current pain and ability [Olugbade et al., 2014, Olugbade, 2015].

Within the applications for use with general wellbeing, the potential for such designs to help overcome barriers to ongoing physical activity was also emphasised. Previous works have explored how technology may support safe and efficient movement [O'Reilly et al., 2015, Whelan et al., 2015] and in tracking and setting goals, [Harrison et al., 2015, Munson and Consolvo, 2012], as was identified in the interview study presented in Chapter 8. This work complements such work by showing how sonification may be designed not only to inform but to also encourage people towards these goals. This highlights for the potential of MoSEM based sonification designs to be used for adaptive feedback for people with low self-efficacy, alongside such automated tracking systems in both general wellbeing [O'Reilly et al., 2015, Whelan et al., 2015] and in chronic pain rehabilitation [Olugbade et al., 2014, Olugbade, 2015]. MuES could be used to provide adaptive feedback as to whether someone should continue with their movement or if it should conclude. While participants did find musical sonifications more encouraging than non-musical ones and highlighted the ability to track one's pacing through the rhythm the sound produced, as seen in [Schaffert et al., 2011], these studies also demonstrated some open questions for the use of such feedback. For instance, it remains unclear how to create differences in stabilities for repeated movements without a) being impacted by the exposure effect [Huron, 2006] or b) disrupting the representation of the data [Vickers et al., 2017]. This may be solved with more long-term use of the sonification, and the individual is made aware that the changes in the sound signify the need to continue repetitions, which was reported by some participants. However, it seems for some individuals; this mapping does not feel natural.

## 9.3. Future work

The work in this thesis offers several avenues for future research, both in consideration of the sound design and the movements to which they are applied. First, while this thesis explores musical expectation with movement sonification, expectancy, in this case, is abstracted to the harmonic stability within a musical cadence. As previously stated, there are numerous other aspects within music which contribute to one's musical expectation, for example, rhythm and melodic structure [Bigand and Poulin-Charronnat, 2006, Farbood, 2012]. Additionally, this thesis explores only instances where the endings are designed to sound distinctly stable or unstable; it has yet to be explored how various other aspects related to musical expectation may be used to create more nuanced expectations within music in which the completion of the cadence may be more open to interpretation. This may be beneficial for generating future iterations of the gap design shown in Chapter 7, where instead of the use of a gap to allow for people to confirm their desire to continue, a series of endings which could be perceived as either complete or incomplete could be used to allow for a more flexible end-point, which still feels complete.

In addition to musical expectation, there are also further musical structures which should be considered empirically for use in movement sonification design; previous works have begun to consider both rhythm, for both pacing [Schaffert et al., 2011] and gait retraining [McIntosh et al., 1997] and the use of melodic structure for motor-learning [Dyer et al., 2017]. However, such works could be extended along with this work on musical expectation and unexplored musical elements, such as texture [Newbold et al., 2015], to develop a design framework for creating musically-informed sonifications to be used for physical activity. In addition to musical structure, there is also scope to use the MoSEM to explore non-musical expectations impact on movement behaviour and perception, for example as created from altered audio feedback [Tajadura-Jiménez et al., 2015a, Tajadura-Jiménez et al., 2017a, Serafin et al., 2013] or from one's embodied sense of pitch direction [Roddy and Furlong, 2015]

Likewise, there are aspects of movements that could be further explored. In addition to more long-term use for physical activity and additional exploration for repeated movements highlighted previously, there are also other kinds of movement which could be considered with the MoSEM. For example, explorations on extending the MoSEM to cover compound movements with multiple target points or movements involving numerous body parts or even multiple individuals. Moreover, outside of movement, this work on musical expectancy could be used to inform future research on other sonification types. For example, within sonification for breathing feedback, in which certain designs have previously demonstrated to better match people's understanding of breathing patterns, the MoSEM could be used to develop sonifications which use this to encourage specific breathing patterns [Newbold et al., 2015].

In addition, MuES could be used outside movement feedback for general sonification. The impact of musical tension and resolution has on the perception of the feeling of continuation or conclusion of the sonified data, should be considered when design sonification such that it matches the expected endpoint of the data. This may be utilised when designing sonifications for analysis of data to highlight different breakpoints in the data or to highlight an upcoming endpoint, for example, to support auditory progress bars to allow people to track progression overtime [Garcia and Peres, 2012]. The implications for design put forward in the MoSEM should be considered when developing sonification to either leverage or avoid impacts on behaviour and perceptions, especially those that leverage musical structure.

## 9.4. Conclusions

This thesis outlines the development of a sonification design method to use musical expectation within movement sonification to impact movement behaviour and perceptions for people with low self-efficacy. Through the design of a movement expectation sonification model (MoSEM), this design concept is explored through a series of control studies and two case studies with populations with low self-efficacy. The findings from these investigations show the benefits of musical expectation sonifications, how they can impact movement behaviour and perceptions, how they interact with people's own movement expectation and how they may be applied in real-life scenarios. Namely, it is demonstrated how stable endings can be used to reward movement and invite conclusion, while unstable endings can be used to motivate continuation and encourage additional movement. While it was also found that additional factors such as one's expectation of one's movement and the additional cues available at the end of movement may impact these effects, the two case studies presented show how the MoSEM can be used to design MuES within constraints and the potential benefits for people with low self-efficacy. These findings lead to the three main contributions to the domains of HCI and audio-interaction from this thesis:

1. The MoSEM as a model for understanding and designing sonifications with musical expectancy;
2. A series of control studies which demonstrate not only its impact on movement behaviour and perception but also how it is itself impacted by one's expectation of the movement;
3. Demonstration of how the MoSEM can be used to design sonification for populations with low self-efficacy and a series of considerations for future MuES designs.

From this work, there are several avenues of future work to pursue in relation to extending the MoSEM, explore further methods for musically-informed sonification and the exploration of further applications of MuES a sonification design method both in supporting physical activity and beyond.

# References


[Abdallah and Plumbley, 2009] Abdallah, S. and Plumbley, M. (2009). Information dynamics: patterns of expectation and surprise in the perception of music. *Connection Science*, 21(2-3):89–117.

[Allender et al., 2007] Allender, S., Foster, C., Scarborough, P., and Rayner, M. (2007). The burden of physical activity-related ill health in the UK. *Journal of epidemiology and community health*, 61(4):344–8.

[Anderson, 1982] Anderson, N. H. (1982). *Methods of information integration theory*, volume 2. Academic Press.

[Anshel and Marisi, 1978] Anshel, M. H. and Marisi, D. Q. (1978). Effect of music and rhythm on physical performance. *Research Quarterly. American Alliance for Health, Physical Education and Recreation*, 49(2):109–113.

[Aschersleben, 2002] Aschersleben, G. (2002). Temporal control of movements in sensorimotor synchronization. *Brain and cognition*, 48(1):66–79.

[Bandura, 1977] Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review*, 84:191–215.

[Bandura, 2000] Bandura, A. (2000). Cultivate self-efficacy for personal and organizational effectiveness. *Handbook of principles of organization behavior*, 2:0011–21.

[Bandura, 2002] Bandura, A. (2002). Social foundations of thought and action. In Marks, D. F., editor, *The Health Psychology Reader*, page 94. SAGE.

[Bandura, 2006] Bandura, A. (2006). Guide for constructing self-efficacy scales. *Self-efficacy beliefs of adolescents*, 5(1):307–337.

[Barrass and Vickers, 2011] Barrass, S. and Vickers, P. (2011). Sonification design and aesthetics. In Hermann, T., Hunt, A., and Neuhoff, J. G., editors, *The Sonification Handbook*. Logos Verlag.

[Biddiss and Irwin, 2010] Biddiss, E. and Irwin, J. (2010). Active video games to promote physical activity in children and youth: a systematic review. *Archives of pediatrics & adolescent medicine*, 164(7):664–72.

[Biddle and Mutrie, 2007] Biddle, S. and Mutrie, N. (2007). *Psychology of physical activity: Determinants, well-being and interventions.* Routledge.

[Bigand, 1990] Bigand, E. (1990). Abstraction of Two Forms of Underlying Structure in a Tonal Melody. *Psychology of Music*, 18(1):45–59.

[Bigand, 1997] Bigand, E. (1997). Perceiving musical stability: The effect of tonal structure, rhythm, and musical expertise. *Journal of Experimental Psychology: Human Perception and Performance*, 23(3):808.

[Bigand and Poulin-Charronnat, 2006] Bigand, E. and Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, 100(1):100–30.

[Blandford et al., 2008] Blandford, A., Cox, A. L., and Cairns, P. (2008). Controlled experiments. In *Research Methods in Human-Computer Interaction.* Cambridge University Press.

[Blandford et al., 2016] Blandford, A., Furniss, D., and Makri, S. (2016). Qualitative hci research: Going behind the scenes. *Synthesis lectures on human-centered informatics*, 9(1):1–115.

[Borg, 1998] Borg, G. (1998). *Borg's perceived exertion and pain scales.* Human kinetics.

[Botvinick et al., ] Botvinick, M., Cohen, J., et al. Rubber hands' feel'touch that eyes see. *Nature*, 391(6669):756–756.

[Boyer et al., 2013] Boyer, E. O., Babayan, B. M., Bevilacqua, F., Noisternig, M., Warusfel, O., Roby-Brami, A., Hanneton, S., and Viaud-Delmon, I. (2013). From ear to hand: the role of the auditory-motor loop in pointing to an auditory source. *Frontiers in computational neuroscience*, 7:26.

[Bradley and Lang, 1994] Bradley, M. M. and Lang, P. J. (1994). Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry*, 25(1):49–59.

[Braun and Clarke, 2013] Braun, V. and Clarke, V. (2013). *Successful qualitative research: A practical guide for beginners.* sage.

[Bruscia, 1998] Bruscia, K. E. (1998). *Defining Music Therapy*. Barcelona Publishers.

[Caramiaux et al., 2014] Caramiaux, B., Françoise, J., Schnell, N., and Bevilacqua, F. (2014). Mapping Through Listening. *Computer Music Journal*, 38(3):34–48.

[Castiello et al., 2010] Castiello, U., Giordano, B. L., Begliomini, C., Ansuini, C., and Grassi, M. (2010). When Ears Drive Hands: The Influence of Contact Sound on Reaching to Grasp. *PLoS ONE*, 5(8):e12240.

[Cepeda et al., 2006] Cepeda, M. S., Carr, D. B., Lau, J., and Alvarez, H. (2006). Music for pain relief. *The Cochrane database of systematic reviews*, (2):CD004843.

[Cesarini et al., 2014] Cesarini, D., Hermann, T., and Ungerechts, B. E. (2014). An interactive sonification system for swimming evaluated by users. In *SoniHED- Conference on Sonification of Health and Enviromental Data*.

[Chew, 2000] Chew, E. (2000). *Towards a mathematical model of tonality*. PhD thesis, Massachusetts Institute of Technology.

[Chew, 2016] Chew, E. (2016). Playing with the edge: Tipping points and the role of tonality. *Music Perception: An Interdisciplinary Journal*, 33(3):344–366.

[Colavita, 1974] Colavita, F. B. (1974). Human sensory dominance. *Perception & Psychophysics*, 16(2).

[De Sá Teixeira et al., 2008] De Sá Teixeira, N. A., De Oliveira, A. M., and Viegas, R. (2008). Functional approach to the integration of kinematic and dynamic variables in causal perception: Is there a link between phenomenology and behavioral responses? 1. *Japanese Psychological Research*, 50(4):232–241.

[Degara et al., 2013] Degara, N., Nagel, F., and Hermann, T. (2013). Sonex: an evaluation exchange framework for reproducible sonification. In *Proceedings of the 19th International Conference on Auditory Displays*.

[Deutsch, 1972] Deutsch, D. (1972). Octave generalization and tune recognition. *Perception & Psychophysics*, 11(6):411–412.

[Dichgans and Brandt, 1978] Dichgans, J. and Brandt, T. (1978). Visual-vestibular interaction: Effects on self-motion perception and postural control. In *Perception*, pages 755–804. Springer.

[Dix, 2008] Dix, A. (2008). Theoretical analysis and theory creation. In *Research Methods in Human-Computer Interaction*, pages 175–195. Cambridge University Press.

[Donaldson, 2009] Donaldson, L. (2009). 150 years of the Annual Report of the Chief Medical Officer: on the state of public health 2008. *London:Department of Health*.

[Dubus and Bresin, 2013] Dubus, G. and Bresin, R. (2013). A systematic review of mapping strategies for the sonification of physical quantities. *PloS one*, 8(12):e82491.

[Dyer et al., 2017] Dyer, J. F., Stapleton, P., and Rodger, M. W. M. (2017). Advantages of melodic over rhythmic movement sonification in bimanual motor skill learning. *Experimental Brain Research*, 235(10):3129–3140.

[Effenberg, 2005] Effenberg, A. O. (2005). Movement Sonification: Effects on Perception and Action. *IEEE Multimedia*, 12(2):53–59.

[Farbood, 2012] Farbood, M. M. (2012). A parametric, temporal model of musical tension. *Music Perception: An Interdisciplinary Journal*, 29(4):387–428.

[Field, 2013] Field, A. (2013). *Discovering statistics using IBM SPSS statistics.* sage.

[Fitzsimmons et al., 1991] Fitzsimmons, P. A., Landers, D. M., Thomas, J. R., and van der Mars, H. (1991). Does self-efficacy predict performance in experienced weightlifters? *Research Quarterly for Exercise and Sport*, 62(4):424–431.

[Frederick and Ryan, 1993] Frederick, C. and Ryan, R. (1993). Differences in motivation for sport and exercise and their relations with participation and mental health. *Journal of sport behavior*.

[Frid et al., 2018] Frid, E., Moll, J., Bresin, R., and Sallnäs Pysander, E.-L. (2018). Haptic feedback combined with movement sonification using a friction sound improves task performance in a virtual throwing task. *Journal on Multimodal User Interfaces*, pages 1–12.

[Fritz et al., 2013] Fritz, T. H., Hardikar, S., Demoucron, M., Niessen, M., Demey, M., Giot, O., Li, Y., Haynes, J.-D., Villringer, A., and Leman, M. (2013). Musical agency reduces perceived exertion during strenuous physical performance. *Proceedings of the National Academy of Sciences*, 110(44):17784–17789.

[Gammage et al., 2001] Gammage, K. L., Hardy, J., and Hall, C. R. (2001). A description of self-talk in exercise. *Psychology of Sport and Exercise*, 2(4):233–247.

[Garcia and Peres, 2012] Garcia, A. and Peres, C. S. (2012). Auditory progress bars: The effects of feedback, endpoint and free response on estimations of time remaining. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 56, pages 1674–1678. SAGE Publications Sage CA: Los Angeles, CA.

[Giles-Corti and Donovan, 2002] Giles-Corti, B. and Donovan, R. J. (2002). The relative influence of individual, social and physical environment determinants of physical activity. *Social Science & Medicine*, 54(12):1793–1812.

[Hale et al., ] Hale, R., Hausselle, J., and Gonzalez, R. V. Impact of error sonifcation auditory feedback for neromuscular training across two degrees of freedom. In *Proceedings of the Annual American Society of Biomechanics, 2015*.

[Handel, 2011] Handel, M. J. (2011). mhealth (mobile health)âĂŤusing apps for health and wellness. *EXPLORE: The Journal of Science and Healing*, 7(4):256–261.

[Hao et al., 2015] Hao, T., Xing, G., and Zhou, G. (2015). Runbuddy: a smartphone system for running rhythm monitoring. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pages 133–144. ACM.

[Harrison et al., 2015] Harrison, D., Marshall, P., Bianchi-Berthouze, N., and Bird, J. (2015). Activity tracking: barriers, workarounds and customisation. pages 617–621.

[Harvie et al., 2015] Harvie, D. S., Broecker, M., Smith, R. T., Meulders, A., Madden, V. J., and Moseley, G. L. (2015). Bogus visual feedback alters onset of movement-evoked pain in people with neck pain. *Psychological science*, page 956797614563339.

[Hayden et al., 2005] Hayden, J. A., van Tulder, M. W., Malmivaara, A., and Koes, B. W. (2005). Exercise therapy for treatment of non-specific low back pain. *The Cochrane database of systematic reviews*, (3):CD000335.

[Hayes and Silberman, 2007] Hayes, E. and Silberman, L. (2007). Incorporating video games into physical education. *Journal of Physical Education, Recreation & Dance*, 78(3):18–24.

[Hoare et al., 2017] Hoare, E., Stavreski, B., Jennings, G., and Kingwell, B. (2017). Exploring motivation and barriers to physical activity among active and inactive australian adults. *Sports*, 5(3):47.

[Huang et al., 2005] Huang, H., Ingalls, T., Olson, L., Ganley, K., Rikakis, T., and He, J. (2005). Interactive multimodal biofeedback for task-oriented neural rehabilitation. *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference*, 3:2547–2550.

[Hurling et al., 2007] Hurling, R., Catt, M., De Boni, M., Fairley, B., Hurst, T., Murray, P., Richardson, A., and Sodhi, J. (2007). Using internet and mobile phone technology to deliver an automated physical activity program: randomized controlled trial. *Journal of medical Internet research*, 9(2):e7.

[Huron, 2006] Huron, D. (2006). *Sweet anticipation: Music and the psychology of expectation.* MIT press.

[IASP, 2014] IASP (2014). Unrelieved pain is a major global healthcare problem.

[Karageorghis et al., 2008] Karageorghis, C., Jones, L., and Stuart, D. P. (2008). Psychological effects of music tempi during exercise. *International journal of sports medicine*, 29(7):613–9.

[Karageorghis and Terry, 1997] Karageorghis, C. and Terry, P. (1997). The psychophysical effects of music in sport and exercise: A review. *Journal of Sport Behavior.*

[Kennel et al., 2015] Kennel, C., Streese, L., Pizzera, A., Justen, C., Hohmann, T., and Raab, M. (2015). Auditory reafferences: the influence of real-time feedback on movement control. *Frontiers in Psychology*, 6:69.

[Khan et al., 2018] Khan, R. A., Jeon, M., and Yoon, T. (2018). "Musical Exercise" for People with Visual Impairments: A Preliminary Study with the Blindfolded. In *Pro-*

*ceedings of the 24th International Conference on Auditory Display - ICAD 2018*, pages 204–211, Arlington, Virginia. The International Community for Auditory Display.

[Khot et al., 2015] Khot, R. A., Lee, J., Aggarwal, D., Hjorth, L., and Mueller, F. (2015). Tastybeats: Designing palatable representations of physical activity. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 2933–2942. ACM.

[Kleiman-Weiner and Berger, 2006] Kleiman-Weiner, M. and Berger, J. (2006). The sound of one arm swinging: a model for multidimensional auditory display of physical motion. In *Proceedings of the 12th International Conference on Auditory Display (ICAD 2006)*, pages 278–280.

[Komeilipoor et al., 2015] Komeilipoor, N., Rodger, M. W. M., Craig, C. M., and Cesari, P. (2015). (dis-)harmony in movement: effects of musical dissonance on movement timing and form. *Experimental Brain Research*, 233(5):1585–1595.

[Krumhansl and Kessler, 1982] Krumhansl, C. and Kessler, E. (1982). Tracing the dynamic changes in perceived tonal organization in a spatial representation of musical keys. *Psychological review*.

[Leeuw et al., 2007] Leeuw, M., Goossens, M. E., Linton, S. J., Crombez, G., Boersma, K., and Vlaeyen, J. W. (2007). The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of behavioral medicine*, 30(1):77–94.

[Leman, 2008] Leman, M. (2008). *Embodied music cognition and mediation technology*. Mit Press.

[Leman, 2012] Leman, M. (2012). Musical gestures and embodied cognition. In *Journées d'informatique musicale (JIM-2012)*, pages 5–7. Université de Mons.

[Loui et al., 2010] Loui, P., Wessel, D. L., and Hudson Kam, C. L. (2010). Humans Rapidly Learn Grammatical Structure in a New Musical Scale. *Music perception*, 27(5):377–388.

[Maeda et al., 2004] Maeda, F., Kanai, R., and Shimojo, S. (2004). Changing pitch induced visual motion illusion. *Current Biology*, 14(23):R990–R991.

[Markland, 1999] Markland, D. (1999). Self-determination moderates the effects of perceived competence on intrinsic motivation in an exercise setting. *Journal of Sport and Exercise Psychology*, 21(4):351–361.

[McDonald, 2014] McDonald, J. (2014). Handbook of biological statistics., 3rd edn.(sparky house publishing: Baltimore, md.).

[McGookin and Brewster, 2011] McGookin, D. and Brewster, S. (2011). Earcons. *The Sonification Handbook*.

[McIntosh et al., 1997] McIntosh, G. C., Brown, S. H., Rice, R. R., and Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 62(1):22–26.

[Mercer et al., 2016] Mercer, K., Li, M., Giangregorio, L., Burns, C., and Grindrod, K. (2016). Behavior change techniques present in wearable activity trackers: a critical analysis. *JMIR mHealth and uHealth*, 4(2).

[Merker et al., 2009] Merker, B. H., Madison, G. S., and Eckerdal, P. (2009). On the role and origin of isochrony in human rhythmic entrainment. *Cortex; a journal devoted to the study of the nervous system and behavior*, 45(1):4–17.

[Metcalf et al., 2008] Metcalf, B. S., Voss, L. D., Hosking, J., Jeffery, A. N., and Wilkin, T. J. (2008). Physical activity at the government-recommended level and obesity-related health outcomes: a longitudinal study. *Archives of disease in childhood*, 93(9):772–7.

[Meyer, 1957] Meyer, L. B. (1957). *Emotion and meaning in music.* University of chicago Press.

[Middleton et al., 2018] Middleton, J., Hakulinen, J., Tiitinen, K., Hella, J., Keskinen, T., Huuskonen, P., Linna, J., Turunen, M., Ziat, M., and Raisamo, R. (2018). Sonification with musical characteristics: a path guided by user engagement. In *Proceedings of the 24th International Conference on Auditory Display - ICAD 2018.* The International Community for Auditory Display.

[Mohammadzadeh et al., 2008] Mohammadzadeh, H., Tartibiyan, B., and Ahmadi, A. (2008). The effects of music on the perceived exertion rate and performance of trained and untrained individuals during progressive exercise. *Facta Universitatis-Series: Physical Education and Sport*, 6(1):67–74.

[Müllensiefen et al., 2014] Müllensiefen, D., Gingras, B., Musil, J., and Stewart, L. (2014). The musicality of non-musicians: an index for assessing musical sophistication in the general population. *PloS one*, 9(2):e89642.

[Munson and Consolvo, 2012] Munson, S. A. and Consolvo, S. (2012). Exploring goal-setting, rewards, self-monitoring, and sharing to motivate physical activity. In *Pervasive computing technologies for healthcare (PervasiveHealth), 2012 6th international conference on*, pages 25–32. IEEE.

[Myer et al., 2014] Myer, G. D., Kushner, A. M., Brent, J. L., Schoenfeld, B. J., Hugentobler, J., Lloyd, R. S., Vermeil, A., Chu, D. A., Harbin, J., and McGill, S. M. (2014). The back squat: A proposed assessment of functional deficits and technical factors that limit performance. *Strength and conditioning journal*, 36(6):4.

[Narmour, 1990] Narmour, E. (1990). *The analysis and cognition of basic melodic structures: The implication-realization model.* University of Chicago Press.

[Nazemi et al., 2013] Nazemi, M., Mobini, M., Kinnear, T., and Gromala, D. (2013). Soundscapes: A prescription for managing anxiety in a clinical setting. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13*.

[Newbold et al., 2015] Newbold, J. W., Bianchi-Berthhouse, N., Gold, N. E., and Williams, A. (2015). Musically Informed Sonification for Self-Directed Chronic Pain Physical Rehabilitation. In *Sound and Music Computing*.

[Nogalski and Fohl, 2016] Nogalski, M. and Fohl, W. (2016). Acoustic redirected walking with auditory cues by means of wave field synthesis. In *2016 IEEE Virtual Reality (VR)*, pages 245–246. IEEE, Citeseer.

[Notthoff and Carstensen, 2014] Notthoff, N. and Carstensen, L. L. (2014). Promoting walking in older adults: Perceived neighborhood walkability influences the effectiveness of motivational messages. *Journal of Health Psychology*.

[Oakes et al., 2015] Oakes, K., Siek, K. A., and MacLeod, H. (2015). MuscleMemory: identifying the scope of wearable technology in high intensity exercise communities.

In *International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth)*, pages 193–200. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[Olugbade, 2015] Olugbade, T. (2015). Pain Level Recognition using Kinematics and Muscle Activity for Physical Rehabilitation in Chronic Pain. In *2015 International Conference on Affective Computing and Intelligent Interaction (ACII)*.

[Olugbade et al., 2014] Olugbade, T. A., Aung, M. H., Bianchi-Berthouze, N., Marquardt, N., and Williams, A. C. (2014). Bi-Modal Detection of Painful Reaching for Chronic Pain Rehabilitation Systems. In *Proceedings of the 16th International Conference on Multimodal Interaction - ICMI '14*, pages 455–458, New York, New York, USA. ACM Press.

[O'Reilly et al., 2015] O'Reilly, M., Whelan, D., Chanialidis, C., Friel, N., Delahunt, E., Ward, T., and Caulfield, B. (2015). Evaluating squat performance with a single inertial measurement unit. In *2015 IEEE 12th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*, pages 1–6. IEEE.

[Patel et al., 2016] Patel, M., Asch, D., Rosin, R., and et al (2016). Framing financial incentives to increase physical activity among overweight and obese adults: A randomized, controlled trial. *Annals of Internal Medicine*, 164(6):385–394.

[Patel and O'Kane, 2015] Patel, M. and O'Kane, A. A. (2015). Contextual influences on the use and non-use of digital technology while exercising at the gym. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 2923–2932. ACM.

[Petrini et al., 2015] Petrini, K., Jones, P. R., Smith, L., and Nardini, M. (2015). Hearing where the eyes see: Children use an irrelevant visual cue when localizing sounds. *Child Development*, 86(5).

[Pizzera and Hohmann, 2015] Pizzera, A. and Hohmann, T. (2015). Acoustic Information During Motor Control and Action Perception: A Review. *The Open Psychology Journal*, 8(1):183–191.

[Polotti and Rocchesso, 2008] Polotti, P. and Rocchesso, D. (2008). *Sound to Sense , Sense to Sound A State of the Art in Sound and Music Computing.* Logos Verlag Berlin GmbH.

[Posner et al., 1976] Posner, M. I., Nissen, M. J., and Klein, R. M. (1976). Visual dominance: an information-processing account of its origins and significance. *Psychological review*, 83(2):157.

[Preece et al., 2005] Preece, J., Rogers, Y., and Sharp, H. (2005). *Interaction design : beyond human-computer interaction.* J. Wiley & Sons.

[Prensner and Yowler, 2001] Prensner, J. and Yowler, C. (2001). Music therapy for assistance with pain and anxiety management in burn treatment. *The Journal of burn care & rehabilitation.*

[Repp, 2005] Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review*, 12(6):969–992.

[Rocchesso et al., 2008] Rocchesso, D., Serafin, S., Behrendt, F., Bernardini, N., Bresin, R., Eckel, G., Franinovic, K., Hermann, T., Pauletto, S., Susini, P., and Visell, Y. (2008). Sonic interaction design: Sound, information and experience. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '08, pages 3969–3972, New York, NY, USA. ACM.

[Roddy, 2016] Roddy, S. (2016). *Embodied Sonification.* PhD thesis.

[Roddy and Bridges, 2018] Roddy, S. and Bridges, B. (2018). Sound, Ecological Affordances and Embodied Mappings in Auditory Display. pages 231–258. Springer, Cham.

[Roddy and Furlong, 2015] Roddy, S. and Furlong, D. (2015). Sonification listening: An empirical embodied approach. In *Proceedings of the 21st International Conference on Auditory Display (ICAD 2015).*

[Rodger and Craig, 2011] Rodger, M. W. M. and Craig, C. M. (2011). Timing movements to interval durations specified by discrete or continuous sounds. *Experimental Brain Research*, 214(3):393–402.

[Scaletti, 2018] Scaletti, C. (2018). Sonification$\neq$ music. *The Oxford Handbook of Algorithmic Music*, page 363.

[Schaffert et al., 2019] Schaffert, N., Janzen, T. B., Mattes, K., and Thaut, M. H. (2019). A review on the relationship between sound and movement in sports and rehabilitation. *Frontiers in Psychology*, 10:244.

[Schaffert et al., 2011] Schaffert, N., Mattes, K., and Effenberg, A. O. (2011). The sound of rowing stroke cycles as acoustic feedback. In *Proceedings of the 17th International Conference on Auditory Display (ICAD 2011)*. International Community for Auditory Display.

[Schellenberg, 1996] Schellenberg, E. G. (1996). Expectancy in melody: tests of the implication-realization model. *Cognition*, 58(1):75–125.

[Schellenberg et al., 2005] Schellenberg, E. G., Bigand, E., Poulin-Charronnat, B., Garnier, C., and Stevens, C. (2005). Children's implicit knowledge of harmony in Western music. *Developmental science*, 8(6):551–66.

[Schmitz et al., 2018] Schmitz, G., Bergmann, J., Effenberg, A. O., Krewer, C., Hwang, T.-H., and Müller, F. (2018). Movement Sonification in Stroke Rehabilitation. *Frontiers in neurology*, 9:389.

[Scholz et al., 2015] Scholz, D. S., Rhode, S., Großbach, M., Rollnik, J., and Altenmüller, E. (2015). Moving with music for stroke rehabilitation: a sonification feasibility study. *Annals of the New York Academy of Sciences*, 1337(1):69–76.

[Schunk, 1982] Schunk, D. H. (1982). Effects of effort attributional feedback on children's perceived self-efficacy and achievement. *Journal of educational psychology*, 74(4):548.

[Schunk, 1995] Schunk, D. H. (1995). Self-efficacy, motivation, and performance. *Journal of applied sport psychology*, 7(2):112–137.

[Sears et al., 2014] Sears, D., Caplin, W. E., and McAdams, S. (2014). Perceiving the classical cadence. *Music Perception: An Interdisciplinary Journal*, 31(5):397–417.

[Serafin et al., 2011] Serafin, S., Franinovic, K., Hermann, T., Lemaitre, G., Rinott, M., and Rocchesso, D. (2011). Sonic interaction design. In *The Sonification Handbook*. Logos Verlag Berlin.

[Serafin et al., 2013] Serafin, S., Nilsson, N. C., Sikstrom, E., De Goetzen, A., and Nordahl, R. (2013). Estimation of detection thresholds for acoustic based redirected walking techniques. In *Virtual Reality (VR), 2013 IEEE*, pages 161–162. IEEE.

[Shieh et al., 2015] Shieh, C., Weaver, M. T., Hanna, K. M., Newsome, K., and Mogos, M. (2015). Association of self-efficacy and self-regulation with nutrition and exercise behaviors in a community sample of adults. *Journal of community health nursing*, 32(4):199–211.

[Sigrist et al., 2013] Sigrist, R., Rauter, G., Riener, R., and Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review*, 20(1):21–53.

[Singh, 2016] Singh, A. (2016). *Staying active despite pain: Investigating feedback mechanisms to support physical activity in people with chronic musculoskeletal pain*. Upgrade thesis, UCL (University College London).

[Singh et al., 2017] Singh, A., Bianchi-Berthouze, N., and Williams, A. C. (2017). Supporting everyday function in chronic pain using wearable technology. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 3903–3915. ACM.

[Singh et al., 2014] Singh, A., Klapper, A., Jia, J., Fidalgo, A., Tajadura-Jiménez, A., Kanakam, N., Bianchi-Berthouze, N., and Williams, A. (2014). Motivating People with Chronic Pain to Do Physical Activity: Opportunities for Technology Design. In *CHI '14*, CHI '14, pages 2803–2812, New York, NY, USA. ACM.

[Singh et al., 2016] Singh, A., Piana, S., Pollarolo, D., Volpe, G., Varni, G., Tajadura-Jiménez, A., Williams, A. C., Camurri, A., and Bianchi-Berthouze, N. (2016). Go-with-the-flow: Tracking, analysis and sonification of movement and breathing to build confidence in activity despite chronic pain. *HumanâĂŞComputer Interaction*, 31(3-4):335–383.

[Smith and Claveau, 2014] Smith, K. M. and Claveau, D. (2014). The Sonification and Learning of Human Motion. In *International Conference on Auditory Display*.

[Snelling, 1994] Snelling, J. (1994). The effect of chronic pain on the family unit. *Journal of advanced nursing*, 19(3):543–51.

[Sonstroem and Morgan, 1989] Sonstroem, R. J. and Morgan, W. P. (1989). Exercise and self-esteem: rationale and model. *Medicine and science in sports and exercise*, 21(3):329–37.

[Standage et al., 2003] Standage, M., Duda, J., and Ntoumanis, N. (2003). A model of contextual motivation in physical education: Using constructs from self-determination and achievement goal theories to predict physical activity intentions. *Journal of educational psychology*, 95(1):97.

[Steinicke et al., 2010] Steinicke, F., Bruder, G., Jerald, J., Frenz, H., and Lappe, M. (2010). Estimation of detection thresholds for redirected walking techniques. *Visualization and Computer Graphics, IEEE Transactions on*, 16(1):17–27.

[Strauss and Corbin, 1998] Strauss, A. and Corbin, J. (1998). *Basics of qualitative research techniques*. Sage publications Thousand Oaks, CA.

[Sullivan and Lachman, 2017] Sullivan, A. N. and Lachman, M. E. (2017). Behavior change with fitness technology in sedentary adults: A review of the evidence for increasing physical activity. *Frontiers in Public Health*, 4:289.

[Tajadura-Jiménez et al., 2015a] Tajadura-Jiménez, A., Basia, M., Deroy, O., Fairhurst, M., Marquardt, N., and Bianchi-Berthouze, N. (2015a). As light as your footsteps: altering walking sounds to change perceived body weight, emotional state and gait. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 2943–2952. ACM.

[Tajadura-Jiménez et al., 2019] Tajadura-Jiménez, A., Joseph, N., Linge, Z., Rick, P., and Bianchi-Berthouze, N. (2019). As light as you aspire to be: Changing body perception with sound to support physical activity. In *Proceedings of the 37th Annual ACM Conference on Human Factors in Computing Systems*. ACM.

[Tajadura-Jiménez et al., 2015b] Tajadura-Jiménez, A., Tsakiris, M., Marquardt, T., and Bianchi-Berthouze, N. (2015b). Action sounds update the mental representation of arm dimension: contributions of kinaesthesia and agency. *Frontiers in psychology*, 6:689.

[Tajadura-Jiménez et al., 2017a] Tajadura-Jiménez, A., Vakali, M., Fairhurst, M. T., Mandrigin, A., Bianchi-Berthouze, N., and Deroy, O. (2017a). Contingent sounds change the mental representation of one's finger length. *Scientific Reports*, 7(1):5748.

[Tajadura-Jiménez et al., 2017b] Tajadura-Jiménez, A., Väljamäe, A., Bevilacqua, F., and Bianchi-Berthouze, N. (2017b). Principles for Designing Body-Centered Auditory Feedback. In *The Wiley Handbook of Human Computer Interaction*, pages 371–403. John Wiley & Sons, Ltd, Chichester, UK.

[Tillmann et al., 1998] Tillmann, B., Bigand, E., and Madurell, F. (1998). Local versus global processing of harmonic cadences in the solution of musical puzzles.

[Turk and E.Rudy, 1987] Turk, D. C. and E.Rudy, T. (1987). IASP taxonomy of chronic pain syndromes: preliminary assessment of reliability. *Pain*, 30(2):177–189.

[Turk and Okifuji, 2002] Turk, D. C. and Okifuji, A. (2002). Psychological factors in chronic pain: evolution and revolution. *Journal of consulting and clinical psychology*, 70(3):678–690.

[Vallières et al., 2009] Vallières, M., Tan, D., Caplin, W. E., and McAdams, S. (2009). Perception of intrinsic formal functionality: An empirical investigation of mozartâĂŹs materials. *Journal of Interdisciplinary Music Studies*, 3(1-2):17–43.

[Varela et al., 1991] Varela, F., Thompson, E., and Rosch, E. (1991). The embodied mind: Cognitive science and human experience.

[Vickers, 2017] Vickers, P. (2017). Sonification and music, music and sonification. In *The Routledge Companion to Sounding Art*, pages 135–144. Routledge, London.

[Vickers et al., 2017] Vickers, P., Hogg, B., and Worrall, D. (2017). Aesthetics of sonification: Taking the subject-position. In Wöllner, C., editor, *Body, Sound and Space in Music and Beyond: Multimodal Explorations*, pages 89–109. Routledge.

[Vlaeyen and Linton, 2000] Vlaeyen, J. W. and Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art. *Pain*, 85(3):317–332.

[Vogt et al., 2009] Vogt, K., Pirró, D., and Kobenz, I. (2009). Physiosonic-movement sonification as auditory feedback. In *Proceedings of the 15th International Conference on Auditory Display, Copenhagen, Denmark*, volume 5954 LNCS, pages 1–7.

[Wallis et al., 2007] Wallis, I., Ingalls, T., Rikakis, T., Olsen, L., Chen, Y., Xu, W., and Sundaram, H. (2007). Real-Time Sonification of Movement for an Immersie Stroke Rehabilitation Environment. In Scavone, G. P., editor, *Proceedings of the 13th International Conference on Auditory Display (ICAD2007)*, pages 497–503, Montreal, Canada. Schulich School of Music, McGill University, Schulich School of Music, McGill University.

[Warburton et al., 2006] Warburton, D. E. R., Nicol, C. W., and Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne*, 174(6):801–9.

[Weller and Baker, 2011] Weller, C. M. and Baker, F. A. (2011). The role of music therapy in physical rehabilitation: a systematic literature review. *Nordic Journal of Music Therapy*, 20(1):43–61.

[Whelan et al., 2015] Whelan, D., O'Reilly, M., Ward, T., Delahunt, E., and Caulfield, B. (2015). Evaluating performance of the single leg squat exercise with a single inertial measurement unit. In *Proceedings of the 3rd 2015 Workshop on ICTs for improving Patients Rehabilitation Research Techniques*, pages 144–147. ACM.

[Woby et al., 2007] Woby, S. R., Urmston, M., and Watson, P. J. (2007). Self-efficacy mediates the relation between pain-related fear and outcome in chronic low back pain patients. *European journal of pain (London, England)*, 11(7):711–8.

[Wolpert and Ghahramani, 2000] Wolpert, D. M. and Ghahramani, Z. (2000). Computational principles of movement neuroscience. *Nature neuroscience*, 3 Suppl:1212–7.

[Yang and Hunt, 2014] Yang, J. and Hunt, A. (2014). Real-time auditory feedback of arm movement and EMG in biceps curl training to enhance the quality . In *SoniHED-Conference on Sonification of Health and Enviromental Data*, York, U.K.

[Zbikowski, 2009] Zbikowski, L. M. (2009). Music, language, and multimodal metaphor. *Multimodal metaphor*, pages 359–381.

# Appendices

## A. Information sheet for studies 5.2, 6.2, 6.3, 7.4, 7.5

Title of Project: **Emotion & Pain Project**

This study has been approved by the UCL Research Ethics Committee [Project ID Number]:
***UCLIC/1516/012/Staff Berthouze/Singh***

Name, Address and Contact Details of Investigators:

Prof. Nadia Bianchi-Berthouze
University College London Interaction Centre
2nd Floor, 66-72 Gower Street
London WC1E 6EA, United Kingdom
+44 (0)20 3108 7067

We would like to invite you to participate in this research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or you would like more information.

This project aims develop technology to help patients with chronic pain by providing tailored feedback and support for movements performed as part of self-directed rehabilitation.

We will interview you about the needs and uses for such technology. We will ask your opinion of current prototypes we have developed. We will ask you to do everyday activities, exercise or play computer games while wearing movement sensors and/or biosensors; you may also receive multimodal feedback, such as sound, while doing these activities, o inform you about your movement. The activities will be recorded using these sensors, thermal cameras, and video/audio recording. We will also ask you to complete pain questions or movement-related questionnaires.

All data will be handled according to the Data Protection Act 1998 and will be kept anonymous. Researchers working with Prof. Berthouze will analyze the data collected. The information gathered will be used to understand requirements for chronic pain physical rehabilitation technology.

With your permission, we would like to use extracts of the video and audio recordings to demonstrate to people with chronic pain how assistive technology can be used for the management of their condition. If you are not happy for your face to be visible, we will show videos with your face obscured.

With your permission, we would also like to use extracts of the video and audio recordings for teaching, conferences, presentations, publications, and/or thesis work. Please note that these presentations may be recorded by individuals without our knowledge and displayed on social media.

It is up to you to decide whether or not to take part. If you choose not to participate, it will involve no penalty or loss of benefits to which you are otherwise entitled. If you decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

# B. Consent form for studies 5.2, 6.2, 6.3, 7.4, 7.5

Title of Project: **Emotion & Pain Project**

This study has been approved by the UCL Research Ethics Committee [Project ID Number]: ***UCLIC/1516/012/Staff Berthouze/Singh***

**Participant's Statement**

I ……………………………………………......................................

agree that I have

- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study;
- read the guidelines on the use of computer game that may be used in the study;
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that my participation will be taped/video/sensors recorded and I am aware of and consent to the analysis of the recordings;
- I understand that I must not take part if I am not physically able to do the tasks;
- I agree to be invited in the future by UCL researchers to participate in follow-up studies.

For the following, please circle "Yes" or "No" and initial each point.

____I agree for the videotape to be used by the researchers in this project in further research studies YES / NO

____I agree for the videotape to be used by the researchers to demonstrate assistive technology to people with chronic pain and clinicians YES / NO

____I agree for the videotape to be used by the researchers for teaching, conferences, presentations, publications, and/or thesis work. I understand that these presentations may be recorded without the knowledge of the researchers by media or other individuals/researchers YES / NO

____ I agree for the videotape to be used in other projects by members of this research group YES / NO

____I agree for the videotape to be shared with researchers who are not involved in this project YES / NO

I understand that I am free to withdraw from the study without penalty if I so wish and I consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signed: Date:

**Investigator's Statement**

I ………………………………………………………………………..

confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date:

# C. Consent form for studies 5.3, 8.3, 8.4, 8.5

Title of Project: **Sonification for gym activity**

This study has been approved by the UCL Research Ethics Committee as Project ID Number: **UCLIC/1516/003/StaffBerthouze/Newbold**

**Participant's Statement**

I ……………………………………………………………………………

agree that I have

- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study; and
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that I must not take part if I am not physically able to do the tasks
- Given this I am happy to engage in mild physical activity and wear non-intrusive biosensors

For the following please circle "Yes" or "No" and initial each point.

_____ I agree for the videotape and photographs to be used by the researchers in further research studies YES / NO

_____ I agree for the videotape and photographs to be used by the researchers to demonstrate the technology YES / NO

_____ I agree for the videotape and photographs to be used by the researchers for teaching, conferences, presentations, publications and/or thesis work YES / NO

_____ I agree to be contacted in the future by UCL researchers who would like to invite me to participate in follow-up studies YES / NO

I understand that I am free to withdraw from the study without penalty if I so wish, and I consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signed: Date:

**Investigator's Statement**

I ……………………………………………………………………………..

confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date:

# D. Information sheet for studies 5.3, 8.3, 8.4, 8.5

Title of Project: **Sonification for gym activity**

This study has been approved by the UCL Research Ethics Committee as Project ID Number:
**UCLIC/1516/003/StaffBerthouze/ Newbold** ______________________________

| Name, Address and Contact Details of Investigators: | Dr Nadia Bianchi-Berthouze<br>UCL Interaction Centre<br>66 - 72 Gower Street,<br>London WC1E 6EA<br>United Kingdom<br>020 3108 7067 |
|---|---|

We would like to invite you to participate in this research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or you would like more information.

This project aims develop technology to help people doing exercise by providing feedback on their movement performance quality and provide motivation during physical activity. Within this study we may ask you to complete some mild physical activity, so we ask that you only take part if you are able to do so and that you don't know have any physical disability, pain or heart condition that would affect your ability to engage in physical activity. During the study, the amount of activity you take part in is up to you and should you desire to or feel you cannot continue you may take a break or stop doing the activity.

We will be interviewing you to gather the needs for such technology. We may also ask you to try current available technology to motivate and measure physical activity. Hence we may ask you to wear biosensors (such as respiration sensor, movement sensors or Electromyography sensors) and do some physical activity while receiving multimodal feedback and. The activity may be recorded using motion capture technology, non-intrusive biosensors and/or video/ audio recording. We may also ask you to fill in a questionnaire about the experience.

All data will be handled according to the Data Protection Act 1998 and will be kept anonymous. Researchers working with Prof Nadia Berthouze will analyze the data collected. The information gathered will be used to understand the requirements for such a technology.

With your permission, we would like to use extracts of the video recording to demonstrate how technology can be used.

With your permission, we may want to use an extract of the video recording for teaching, conferences, presentations, publications, and/or thesis work.

It is up to you to decide whether or not to take part. If you choose not to participate, you won't incur any penalties or lose any benefits to which you might have been entitled. However, if you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Even after agreeing to take part, you can still withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection Act 1998.

# E. Consent form for Study 7.5 NHS recruitment

University College London Hospitals NHS
NHS Foundation Trust

**Pain Management Centre**
National Hospital for Neurology & Neurosurgery
Queen Square, London WC1N 3BG

Telephone: 0845 155 5000 ext 72-3487
Fax: 020 7419 1714
web-site: www.uclh.nhs.uk

Reference: CF-Evaluation-CP
Centre Number:
Participant Identification Number for this study:
UCLH Project ID number: 10/0514
Form version: 2.0
Date: 14/12/2012

## Consent Form for Evaluation of Technology

Title of project: **Automated psychological & physical feedback for chronic pain rehabilitation**
Name of Principal Investigator: Dr Nadia Berthouze

**Please initial box**

| | | |
|---|---|---|
| 1. | I ……..................……………….......confirm that I have read and understood the information sheet dated *14/12/2011 (version1.0)* for the above study and have had the opportunity to ask questions. | |
| 2. | I confirm that I have had sufficient time to consider whether or not I want to take part in the study | |
| 3. | I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. | |
| 4. | I agree that my evaluation session can be video taped YES/NO | |
| 5. | I agree for the video recording to be used during the study for this research study ONLY YES / NO | |
| 6. | I agree for the video recording to be used by the researchers of this study ONLY YES / NO | |
| 7. | I agree that my interview can be audio-recorded YES/NO | |
| 8. | I agree for the interview transcript to be used during the study for this research study ONLY YES / NO | |
| 9. | I agree for the interview transcript to be used by the researchers of this study ONLY YES / NO | |
| 10. | I agree to take part in the above study | |

**Participant:** _____________________________________ Date ____________ Signature _______________________

**Person taking consent:** ___________________________ Date ____________ Signature________________________

**Dr Nadia Berthouze** Date ____________ Signature ________________________
Researcher (to be contacted if there are any problems)

**Comments or concerns during the study**

If you have any comments or concerns you may discuss these with the investigator. If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL hospitals. Please quote the UCLH project number at the top this consent form.

UCL HOSPITALS

UCL Hospitals is an NHS Foundation Trust incorporating the Eastman Dental Hospital, Elizabeth Garrett Anderson & Obstetric Hospital, The Heart Hospital, Hospital for Tropical Diseases, National Hospital for Neurology & Neurosurgery, The Royal London Homoeopathic Hospital and University College Hospital.

University College London Hospitals NHS
NHS Foundation Trust

**Pain Management Centre**
National Hospital for Neurology & Neurosurgery
Queen Square, London WC1N 3BG

Telephone: 0845 155 5000 ext 72-3487
Fax: 020 7419 1714
web-site: www.uclh.nhs.uk

Reference: CF-Video
Centre Number:
Participant Identification Number for this study:
UCLH Project ID number: 11/0514
Form version: 1.0
Date: 14/12/2011

## Consent form for video recording evaluation (CF-Video)

Title of project: **Automated psychological & physical feedback for chronic pain rehabilitation**
Name of Principal Investigator: Dr Nadia Berthouze

**Please initial box**

| | | |
|---|---|---|
| 1. | I agree for the videotape to be used by the researchers for teaching or conference presentations<br>YES / NO | |
| 2. | I agree for the videotape to be used in other projects by members of this research group<br>YES / NO | |
| 3. | I agree for the videotape to be shared with researchers who are not involved in this project<br>YES / NO | |

**Participant:** ______________________________ Date ____________ Signature _________________________

**Person taking consent:** ______________________________ Date ____________ Signature_________________________

**Dr Nadia Berthouze** Date ____________ Signature _________________________
Researcher (to be contacted if there are any problems)

**Comments or concerns during the study**

If you have any comments or concerns you may discuss these with the investigator. If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL hospitals. Please quote the UCLH project number at the top this consent form.

# F. Information sheet for Study 7.5 NHS recruitment

University College London Hospitals NHS
NHS Foundation Trust

**Pain Management Centre**
National Hospital for Neurology & Neurosurgery
Queen Square, London WC1N 3BG

Telephone: 0845 155 5000 ext 72-3487
Fax: 020 7419 1714
web-site: www.uclh.nhs.uk

Reference: IS-Evaluation-CP
UCL Project ID number: 10/0514
REC number:
Form version: 1.0
Date: 14/12/2011

1. **Study title**

   **Automated psychological & physical feedback for chronic pain rehabilitation**

2. **Invitation paragraph**

   You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. **What is the purpose of the study?**

   The influence of pain on everyday life can be considerable. Pain is a complex and intense experience affecting the way we feel, move and approach different situations. This project aims to develop a technology to encourage people with chronic pain to do more physical activity and give feedback on the activity. In order to evaluate the effectiveness of the technology in giving feedback, we need people with chronic pain to try the technology and tell us how they experience it.

4. **Why have I been invited?**

   We are asking people with chronic low back pain to volunteer for this study.

5. **Do I have to take part?**

   It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and you will be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the care you receive.

6. **What is involved in the study?**

This project aims develop healthcare technology to help patients with chronic pain by providing feedback on their movement performance and psychological support during self-directed rehabilitation.

You will be introduced to the technology and given an introduction and demonstration of the technology. You can then try the technology if you wish for a maximum duration of 5 minutes at a time. This will involve doing physical activity like bending, stretching, and walking. The duration of physical activity will not exceed 30 minutes. A researcher will always be present with you. You may be asked to wear some motion sensors, heart rate monitor or EMG sensors (sensors to measure muscle activity). These sensors will not do any harm and are often used in therapy. If at any stage of the activity you feel uncomfortable, you can withdraw from the study. After the evaluation session, there will be a short interview to discuss your experience with the technology. You will be video recorded during the activity session and audio recorded during the interview. All data will be held in accordance with the data protection act.

7. **What are the possible benefits of taking part?**

There is no direct benefit to you from taking part in this study: we are asking you to do it to help design a technology to support and motivate physical activity in people with chronic pain.

8. **How will Information be kept?**

A unique research ID number will be assigned to the information we collect from you, and any personal identifiable information, such as your name and data of birth, will be in a separate file and not linked directly with the rest of the information.

All the information collected will be treated according with the Data Protection Act 1998 and UCL Data Protection Act Policy 2000 (http://www.ucl.ac.uk/efd/recordsoffice/data-protection/). Paper records will be stored in locked filing cabinets. Digital information (e.g. your movement data and the video recording which will be encrypted) will be stored in password protected and secure computers to be used by researchers involved in the project.

9. **What if something goes wrong?**

Every care will be taken in the course of this study. However, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated by members of staff or about any side effects (adverse events) you may have experienced due to your participation in the study, the normal National Health Service complaints mechanisms are available to you. Please ask to a member of the research team if you would like more information on this. Details can also be obtained from the Department of Health website: http://www.dh.gov.uk

10. **What will happen to the results of the research study?**

This research project is 4 years long, and we would hope to publish and disseminate the results, or to present them at conferences, during and after the project. During the

# G. Adapted GMSI [Müllensiefen et al., 2014], for general musical sophistication and musical training subscales

1. I spend a lot of my free time doing music-related activities.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

2. I enjoy writing about music, for example on blogs and forums.

| 1 | 2 | 3 | | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

3. If somebody starts singing a song I don't know, I can usually join in.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

4. I can sing or play music from memory.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

5. I am able to hit the right notes when I sing along with a recording.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

6. I can compare and discuss differences between two performances or versions of the same piece of music.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

7. I have never been complimented for my talents as a musical performer.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

8. I often read or search the internet for things related to music.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

9. I am not able to sing in harmony when somebody is singing a familiar tune.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

10. I am able to identify what is special about a given musical piece.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

11. When I sing, I have no idea whether I'm in tune or not.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

12. Music is kind of an addiction for me - I couldn't live without it.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

13. I don't like singing in public because I'm afraid that I would sing wrong notes.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

14. I would not consider myself a musician.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

15. After hearing a new song two or three times, I can usually sing it by myself.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

16. I engaged in regular, daily practice of a musical instrument (including voice) for **0 / 1 / 2 / 3 / 4-5 / 6-9 / 10** or more years.

17. At the peak of my interest, I practiced **0 / 0.5 / 1 / 1.5 / 2 / 3-4 / 5 or more** hours per day on my primary instrument.

18. I can play **0 / 1 / 2 / 3 / 4 / 5 / 6 or more** musical instruments.

19. I have had formal training in music theory for **0/ 0.5 / 1 / 2 / 3 / 4-6 / 7 or more** years

20. I have had **0 / 0.5 / 1 / 2 / 3-5 / 6-9 / 10** or more years of formal training on a musical instrument (including voice) during my lifetime.

# H. Materials Study 5.2

Stability Ratings- M1C1

1. **At the end of the movement did you feel the music should have:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Concluded — Continued

2. **Were you motivated to continue moving at the end of the sound?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Very motivated — Very un-motivated

3. **At the end of the movement I felt rewarded**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Not very rewarded — Very rewarded

4. **How far do you feel you stretched?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Minimum — Maximum

# I. Materials Study 5.3

Stability Ratings- M1C1

**1. At the end of the movement did you feel the music should have:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Concluded | Continued

**2. Were you motivated to continue moving at the end of the sound?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Very motivated | Very un-motivated

**3. At the end of the movement I felt rewarded**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Strongly disagree | Strongly agree

**What was the maximum angle that you believe you reached at the end of the squat?**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |

# J. Materials Study 6.2

**1. At the end of the movement did you feel the music should have:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Concluded — Continued

**2. Were you motivated to continue moving at the end of the sound?**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Very motivated — Very un-motivated

**3. At the end of the movement I felt rewarded**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Strongly disagree — Strongly agree

# K. Materials Study 6.3

I. Sound Name ___________________________________

**Demo sound** ☐

| | **1 not at all** | **2** | **3** | **4** | **5** | **6** | **7 completely** |
|---|---|---|---|---|---|---|---|
| **At the end of the movement did you feel the music should have:** | | | | | | | |
| **At the return did you feel the music should have:** | | | | | | | |
| **How confident are you that you reached the target** | | | | | | | |
| **How informative did you find to sound?** | | | | | | | |
| **At the end of the movement I felt rewarded** | | | | | | | |
| **How would you rate the pacing of your movement** | | | | | | | |

# L. Materials Study 7.5

Date: ________________

Id: ________________

## Reach Forward feedback study

**A. To filled by participant at the start**

1. Age**:** ______
2. Gender: (circle appropriate) Male Female Other_______
3. Years with pain ______
4. What movements do you face difficulty with?
5. How confident are you in competing the reach forward movement?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Not confident Very confident

6. How anxious are you in competing the reach forward movement

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | | | | | | |

Not anxious Very anxious

Usual pain out of 10 ______

Current pain out of 10 ______

Date: ________________

Id: ________________

I. Sound Name ________________________________

II. Demo sound ☐

| | 1<br>not at all | 2 | 3 | 4 | 5 | 6 | 7<br>completely |
|---|---|---|---|---|---|---|---|
| **At the end of the movement did you feel the music should have continued** | | | | | | | |
| **How motivated were you to reach the end of the movement** | | | | | | | |
| **How informative did you find to sound?** | | | | | | | |
| **At the end of the movement I felt rewarded** | | | | | | | |

**Pain Score out of ten ____**

**Maximum angle ___**

How did you use the feedback? Thoughts?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

# M. Materials Study 8.5

Date: ___________________

Id: ___________________

## Squat feedback study

**A. To filled by participant at the start**

1. Age**:** ______
2. Gender: (circle appropriate) Male Female Other
3. Do you engage in regular physical activity?
4. How many hours per week?

☐ Under 1 hour ☐ 1 – 3 hours ☐ 3 – 7 hours ☐ 7 – 15 hours ☐ Over 15 hours

5. If yes, please describe it.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

6. What movements do you face difficulty with? ✓ for struggle with X for never done

☐ Squats ☐ Lunges ☐ Chin up ☐ Push up ☐ Back extension ☐ Sit-ups

Date: ___________________

Id: ___________________

If you were asked to do a certain number of squats **<u>RIGHT NOW</u>**, how certain are you that you complete each set lift described below?

Rate your degree of confidence by recording a number from 0 to 100 using the scale given below. You can write any number from 0 to 100 (e.g. 42).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

**Cannot** **Moderately** **Highly certain**

**do at all** **can do** **can do**

| **Squats** | **Confidence (0-100)** |
|---|---|
| A set of 5 squats | |
| A set of 10 squats | |
| A set of 15 squats | |
| A set of 20 squats | |
| A set of 30 squats | |
| A set of 50 squats | |
| A set of 80 squats | |
| A set of 100 squats | |

Date: _________________

Id: _________________

I. Sound Name __________________________________

II. Goal _____________Per_____________Actual_______________

III. How confident are you in competing your goal? 1-7 _________________

IV. **Demo sound**☐

| | 1 not at all | 2 | 3 | 4 | 5 | 6 | 7 completely |
|---|---|---|---|---|---|---|---|
| **At the end of the movement did you feel the music should have:** | | | | | | | |
| **How motivated for each squat** | | | | | | | |
| **To continue the squats** | | | | | | | |
| **How informative did you find to sound?** | | | | | | | |
| **At the end of the movement I felt rewarded** | | | | | | | |
| **How would you rate the quality of your squats** | | | | | | | |

| # | Level of Exertion |
|---|---|
| 6 | No exertion at all |
| 7 | |
| 7.5 | Extremely light (7.5) |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard (heavy) |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

I. How did you use the feedback? Thoughts?

______________________________________________________________________________
______________________________________________________________________________

Date: ___________________

Id: ___________________

Now please circle the number you think that best expresses your level of agreement with the sentences below.

**During the experience I felt:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

**Slow** **Quick**

**During the experience I felt:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

**Light** **Heavy**

**During the experience I felt:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

**Weak** **Strong**

**During the experience it felt I was squatting:**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

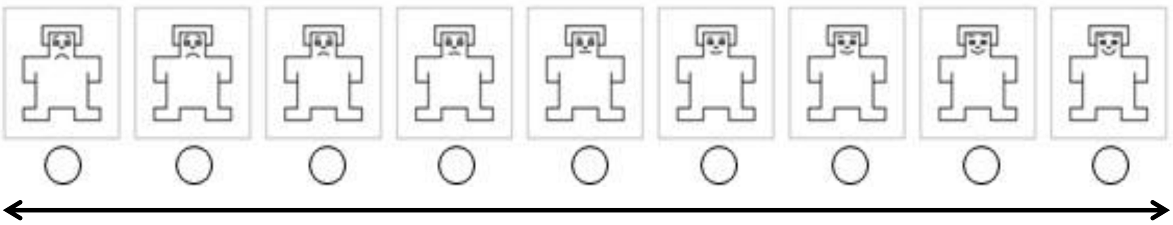
**Stooped, Hunched** **Straight**

Date: _________________

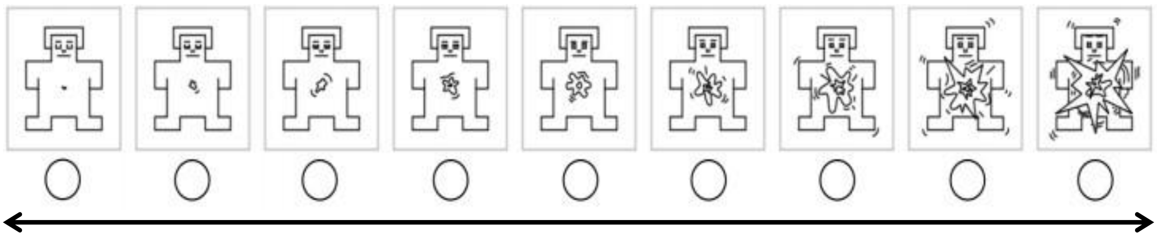
Id: _________________

How did you feel during the experience?

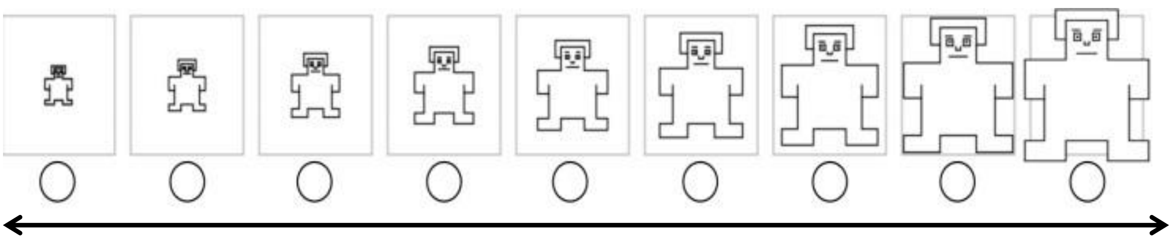
You will have to rate the way you felt by selecting a figure from each of 3 different scales. Each scale shows different kind of feelings: happy/positive vs unhappy/negative, aroused/excited vs unaroused/calm, dominant/important vs submissive/awed (slightly frightened).



**Unhappy, Negative** **Neutral** **Happy, Positive**



**Unaroused, Calm** **Neutral** **Aroused, Excited**



**Submissive, Awed** **Neutral** **Dominant, Important**