

Go large: The impact of size on gestural interaction in digital musical instrument design

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Submitted in partial fulfilment of the requirements
of the University of London Degree of Doctor of
Philosophy

School of Electronic Engineering and Computer
Science, Queen Mary University of London



2022

Lia Mice: *Go large*: The impact of size on gestural interaction in digital musical instrument design

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Thesis Submitted: 17 December, 2022

Viva Voce: 24 February, 2023

Abstract

This research is about the impact on musical gestural interaction of over-sized Digital Musical Instrument (DMI) design, that is instruments with physical dimensions that are larger than the human body performing them, but smaller than the size of the room they are in.

When interacting with an interface not only does the performer move their body to control the interface, the interface design and affordances control the way the performer moves their body. In the context of DMIs, two instruments with the same sonic capabilities will elicit different patterns of gestural interaction depending on their physical layout. Using the methodology of designing instruments for the purpose of exploring research questions, this research examines the gestural interaction and music made by musicians performing with large DMIs to investigate impact of instrument size on music making.

In this thesis I propose a process of investigating gestural interaction and how it shapes compositional choices through two studies. Each study examines the relative effects on performance and composition of various factors of affordances and idiomatic gestural language performed with large DMIs.

Studying performer interactions and music composed with large instruments with novel layouts that participants have not yet developed idiomatic gestural languages for results in new discoveries that are relevant to the design of large instruments as well as instruments of all sizes.

This research is relevant for digital musical instrument designers and Human Computer Interaction researchers as it will elucidate the influence that a DMI's physical size and layout has on the performances and compositions created using digital musical instruments, so that designers can make informed decisions to either support or suppress specific influences in future DMI design. Further, this research contributes the design of a new digital musical instrument, Chaos Bells, that can be used by digital musical instrument performers and researchers in the future.

Acknowledgements

I would like to thank all the inspiring artists out there making new instruments and extraordinary music with them. Thanks to all the new instrument researchers for expanding my mind and welcoming me into your world. I like it here. I think I'll stay.

In 2017, one week before the MAT PhD application deadline, I cold emailed Andrew McPherson with the wild idea that I would like to do a PhD with a focus on instrument design. Not only did Andrew make time to meet up with me and encourage me to apply, he regularly met with me for the following five years, supervising this PhD and mentoring me in research practices, academic writing and instrument design. I learned so much from Andrew, not least of all how to be a better human being. Around the mid-point of this PhD, I got a migraine that lasted a six months, coupled with non-stop double vision that I am still trying to manage. Andrew continued to regularly check in with me even though my ability to work was at a standstill. Thanks to Andrew's patience and endless encouragement I never lost focus and only gained enthusiasm for this research. Submitting this thesis is bittersweet as it marks the end of this sublime era of my life. Thank you Andrew.

Thank you Nick Bryan-Kinns (my wonderful second supervisor and director of the MAT PhD programme) and Atau Tanaka for offering invaluable insight and guidance during my PhD stage reviews. Our conversations ultimately shaped the trajectory of this research.

It would not have been possible to conduct this research without the insight and perspectives of expert musicians. I am eternally grateful for each and every musician who contributed their time and energy towards these studies.

The researchers, instrument designers and musicians that comprise the Augmented Instruments Laboratory have been inspiring and supportive peers throughout this research and provided much needed humour in the darkest hours such as those right before a conference submission deadline. Thank you all!

Research requires funding and this research would not be possible without financial support from the EPSRC under grants EP/L01632X/1 (Centre for

Doctoral Training in Media and Arts Technology).

The embedded technology and software that I modified to create the study instrument was developed by the folks at <https://bela.io/> and CHAIR Audio (the Centre for Haptic Audio Interaction Research), both of whom came to my rescue at various times throughout this research when I found myself in a pickle with an instrument study imminent. Thank you for your kindness and sharing your knowledge with me.

Too many people to name have contributed to my ability to do this work by cheering me on every step of this marathon. I would like to specifically thank the greatest friend the universe has ever magically created Janine A’Bear, and the love of my life Alex Wallwork.

Declaration

I, Lia Mice, confirm that the research included within this thesis is my own work or that where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged throughout.

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17 December, 2022

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Publications

Portions of the work detailed in this thesis have been presented in international scholarly publications, as follows:

- Chapter 3: Mice, L., McPherson, A. P.: *Embodied cognition in performers of large acoustic instruments as a method of designing new large digital musical instruments*. In: Proceedings of the 14th International Symposium on Computer Music Multidisciplinary Research. Marseille, France. (2019)
- Chapter 5: Mice, L., McPherson, A. P.: *From Miming to NIMEing: the Development of Idiomatic Gestural Language on Large Scale DMIs*. In: Proceedings of the International Conference on New Interfaces for Musical Expression (NIME). Birmingham, UK. (2020)
- Chapter 6: Mice, L., McPherson, A. P.: *Super Size Me: Interface Size, Identity and Embodiment in Digital Musical Instrument Design*. In: Proceedings of the Conference on Human Factors in Computing Systems (CHI). New Orleans, USA. (2022)
- Chapter 7: Mice, L., McPherson, A. P.: *The M in NIME: Motivic analysis and the case for a musicology of NIME performances*. In: Proceedings of the International Conference on New Interfaces for Musical Expression (NIME). Auckland, NZ. (2022)
- Chapter 8: Mice, L., McPherson, A. P.: *Chaos Bells: Instrument size and entangled music performance*. In: Contemporary Music Review. (2023)

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Chapter 1

Introduction

This chapter contains some material from ‘Embodied cognition in performers of large acoustic instruments as a method of designing new large digital musical instruments’ by Mice and McPherson, originally published in the proceedings of the Fourteenth International Symposium on Computer Music Multidisciplinary Research, 2019 [119].

This research is about the impact of instrument size on gestural interaction. Specifically it examines how the dimensions and layout of a Digital Musical Instrument (DMI) shapes the idiomatic gestural language which in turn influences performers’ compositional choices.

DMIs are not confined to the same laws of physics that govern traditional musical instruments. Unlike acoustic musical instruments, the size, shape and materiality of DMIs do not necessarily influence its sonic affordances. An acoustic double bass is larger than a violin because it is physically impossible for a violin string to create the low frequency of a double bass, however a digital version of either instrument could be any size. As DMIs can be any shape and dimension, how do physical design choices impact the performances created with DMIs?

In rejection of the anthropocentric approaches of traditional HCI that regard an instrument and performer as independent entities, emerging *entanglement theories* of HCI [52], including actor-network theory [95] and postphenomenology [183], assert that musicality emerges when an object or person is part of a musical system [188], and each factor within the system contributes to the dynamic formation of instrument and performer identities. I am interested in finding out the role that size plays in musical systems.

Through an interview-based study examining the impact that instrument size has on performers of large acoustic instruments and two laboratory-based studies examining musicians’ compositional choices when interacting with a

large DMI, this research gains new insight into the relationship between instrument affordances and aesthetic features, such as size and layout; the development of idiomatic gestural language and in turn performances; and the role of instrument size on musical entanglements.

This research is relevant to DMI researchers, such as the New Interfaces For Musical Expression (NIME) community, as well as Human Computer Interaction (HCI) researchers working with physical interfaces.

1.1 Motivation and aims

Through elucidating the ways in which the size of large instruments influence performance, instrument designers can learn about the ways large instruments are more than small instruments scaled up, and consider the impact of size-related affordances when designing new instruments. Now that DMIs can be any shape and dimension, and performed with virtually any gesture, exploring the impact of instrument size on performer's choices is useful for DMI designers when deciding what size to create instruments. As music production increasingly takes place in the home (due to faster consumer computers capable of running professional grade digital audio workstations), there is a trend in commercial DMI design of scaling down instruments and interface dimensions, resulting in smaller and smaller '*desktop*' instruments such as the Korg Volca series of miniature synthesizers. But what is lost when an instrument is scaled down? More research is needed to understand the true impact of an instrument's size and dimensions on music creation and performance.

1.2 My personal motivations for researching large DMIs

My motivation to undertake this research is informed by my musical background, interests and experiences with large DMIs. My first instrument was piano, which I learned I learned from age five to age nine, but I consider my primary instrument to be trumpet, which I learned from ages nine to 16 and performed in high school orchestras and jazz bands. Despite over a decade of classical training, pop music was my true passion, having spent my childhood listening to cassettes of both mainstream and underground artists, day and night. At 14 I bought a secondhand electric bass guitar which I taught myself by playing along with a video recording of a live concert by The Cure¹. I spent my late teens and early 20's touring Australia in bands, one of which signed to a major label.

¹www.thecure.com

At 30 I began a solo practice performing and self-producing electronic music. I have since performed my solo live set in 15 countries in venues ranging from *DIY* parties (in boats, underground bunkers and at top of clock towers) to high art institutions including London’s Tate Modern and New York’s Museum of Arts and Design. In the early 2010’s while developing my solo electronic live set I became interested in large DMIs. In 2012 I opened for Daedelus² in Calgary, Canada and was captivated by Archimedes [158], the large-scale robotic mirror light display that was part of Daedelus’ live performance. I thought ‘*If only it made sound!*’ Around this time I discovered large DMIs by Andy Cavatorta [110] and Kathy Hinde [73]. These large sculptural instruments first interested me because of their capacity to instill a sense of awe in the audience. However it was not until beginning this PhD research in 2017 that I considered exploring the ways that instrument size contributes to music performance, and it is through this research that I built my own large DMI (Chapter 4). While my solo music is situated in the experimental ‘DIY’ counterculture and I have no aspirations to return to performing and releasing within the mainstream music industry, there is no reason that large DMIs should forever remain situated in the alternative counterculture. I can imagine a future in which mainstream pop artists perform large-scale digital instruments at music festivals and arenas.

1.3 Central research questions

The key research questions contained within this research are:

- Question 1: How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?
- Question 2: By conducting research with instruments that are physically larger than the performer’s body, what can we learn about instruments of all sizes with regards to the impact that design choices have on performance and compositional choices?

1.4 Methodology

The work done in this thesis involved a series of studies conducted through a variety of methods inspired by prior work in HCI and DMI research. Each study was independently evaluated and the results informed the design of the subsequent studies. This research began with an interview-based scoping study

²[https://en.wikipedia.org/wiki/Daedelus_\(musician\)](https://en.wikipedia.org/wiki/Daedelus_(musician))

in which performers of large acoustic instruments discussed ways that the size of large instruments contribute to musical features and interactions that are not possible with smaller versions of the same instrument. The findings of the Scoping Study influenced the design of a large DMI, Chaos Bells, that was created for use in two laboratory-based studies.

While some HCI research into large DMI performance has been conducted from the perspective of the audience [11], this research focuses on gaining insights from the perspective of the performer, the most common perspective explored within performance context NIME research [6].

1.4.1 Methods of data collection

Designing instruments for the purpose of exploring research questions

This research is conducted through the methodology of designing instruments for the purpose of exploring the research questions. This methodology has been used within HCI in the NIME and DMI designer community in previous studies to successfully deliver interesting insights into DMI design [67], [63], [83]. This methodology is particularly useful for this research as affordances of the instruments used in the study are designed-in, so as to probe the performers for insight into how performers respond to these affordances.

Laboratory based semi-structured interview sessions

This research uses the methodology of laboratory-based research studies conducted in the form of semi-structured interviews [146] in which participants engage with the study instrument in solo-sessions, during which time they respond to creative prompts and interview questions. This methodology is common in the NIME community due to its reliability to deliver comparable results [169], and compared to other ways to discover the participants' thoughts such as questionnaires, semi-structured interviews result in the ability for the interviewer to dig deeper into participants' responses [140].

During each study session that comprises this research, each participant was interviewed by the same investigator who instructed the participants to complete the creative prompts in the same order. The investigator referred to an interview script when introducing creative prompts and interviewing the participants, but deviated from the script at times to ask follow-up questions to encourage the participants to elaborate on their answers.

Each study session was video recorded. The Scoping Study sessions were video recorded from one angle, meanwhile the Study 1 and 2 sessions were video recorded from three angles to ensure all musical interactions and interview

responses were documented.

Study session locations

The Scoping Study interviews either took place in the musician's studio, the Listening Room (music studio) at Queen Mary University of London, or over `skype.com`.

For the duration of Studies 1 and 2, a dedicated location was required that included enough floor space for the installation of Chaos Bells (the large study instrument, discussed in Chapter 4) as well as specialist equipment including a PA system, three digital cameras and an audio recorder. The study instrument takes several hours to construct, therefore the most practical way of conducting the study sessions was to occupy a location for the duration of the research so as to leave the study instrument set up at all times. Fortunately the Performance Laboratory in the Engineering Building at Queen Mary University of London is purpose built for such studies. All Study 1 and 2 sessions were conducted in this location.

Rejected methodologies

Other methodologies were deemed unsuitable for this research for various practical reasons. Focus groups (a small group of participants gathered together for a group session to explore their perspectives through open questions) are generally avoided in new instrument design research due to the participants' ability to influence each other. Ethnography (observation of participants in their natural setting) was disregarded as a suitable methodology because, aside from the limited nature of the study instrument, its large size makes it unlikely to fit in musicians' personal music studios. Auto-ethnography (research that centres the researcher themselves) was avoided because I was more interested in the perspective of other musicians besides myself.

1.4.2 Participant selection

The study participants were carefully selected to result in the optimum data set that would be relevant for answering the central research questions. Therefore groups of participants were chosen so that the data generated could be adequately compared to one another. Participants were therefore selected in accordance to the following considerations:

Similar experience in performance and composition

The selected participants have comparable years of experience in traditional instrument performance and music composition. If the participants' background knowledge in musical performance and composition varied too much from one another, the results would not be comparable as the results may vary due to level of experience rather than other factors.

Similar cultural knowledge of Western music

Participants were selected that all have similar knowledge of Western music including a background in reading Western music notation, gained from learning an instrument such as piano or violin that requires reading western notation. This prerequisite for the studies was decided upon because it confirms that the participants are all drawing from a common cultural knowledge of music, which frames their improvised and fixed performances within the same context making them more comparable than performances that draw from varied music cultures.

Varied gestural musical skills

As the central research questions relate to the development of musical gestural languages and embodied musical interaction, the participants selected for Studies 1 and 2 were trained musicians with experience of embodied musical interaction.

As Study 1 focuses on the development of idiomatic gestural languages, it was important that the participants did not have a pre-existing skill set required to perform the study instrument. Therefore participants for this study were only selected if they had not previously seen or heard the study instrument, guaranteeing that the study session is the participant's first encounter with the instrument, and ensuring that they create a gestural language for its performance that is not biased by seeing other musicians performing with the instrument. To ensure that the participants had not seen or heard the study instrument, I made sure to not post any images of the instrument or performances with the instrument to social media until the completion of all Study 1 and 2 sessions.

During Study 1, when introducing the participants to the instrument, so as not to influence the development of an original gestural language, the instrument was not demonstrated by the investigator. Instead the participants were told that the instrument is intended to be played using two hands and optionally with the mallets provided.

During the first session of Study 2, so as to provide the same introduction of the instrument to all participants, when introducing the participants to the

instrument the investigator demonstrated some basic performance techniques for performing the instrument and explained the instrument’s tuning and pattern of tones.

So as to create data that reveals how musicians in general develop new musical languages, musicians were selected that each have a range of musical instrument training, such as some who are trained in piano, some trained in guitar, and some trained in percussion. This way, similar gestures performed by musicians with different tacit knowledge can be identified as the idiomatic gestures of the study instrument.

1.4.3 Methods of analysis

Thematic analysis

The interview data for each study was analysed following a thematic analysis methodology [41] that took either a solely *a priori* approach (Scoping Study) or both an inductive (from the data) and *a priori* approach (Studies 1 and 2) [157]. Codes emerged through an iterative process [157], in that the raw interview data was examined for trends and correlations. Multiple iterations of coding were performed per set of study interviews, resulting in a codebook per study that was updated and refined at each coding iteration.

Interaction analysis

While interaction logs are a less common evaluation approach within the NIME community [151], I took this approach during Studies 1 and 2 to identify idiomatic gestures and physical performance patterns of the study instrument. Furthermore, I compared the outcomes of the interaction analyses to the layout of instruments assigned to the participants (Studies 1, 2a and 2b) and the music created with the instrument (Study 2b) to determine the impact of instrument size on these results.

My method of interaction analysis for Studies 1 and 2 was to watch the videos of each performance created by the participants and log each gesture performed by the participant, including which part of their body performed the gesture, and the location of the instrument. Once logged, the interaction analysis was further examined for repetitive performance patterns, such as alternating neighbouring tones or tones performed in sequential order according to location on the instrument, and whether the overall gestural interaction reveals a trend such as performing only tones located within a specific location of the instrument.

Motivic analysis

During Study 2a I analysed the musical content of the fixed concert performances created by the participants through a self-devised method of motivic analysis (outlined in Section 7.3). A musical motive is a small, analysable fragment of music or phrase important to or characteristic of a composition [134]. My method of motivic analysis was a two-step process. First I logged the elements of music present in each concert performance, then I selected from those elements only the elements that are important to or characteristic of the performance.

Elements of music that I logged during the motivic analysis included performance of:

- The lowest tone of the instrument
- The second lowest tone of the instrument
- The highest tone of the instrument
- A melody descending in minor third intervals (at least three tones in a row)
- A descending scale (all tones of the scale in order with no missing tones)
- An ascending scale (all tones of the scale in order with no missing tones)
- An extended drone (longer than 10 seconds) in the lower register (which tone)
- An extended drone (longer than 10 seconds) in the higher register (which tone)
- Juxtaposition of high and low registers performed at the same time (which tone)
- Rapid tremolo of a droning tone on the same tone or a neighbouring tone (which tone)
- Slow tremolo of a droning tone (which tone)
- Crescendo over multiple notes (which tone)
- Decrescendo over multiple notes (which tone)
- Melodic alternation of two tones (which tone)
- Harmonic intervals: intervals in the same register performed at the same time (which tones)

- *Ritardando* (becoming slower)
- *Accelerando* (becoming faster)

1.4.4 Limitations of data collection as a result of the chosen methodology

All research has limitations. This section outlines the limitations created by conducting this research in accordance with this methodology.

Limitations of musicians responding to creative prompts with a study instrument

Outside a laboratory environment, musicians provide themselves with their own creative prompts when composing and performing, and can select for themselves whichever instrument to perform at any given time. Therefore while this study reveals trends about performers' choices when playing Chaos Bells in response to the creative prompts provided during each study session, it is important to acknowledge that the results should not be overstated to claim that when responding to the same creative prompts all musicians would make these choices when interacting with all large DMIs. In accordance with the aforementioned *entanglement theories of HCI*, instruments are only one component of any musical system and replacing the instrument would make changes to the overall musical entanglement. More research would be required before claims could be made about the meaning of this research in relation to other instruments.

Limitations of time

An important aspect of the study design was to create the most meaningful data to investigate in response to the central research questions within the limitations of the time available to the study participants and the researcher.

While designing the studies I was critically aware that if I asked for too much of the participants' time they may not complete the study sessions or volunteer to participate in the first place. I therefore designed the sessions to be the least possible inconvenience for each participant while gaining the maximum insight into the research questions. Even so, the methodology of data collection is time consuming for the participants for the following reasons:

- For each study (Scoping Study, Study 1 and Study 2), each participant, including those not selected for the studies, answered pre-selection questionnaires that took approximately five minutes.

- In the lead-up to each session each participant communicated with me via email to book in the study session. This sometimes involved several conversations before a final schedule was confirmed.
- With the exception of some Scoping Study participants who completed their study sessions in their own music studio or via `Skype.com`, each study session required participants to attend an in-person interview at Queen Mary University of London. Therefore each participant dedicated one hour of their time plus the time it takes for them to travel to and from Queen Mary University of London per session.

As a researcher working towards the outcomes of this research, I designed the studies to result in the maximum findings within the time frame available to me (full time for four years). For the researcher, this methodology of data collection and analysis is time consuming for the following reasons:

- To select participants such that the data would be comparable and would address the central research questions, each prospective participant was pre-interviewed to screen for their musical history, instruments performed, genres performed and availability.
- Scheduling the one-to-one sessions with each participant required communication and planning with each participant.
- Conducting the one-to-one sessions was in itself time consuming as each session required the attendance of the investigator (myself) for the entirety of the session.
- Analysing the video and interview data took many hours per session and involved transcribing the interview audio manually (Scoping Study and Study 1 interviews) or by an automated programme and then manually corrected (Study 2 interviews)
- Analysing the video footage of the participants' performances created in Studies 1 and 2 involved first editing the multiple camera angles together onto one video file, then notating the gestural performances, which took several hours per study session.
- Transcribing the concert performances (Study 2) involved watching and pausing each performance to manually notate the composition, which took approximately 20 minutes per three-minute performance.
- Conducting the thematic analysis of every interview (Scoping Study, Study 1 and Study 2) resulting in a codebook per study required many iterations

of reading the transcribed interviews to reveal the trends in the participants' answers and performances, which took weeks per study.

1.5 Statement of contributions

The main contribution of this thesis is the exploration of the role of physical dimensions of a DMI on musical performance. The following is a summary of the contributions of this thesis in the order they appear:

- In Chapter 3, I present design considerations for the design of large DMIs. These design considerations were developed based on findings from an interview-based scoping study with performers of large acoustic instruments about the musical affordances unique to large acoustic instruments.
- In Chapter 4, I describe the design of a new large DMI, Chaos Bells, for use in lab-based studies exploring the role of instrument size on music performance. This instrument was designed using the design considerations presented in Chapter 3
- In Chapter 5, I present insights on how the physical dimensions of an instrument influence gestural language, as discovered via a lab-based study with musicians interacting with Chaos Bells.
- In Chapter 6 I describe an investigation into the role of instrument size on musical entanglements and the formation of performer identities.
- In Chapter 7 I present a method of motivic analysis for analysing music performed with new instruments. Using this method of motivic analysis I highlight the role of instrument design choices such as dimensions and tonal layout on elements of music that are characteristic of music created with the instrument.
- In Chapter 8 I summarise the research, present insights gained from touring with a large DMI and consider ways that designers of smaller instruments can benefit from adopting the approaches of large instrument design.

1.6 Structure of this thesis

The structure of this thesis is as follows:

Chapter 2 is a review of the literature related to the topics of DMI research and large DMIs. It is split into three main sections: DMI research, frameworks

of DMI research, and large DMIs. ‘*DMI research*’ provides an introduction to key concepts and terminology of academic DMI research. ‘*Frameworks of DMI research*’ provides an overview of frameworks for exploring DMI design. ‘*Large DMIs*’ provides a state of the art of large DMI design and insights into the current trends and gaps in large DMI research.

Chapter 3 provides a scoping study exploring embodied cognition in performers of large acoustic instruments. Here, I interview seven performers of large acoustic instruments to explore the possible impact musical instrument dimensions may have on the performance of composed and improvised repertoire and how those affordances impact the performer’s choices.

Chapter 4 presents Chaos Bells, a new large digital musical instrument designed for use in this research. This chapter outlines why this new instrument was necessary as well as a technical description of the instrument and its various versions.

Chapter 5 presents Study 1, a lab-based study in which 10 musicians interact with Chaos Bells responding to various prompts. This chapter reveals the role of the instrument’s physical layout (a combination of the tonal layout and size) and the performers’ bodies on musical gestures and compositional patterns.

Chapter 6 presents Study 2a, a lab-based study that highlights the role of instrument size in the complex entanglement of bodies, instruments, social and cultural contexts which are present in musical performance.

Chapter 7 presents Study 2b, in which the findings of Study 2 are explored through motivic analysis to reveal that the physical layout of tones on Chaos Bells influences the melodies that are characteristic of each performance. Four motives are identified that I propose are characteristic to the instrument’s idiomatic writing, and I uncover the elements of instrument design that may influence their appeal.

Finally, Chapter 8 presents insights gained through touring with Chaos Bells and designing a desktop version of Chaos Bells. A discussion follows surrounding the ways that designing large instruments can benefit designers of instruments of all sizes.

Chapter 2

Background

Some content in this chapter appears in:

- ‘*From miming to NIMEing: The development of idiomatic gestural language on large scale DMIs*’ by Mice and McPherson, originally published in the *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2020 [120].
- ‘*Embodied cognition in performers of large acoustic instruments as a method of designing new large digital musical instrument*’ by Mice and McPherson, originally published in the *proceedings of the Fourteenth International Symposium on Computer Music Multidisciplinary Research*, 2019 [119].
- ‘*Super size me: Interface size, identity and embodiment in Digital Musical Instrument design*’ by Mice and McPherson, originally published in the *proceedings of the Conference on Human Factors in Computing Systems (CHI)*, 2022 [121].
- ‘*The M in NIME: Motivic analysis and the case for a musicology of NIME performances*’ by Mice and McPherson, originally published in the *proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, 2022 [122].

This chapter provides an overview of the the themes of large DMIs, an understanding of musical systems and a discussion of frameworks and methodologies used for the design and research of DMIs. I identify gaps in the research about the influence of aesthetic features such as size, scale and layout of DMIs on music performance; and discuss potential frameworks for conducting DMI research to close these gaps. But first, I provide an overview of my musical history to provide context surrounding my interests in conducting this research in the first place.

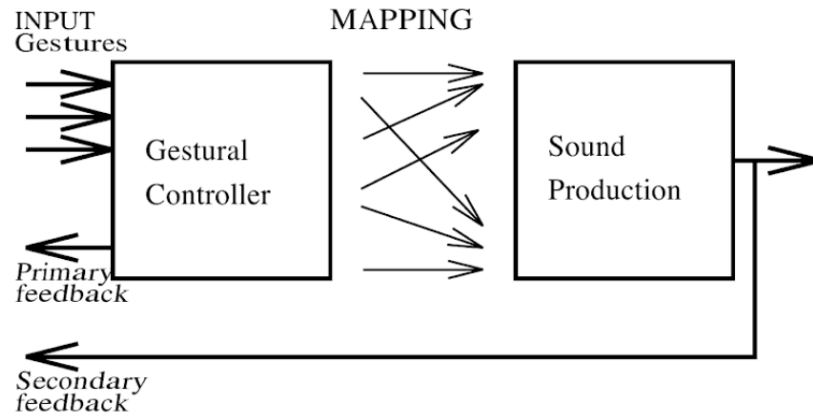


Figure 2.1: A possible representation of a DMI [126, page 3]

2.1 DMI research

2.1.1 What DMI means in this thesis

DMI has many definitions, partly because the practice of designing and performing DMIs is still emerging [12]. In 2006, Miranda and Wanderley [126, page 3] defined a DMI as ‘*an instrument that contains a control surface (also referred to as a gestural or performance controller, an input device, or a hardware interface) and a sound generation unit. Both units are independent modules related to each other by mapping strategies.*’ Figure 2.1 shows a possible representation of a DMI according to this definition [126, page 3]. As the practice of DMI design continues to develop so too does the technology, and the definition of DMI may well now include any range of input sensors as well as automated, virtual and hybrid musical systems. As a result, Cadoz [26] argues the ‘*I*’ (instrument) in ‘*DMI*’ has been overextended, and offers the term ‘*instrumental interaction*’ to differentiate instruments that require performance via a mechanical process through which there is an energetic exchange. In this thesis I will therefore draw on Miranda and Wanderley’s and Cadoz’s definitions of DMIs and primarily discuss gesturally controlled DMIs that require ‘*instrumental interaction*’ for performance.

2.1.2 DMI performance

Musical gesture is defined by Miranda and Wanderley as ‘*any human action used to generate sounds*’ and includes actions such as ‘*grasping, manipulation, and noncontact movements*’ as well as ‘*general voluntary body movements*’ [126].

Musical gestures that are well suited for an instrument so as to feel natural are often called ‘*idiomatic*’ [79]. Tanaka points out that ‘*the lack of history that new instruments enjoy means that what is idiomatic has not yet been defined. There is a priori no codified performance practice for a new instrument - this must be created for each new sensor instrument*’ [173]. Tahiroğlu et al. surveyed the emergence of idiomatic gestures of a range of DMIs and argue that composing from the basis of idiomatic gestures results in performances rich in style and meaning, the very foundations of valued musical repertoire [170].

While musicians may think when performing an instrument they have full agency over their gestural and compositional decisions, the very existence of idiomatic gestures reveals there is more at play. At a granular level, the framework of idiomatic theory helps explain how an instrument’s affordances govern the development of players’ gestural languages resulting in music idiomatic to that instrument, that is ‘*distinctive musical dialects made of seemingly prefabricated patterns*’ [43]. Idiomatic patterns are the patterns of tones or phrases most commonly and naturally performed on an instrument [43]. Digital, and indeed all, instruments contain values and scripts that tell us what music can and should be made with them [104]. The music on offer is a result of a combination of the instrument’s affordances and cultural knowledge [106]. Visi et al. explored cultural influence on gestural language finding that musicians without violin training asked to mime along to a recorded musical performance using a silent violin resulted in similar performances [185].

Tuuri, Parviainen and Pirhonen argue that while gesture functions as an instrument of control (*‘instrumental control’*), the interface design contributes towards ‘experiential control’ in which the user feels their tacit bodily movement is constrained by an interface (*‘push’* effects) or the interface enables their tacit and spontaneous engagement (*‘pull’* effects) [179]. ‘*Push*’ and ‘*pull*’ effects have been observed to influence DMI performance technique showing that performers optimise their gestures to correspond with the sensing modalities of the instrument [5]. Musicians playing non-functional mock-up instruments will alter their gestures and imagined sound of the instrument in response to its material properties [145].

Bin et al. explore the impact of instrument size on perception from an audience perspective [11], however more research is required from the performer’s perspective to fully understand the impact of size, tonal layout and sound design on the music and performances created using DMIs.

2.1.3 The importance of improved DMI design

Despite continued advancements in sensor technology and computer processing power, the technical advancements required for designing new DMIs, a standard electronic instrument is yet to be embraced by the performance community at large, and surprisingly few artists are virtuosic with new instruments [89]. As Jorda argues ‘*many new instruments are being invented. Too little striking music is being made with them*’ [89]. DMIs are ephemeral [60] and more research is required to design instruments for longevity [129]. I argue more is to be learned in DMI design so that we can create meaningful instruments and repertoire that last the test of time.

2.2 Frameworks of DMI research

There are many frameworks through which to explore DMIs. There is a current trend in NIME research to draw on the frameworks of design fiction [102], lucid design [128], participatory design [186], musical engagement [171] and audience experience [11] [12]. However, as my research is specifically focused on the experience of DMI performance from the performer’s perspective, I will discuss my research in the frameworks of embodied music cognition and affordance theory, as these tangentially-related frameworks can elucidate the ways the physical design of an instrument can influence the performers’ choices.

Leman’s embodied music cognition theory provides an interesting framework for exploring the impact of an instrument’s scale and dimensions on music creation and performance, arguing that our bodily interactions shape our perception of music [99]. In the context of musical instrument performance, the body’s ‘*vehicle*’ for mediation is musical gestures, which have an important experiential component that is related to intentions, goals, and expression [100]. Not only are musical gestures linked to musical intentions, they are also linked to cognitive processing of the sounds they create, and in this way physical interaction with instruments involving gesture/action consequences changes our performance gestures and choices, and therefore our thinking. This ‘*direct coupling between action and perception*’ is known as embodied interaction [55, page 271], and is central to musical instrument performance.

With practice, an instrument performer develops an embodied relationship with their instrument. This relationship can be compared to the embodied interaction experienced by visually-impaired cane users who may no longer perceive the cane itself but perceive the world *through* the cane [118]. Exploring embodied interaction of keyboard performers, Palmer and Meyer [142] show that novice keyboard performers focus on the control mechanism, that is their hand

movements, while expert keyboard performers focus on the output, that is the sound of the instrument.

Expanding or contracting the physical dimensions of an instrument results in changes to the musical gestures. In the taxonomy of affordance theory [56, 139, 178], it could be said that the size of an instrument influences its affordances, that is the possibilities, such as the gestural language for performance. Additionally, as De Souza argues, affordances offer the performer ‘*distributed cognition*’ in that an instrument may ‘*know*’ things for the performer [43]. In this way, the performer does not need to know every detail about the instrument to play it. As Magnusson [104] illustrates, the piano knows a pitch class represented by each of its keys. By only offering the tones created by pressing the piano keys, and not all the microtones in between, the embedded knowledge contained in a piano forms a ‘*script*’ that influences compositions created with the instrument. Far from being a blank slate, all instruments are embedded with ‘*scripts*’ [104] that encourage certain types of music-making and discourage others. It follows that ‘*distributed cognition*’, or as Magnusson [105] calls it ‘*material epistemology*’, not only offers affordances but also constraints, and it is therefore through both that instruments elicit influence on performer’s choices.

Tuuri et al. [179] argue that an interface enforces ‘*experiential control*’ on a user through ‘*push*’ effects (affordances that result in the user feeling the technology guides or constrains their embodied interaction) and ‘*pull*’ effects (affordances that result in the user feeling they are in control of the technology). Experiential control is not always subliminal to the performer. It can therefore be argued that the gestural language for performing an instrument is governed by the ‘*push*’ and ‘*pull*’ effects of the instrument’s affordances and constraints.

When ‘*push effects*’ of an instrument’s design are too strong a performer may feel overpowered into creating only the sounds and music idiomatic to the instrument. According to Jordà, designing instruments with affordances resulting in stifling ‘*push effects*’ is to be avoided, arguing that ‘*a good instrument should not impose its music on the player*’ [89]. Jack, Stockman and McPherson [82] provide evidence of ‘*push*’ and ‘*pull*’ effects of a DMI’s design on musical gestural interaction, showing that performers optimise their gestures to correspond with the sensing modalities of the instrument. It can therefore be argued that the gestural language for performing an instrument is governed by the ‘*push*’ and ‘*pull*’ effects of the instrument’s affordances and constraints.

Other factors affect embodiment in musical performance. Dalsgaard and Hansen [40] point out that it is not only the interaction between the performer and the system (instrument) that changes the performer’s perception, but also the performer’s knowledge of being observed by an audience. Dalsgaard and Hansen call the perception created by this three-way engagement between user,

system and spectator ‘*performing perception*’, and they acknowledge that during all performances the user is simultaneously engaged in all three actions: interacting with the system (understanding the performance possibilities and how to operate the system); perceiving the relation between the user, the system and the surroundings; and performing for others to observe.

2.2.1 Idiomatic music

De Souza explores the link between affordances and distributed cognition, proposing ‘*idiomatic music*’ as those compositions which feature ‘*characteristic patterns that cannot be predicted by grammatical rules alone*’, arguing these characteristic patterns are the result of players interacting with the affordances of the instrument, composing not on a note-by-note basis but also through selection of ‘*ready-made sequences*’ on offer [178]. This music that is ‘*suited, adapted, and optimised for an instrument*’ is what Tanaka [173] refers to as ‘*idiomatic writing*’, and is therefore the result of the physical affordances of the instrument. Huron and Berec [79] show idiomatic writing for an instrument can become less idiomatic if the circumstances change, observing that trumpet players find it more difficult to perform trumpet repertoire that is shifted in key or tempo so as to alter key fingerings and duration of breath.

One example of idiomatic music is Chopin’s Etude op.10 no.5, a composition so suited to performance on the piano that it can be performed rolling an orange over the raised black keys which form a pentatonic scale [43]. It could be argued that countless pentatonic compositions created on the piano by western composers are the result of the ‘*experiential control*’ or ‘push effects’ of the influence of the tuning and layout of the black keys

As well as influencing composition, an instrument’s affordances and constraints influence the sounds created when performing an instrument, and not only through the obvious ways such as sound design, but through ‘*instrument idiomaticity*’, that is sounds that are naturally created on an instrument, such as the harmonica’s bend and the horn’s hunting call [43].

What is idiomatic to perform with new instruments has not yet been defined [173]. Musical patterns can be shaped by idiomatic gestures [170] or by patterns of thought promoted by music programming languages [116].

Composers have long known about ‘*instrument idiomaticity*’ and ‘*idiomatic music*’ [163], as evidenced by repertoire can be traced back to the instrument used to compose it. A composition featuring a passage of chromatic notes indicates the instrument it was composed on affords performance of chromatic notes, such as the piano, rather than one that does not, such as the harmonica [43].

While a performer’s cultural and musical background influence what they do with an instrument [113, 64, 43], idiomatic music reveals the instrument’s influence on the act of composing, and has been credited for the creation of new styles, genres and performance trends [182]. The baroque, jazz and rock music genres are testament to the influence of the design and affordances of the piano, saxophone and guitar, having only come about after these instruments were popularised. Composers Harry Partch and John Cage were so aware of the inevitable influence of instrument design on compositional choices that they incorporated instrument design into their compositional practice [163].

Instrument idiomaticity is not only a function of the physical construction of an instrument but also the performer’s cultural viewpoint, for example classical violin and fiddle share some idioms and not others [43]. Instrument idiomaticity and idiomatic music are an emerging research area, and while more research is required to understand the exact mechanisms of how the factors of influence work, in accordance to Tuuri’s ‘*push effects*’ and ‘*pull effects*’ it is not possible to design a musical instrument that elicits no compositional influence [179].

In the context of DMIs, because the designers’ ideas of music are embedded in the instrument, instrument building has been compared to composing [132], and performing with someone else’s instrument has been likened to performing their composition [94]. The same principle holds to a certain extent with any instrument, even traditional acoustic ones: to perform an instrument is to engage in an artistic conversation across time and distance with its creator/s.

The size of the instrument changes its relationship to the body and therefore its affordances, and in turn influences the idiomatic music of the instrument. However, more research is required to fully understand the extent of this influence as well as other factors that may be at play. In particular, the preceding reference raises the question of what circumstances DMI designers can control and change, and the resulting impact on DMI repertoire and performance.

Current trends in exploring idiomatic patterns include examining music performance through coarticulation for ‘*chunking*’ [58]. Godoy [57] defines chunking as ‘*sequentially occurring body movement and sound (that) is perceived holistically as a series of units. This means that body movements are compressed into more instantaneously retrievable action images in our minds.*’. Through examining recurring musical gestures, we can elucidate the performer’s understanding of the music they are creating. While coarticulation and chunking are commonly explored through motion capture research [59], I argue that there is more to be learned from exploring chunking and recurring idiomatic patterns through the analysis of repertoire, especially in the context of understanding the design implications of large DMIs.

2.2.2 Bodies, interfaces and size

The history of human-computer interaction (HCI) research can be traced not only through successive generations of technology, but through an evolving understanding of humans. As part of HCI’s ‘*somatic turn*’ [162], focus has gradually shifted from the ‘*user*’ in traditional user-centred design [138] to the body [45, 78]. Human perception and action have always been interdependent [165], and interfaces can serve a mediating role such that they become effectively extensions of the body. This feeling is especially common amongst instrumental performers, where the instrument becomes a part of the body [137, 97, 43, 98] and integral to the performer’s identity [8]. More recently, the notion of a singular ‘*body*’ in embodied interaction has been problematised [167], identifying harmful gender and cultural norms on how bodies should exist and behave. Taking support from feminist theories of HCI [7, 154], a shift is now underway from a ‘*body*’ to the plural ‘*bodies*’, reflecting a diversity of experience and perspectives [167, 77].

The role of interface size in HCI has been examined periodically throughout this shift. Through a traditional user-centred design lens, size-related inquiries include comparisons of size of interactive tabletops for around-the-table collaboration [192]; impact of screen scale on moving target selection [24]; how display size affects spatial memory [193] and the effect of table and mobile phone screen sizes on communication modality [91]. From an embodiment perspective, the size of our body plays an important role in how we visually experience the world: the world appears larger to a small observer and smaller to a large observer [181]. Changing the size of an interface changes its dimensions relative to any individual’s body, affecting the way in which it mediates perception and action. However, despite the obvious importance of size, relatively few studies explicitly consider large-scale interfaces from the perspective of subjective experience.

2.2.3 Size, effort and context in musical interfaces

In the domain of musical interaction [74], large-scale instruments are often studied through the lens of effort [156]. Effort is an important aspect of musical creation for both performer and audience [184]. Waisvisz credits physical effort as a cause of musical tension perceived by audiences¹ [92]. Similarly, Waters [187] explored the role of resistance and difficulties in music performance through

¹ ‘*The creation of an electronic music instrument shouldn’t just be the quest for ergonomic efficiency. You can go on making things technically easier, faster, and more logical, but over the years I have come to the conclusion that this doesn’t improve the musical quality of the instrument. I’m afraid it’s true one has to suffer a bit while playing; the physical effort you make is what is perceived by listeners as the cause and manifestation of the musical tension of the work.*’ — Michel Waisvisz [92].

his VPFI (Virtual/Physical Feedback Instrument), finding that difficulties and resistance of the instrument give its repertoire character and meaning [188].

Instrument designers aiming to penetrate the industrial mainstream of instrument design know that what is on the mass market must be accessible. New DMIs featured on crowdfunded websites (such as Kickstarter) have been steadily aiming for effortlessness, often advertising instruments for their ostensible expressive power or ease of use [115]. Reducing the size and weight of interfaces has been part of that trend, which also provides the companies with other economic benefits for manufacturing and distribution. Not all new DMIs are designed for ease of use. Some, such as Eigenharp², the Karlax³ and the Sylphyo⁴, deliberately target a small market of players willing to put in the time to develop the expertise, but these instruments tend to emerge from and exist within a niche counter-commercial music community. DMIs are designed both as part of quantitative research methods and artistic performance practices [89, 27], and the work presented in this chapter essentially draws on both of those reasons. I am doing this study to investigate impacts of interface size while also being motivated by my own creative practices.

Another factor related to size is the feel of the instrument. A large instrument may typically feel sturdy whereas a small instrument may feel fragile. Gallagher finds that the feel of an instrument is intimately tied to how the performer interacts with it [54].

Ryan [156] observes that over time, instruments have ‘*improved*’ in many ways but not regarding effort, while Ihde [80] notes that each evolution of music technology has brought changes in embodiment relations. Ryan suggests that it might be more interesting to make a digital controller as difficult as possible, noting that beyond its impact on expression, effort plays an important role in the formal construction of music: ‘*Effort maps complex territories onto the simple grid of pitch and harmony. And it is upon such territories that much of modern musical invention is founded*’ [156].

2.2.4 More-than-human bodies and entanglement

The most recent, and most radical, reconception of bodies in HCI has been to challenge the independent existence of a body and an interface. Arguably, the body is always more-than-human: ‘*Not only can bodies not be separated from all that surrounds them, whether these are animals, technological objects or societal or cultural constructions, but their combination produces something new*’ [77]. The idea that humans and technologies are ontologically inseparable forms the

²<http://www.eigenlabs.com/>

³<http://www.dafact.com/>

⁴<https://www.aodyo.com/>

basis of so-called *entanglement theories* of HCI [52], including actor-network theory [95] and postphenomenology [183], which explicitly decentre the human, recognising the agency of objects and also of political and sociocultural systems. Barad’s agential realism goes further by redefining agency as an enactment, and therefore not something that belongs to an entity but rather emerges via an entanglement between entities [4]. Therefore, the potential of entities and in turn what they are is *intra-actively* produced. In this way, entities (both human and non-human) co-constitute themselves through intra-actions [52].

Within the context of instrument design this co-constitution of humans and technologies means that something becomes a musical instrument only when it is used for creating music [66]. This perspective counteracts the historical HCI view of an instrument as having a fixed identity that a performer interacts with. From an entanglement standpoint, Waters defines a musical instrument not as an object but ‘*a process: a dynamic system in a constant state of change*’ [188], suggesting that rather than designing instruments, designers create ‘*contexts for musicking*’. Along this line, Rodger et al. [155] consider the instrument as not a device, but a constellation of processes⁵.

In this framing, instrumentality is not an inherent of inert objects, it is a property of musical systems. A piano is a musical instrument when included in a system for music performance, and at other times takes on other roles identities such as that of an ornament, a bed for a cat, or a surface for holding up photo frames. Conversely, random objects attain instrumentality when used within musical systems. For example, spoons are utensils when used for eating but musical instruments when used for performing rhythms. In this way the richness of musical performance is never static and ‘*instruments may mean different things to different musicians*’ [155]. This view carries important implications, in that changes to technology also change human-technology entanglements: ‘*designing technology is designing human beings*’ [183]: people do not exist as musical entities until they are part of these musical systems, and the instrumentalist they become changes in relation to the instrument they are performing, their musical history and cultural context among other factors. This speaks to Barad’s rejection of nature-culture dualism [4], recognising that complex processes cannot be understood via fixed divisions.

2.3 The trend of shrinking interfaces

Human-music entanglements are estimated to have begun in the Ice Age [80], during which time early musical instruments were made of bone or gut. Al-

⁵In line with entanglement theories of HCI, in this thesis I refer to musicians performing *with* rather than *on* and instrument.

though small, these early instruments were likely performed in large resonant caves, hence outsourcing the soundboard (not incorporated into instrument design until the late Ice Age) to the architecture of the cave itself⁶. We could therefore consider the first era of shrinking of instruments the late Ice Ages when the invention of the resonators allowed for instruments to be performed outside of resonant environments.

The design of acoustic instruments is coupled with size as a matter of physics-based necessity and large acoustic instruments afford deeper bass notes than their smaller counterparts. The pipe organ is the largest acoustic instrument [159] and is performed via full body interaction. Organists perform with their hands the organ’s multi-tiered manuals and stop knobs, and with their feet the swell pedals, crescendo pedals and pedal keys. However no tones are heard unless the pipes are filled with air. Nowadays pipe organs feature electrical bellows however the first organs required hydraulics [148] and later mechanical bellows that were strenuously operated by low paid ‘servants’ [39] of whom not much is known [159].

Unlike acoustic instruments, DMIs can be designed at any size and shape irrespective of their sonic output. Mid-to-late 20th century keyboard-based DMIs typically offered 88 keys (reflecting the piano design), however with the emergence of new technologies digital interfaces of all kinds are shrinking, and the trend is especially evident in DMI design. For example, 2019 saw the introduction of jewelry-shaped miniature MIDI controllers designed to be worn on fingers as rings, including Enhancia Neova (now distributed by Roland) and Genki Instruments Wave [31]. Such scaled-down DMIs are the culmination of decades of synthesizer companies offering instruments of increasingly smaller sizes, whether to cater for the desktop music producer (as seen with Korg’s immensely popular Volca series of compact synthesizers and drum machines); for portability (as seen when the same product is available at multiple sizes, such as the Arturia Keylab which comes in sizes of 88, 61, 49 or 25 keys); or for performance via sequencing rather than physical gestures (such as Arturia Minibrute 2S).

2.4 Large DMIs

2.4.1 Large DMIs: The state of the art

This research explores large tangible, physical interfaces. Intangible DMIs such as those performed using motion capture are outside the scope of this research.

⁶Many cave paintings are situated at the most resonant part of the caves, leading anthropologists to hypothesise that caves may have been concert halls [175].

There is a trend in commercial DMI design of scaling down instruments and interface dimensions, resulting in smaller and smaller ‘desktop’ instruments. These desktop instruments are often encased in a rectangular black box and feature keyboard keys, touch pads, display screens, potentiometers and/or sliders that are performed with fingertip control.

Outside the instrument design industry, desktop and regular-size are also the trending dimensions within the academic instrument design counter-culture of the New Interfaces for Musical Expression (NIME) community, however within this sphere, designs are commonly moving away from button-controlled instruments and more towards ‘fluid full-bodied interaction’, as recognised by Jensenius and Lyons [86] while taking stock of over 1200 papers written during the first fifteen years of the NIME conference.

While far from catching on as a trend, in recent years interest in designing large DMIs has increased among independent artists and builders. These larger-than-the-performer instruments tend to take the form of multiplayer designs such as *reacTable* [90], *The Tooka* [48] and *SoundNet* [173]; automated designs such as *The Sharpsichord* [160]; virtual, or hybrid hardware-internet large-scale instruments such as *Global String* [174]; interactive architectural spaces in which the room or building itself is the instrument such as *Water Pavilion* [17] and pre-programmed musical installations, performed robotically or mechanically via smaller control interfaces, such as *Gravity Harps* [110] or *Tipping Point* [73]. As for large single-player DMIs that are performed via instrumental interaction with the large-scale instrument itself, there is a trend for their designs to feature sample players (often MIDI-controlled) with only a limited level of expressivity, such as *The MIDI controlled Pipe Organ* [194], *NICO* [88] and *MOAI* [11, 12].

These trends reveal a gap in the construction and exploration of gesturally performed large DMIs. While there are some large DMIs that are gesturally and expressively controlled through instrumental interaction, such as *Venus Smiles* [28], *Soft Revolvers* [16], *Interferences (String Network)* [93] and some of the *Music Box Village* ‘musical architecture’ house-sized instruments [152], these examples are few and far between.

I argue that without more large scale DMI designs that are controlled gesturally and expressively, the cultural importance of large DMI design will not be recognised. There are not enough gesturally-performed large DMIs capable of nuanced performance being designed, and not enough discussion of design considerations of such instruments. As a result, there is a lack of understanding of how design choices influence the music composed with large DMIs.

2.4.2 Current trends in large DMI research

There are some current trends in DMI research of all sized instruments that would be interesting to explore specifically in the context of large DMIs. These trends include exploring how the physicality of instruments influences performance methods [164] [72], [117], and exploring microscopic and nuanced control [191] [108] [1]. I argue that the quest towards the design of more expressive and nuanced gesturally controlled DMIs can be furthered by including larger DMIs in HCI and NIME research.

One of the challenges about understanding the impact of instrument size on DMI performance is that not enough DMI design and research focuses on large DMIs. Large DMIs are under-explored compared to regular and desktop-sized DMIs.

DMI designers take into account the various ways that design decisions influence performances and compositions created with DMIs and have published design considerations for DMI design in general [2] [156], as well as for specific types of DMIs, such as augmented instruments [135], musical hardware systems for artist-engineer collaborations [69], actuated musical instruments [141] and virtual musical instruments [87], yet there are no design considerations specifically for the design of large DMIs.

The current trends in large-scale DMI research include effort [18] and researching large DMI performance from the audience perspective [11] [12], however more research is required from the performer perspective to fully understand the impact of size and layout of large-scale interfaces and instruments on composer and performance choices.

2.4.3 Summary of the gap in large DMI research

The above research that reviews the current state of the art in regular and large-scale DMI research reveals gaps that are potentially holding back the NIME and HCI communities from further developments in DMI design and performance. More research is needed from the performer’s (as opposed to the audience’s) perspective of performing and composing on large DMIs. More new designs of large-scale DMIs performed via gestural ‘*instrumental interaction*’ are needed. The NIME and HCI community would benefit greatly from the development of design considerations for the design of large DMIs controlled through ‘*instrumental interaction*’. Additionally, research that is exciting at the scale of regular or desktop-size DMI design such as the influence of physicality of instruments and the micro-scale within the macro-scale, should be explored in the context of large DMIs.

2.5 Chapter summary

In this chapter, we have seen current trends in DMI design and frameworks of DMI research. We have seen that there is a trend in commercial DMI design of scaling down instruments and interface dimensions. As a result, large DMI design is a niche practice only being explored by independent artists. Within large instrument design there is a gap in the development of gesturally performed large DMIs. While some research of large DMI performance focuses on the audience's perspective, what is currently missing from the picture is the ways that the dimensions and tonal layout of large DMIs influence music performance from the musician's perspective.

Chapter 3

Scoping Study: Embodied cognition in performers of large acoustic instruments

This chapter is built on significant material from ‘Embodied cognition in performers of large acoustic instruments as a method of designing new large digital musical instrument’ by Mice and McPherson, originally published in the proceedings of the Fourteenth International Symposium on Computer Music Multidisciplinary Research, 2019 [119].

3.1 Introduction

This chapter presents an interview-based scoping study with performers of various large acoustic instruments. The results are analysed via a thematic analysis methodology. The study findings are analysed in terms of embodied cognition, affordances and idiomatic writing to show ways that size-related aesthetic features of large acoustic instruments shape the performer’s choices while improvising, composing and performing repertoire.

3.2 Motivation

The Large Instrument Performers Study was designed to explore the possible impact musical instrument scale and dimensions may have on the performance of composed and improvised repertoire with the instrument by identifying affordances specific to large acoustic instruments, and how these affordances impact the performer’s choices.

3.3 Study design and method

The study consisted of one-on-one interviews with seven instrument performers who are trained on physically large instruments (see Table 3.1). Some participants were trained on more than one instrument of an instrument family in which one instrument is larger than the other, for example baritone saxophone and tenor saxophone. The interviews lasted up to one hour. During the interviews, questions about performance technique and repertoire were asked and participants were encouraged to perform their instrument(s) as examples arose. The interviews were videoed and took place either in a professional music studio, on campus at Queen Mary University of London, or over Skype.

The participants were asked questions, shown in Appendix A, that were designed to reveal how the performers respond to effects introduced by the large size of the instrument, such as physical navigation challenges, the additional physical effort required to perform larger instruments, and the relative changes in tone, timbre, volume and intensity encountered when performing repertoire with a large instrument versus a smaller similar instrument.

The performers were also shown repertoire composed for cello, ‘*Cello Suite no. 1 in G Major*’ (all movements) by J. S. Bach, and asked what issues they would encounter if they attempted to perform it with their instrument. The videos were manually transcribed and the transcription data analysed following a thematic analysis methodology [41] (Section 1.4.3). Codes emerged through an iterative process that took a theory-driven approach [157], in that the raw interview data was examined for trends and correlations that relate to the theories of embodied music cognition, affordances and idiomatic writing. Four iterations of coding were performed resulting in a codebook that was updated and refined at each coding iteration.

3.4 Results

3.4.1 Thematic analysis codebook

The codes that emerged from the thematic analysis methodology were organised by the grouping of codes that shared a theme. The thematic analysis codebook is shown in Appendix B. Table 3.2 presents an overview of the codebook structure and which participants commented on each code.

3.4.2 Overarching themes

At a high level, I noticed a differentiation between themes that describe instrument characteristics, and those that illustrate performer reactions to those

Table 3.1: Scoping Study participants

Participant number	Gender, pronouns	Primary large instrument played	Other instruments played	Primary style
P1	Man, he/him	Contrabassoon	Bassoon, double bass, electronics	Contemporary, ambient
P2	Man, he/him	Contrabass clarinet	Clarinets (soprano, bass, alto), flute, guitar, piano, saxophones (soprano, alto, tenor, baritone)	Contemporary, classical, experimental
P3	Woman, she/her	Organ	Piano, soprano clarinet, voice	Classical, renaissance
P4	Woman, she/her	Contrabass flute	Flutes (bass, alto, concert, piccolo), recorder, piano	Contemporary
P5	Woman, she/they	<i>Gyil</i>	Percussion, drum kit, piano, guitar	World jazz
P6	Man, he/him	Tuba	Guitar, gong, self-designed mechanical instruments	Metal
P7	Man, he/him	Baritone saxophone	Saxophones (alto, tenor, soprano)	Jazz

characteristics.

In the context of how size-related affordances impact performer choices, the codes reveal both trends and individual insights that illustrate how large acoustic instruments impose fatigue issues on the performer influencing their decision of how long or whether to perform the instrument at all; how timbral variations across registers influence choices performers make when improvising with the instrument; and how micro-level control and design of large instruments can result in substantial changes to the sound, and thereby influencing new performance techniques.

The interview content relating to techniques and repertoire performed with large instruments was categorised under three themes: idiomatic, easy and natural; unidiomatic, difficult and unnatural; and virtuosic or impressive composition. Comparing the insights that fell into one or more of these themes resulted in interesting insights into the differentiation between what is easy, natural, idiomatic and/or virtuosic in the context of idiomatic writing for large instruments.

3.4.3 Influence of size and weight on performance fatigue

Six out of the seven interviewees identified the cause of performance fatigue to be uniquely related to the instrument size. Causes included the instrument weight, the posture required to play the instrument due to its size, and extreme use of diaphragm or core muscles to support the air column and air pressure required to perform large scale woodwind instruments. As a result, five out of seven of the participants use a device or performance method designed to minimise performance fatigue caused by the instrument's weight.

The methods of compensation range from altering their performance method once fatigue sets in, to using commercially available and self-created devices, such as a harness or strap for tuba, baritone saxophone and contrabass, and the performer-designed belt clip for supporting the weight of the contrabassoon. P1 describes the inception of the contrabassoon belt clip and how it has improved the issue of weight-induced performance fatigue:

'I was finding that I was using my left arm too much so I was locking my muscles up to the point where playing the notes became difficult. And I thought with saxophones and so on there's a harness, and you really need it for a heavy instrument, and so just by complete chance, I thought what about if I clip it onto me and that's it, I now don't use my arms to support my instrument. This has allowed me to play the instrument for a lot longer because I am not using my body to carry the instrument in any way.' - P1

Table 3.2: Scoping Study thematic analysis codebook.

Code Mentioned By Participants	P1	P2	P3	P4	P5	P6	P7
Impact of Size, Weight or Fatigue of Large Instruments on Performers							
Which technique/passage makes the performer move the most	×	×	×		×	×	×
Fatigue	×	×	×	×	×		×
Weight		×		×		×	×
Strength required to perform large instrument	×	×	×		×	×	
Size		×					
Timbral Variation Across Registers in Large Instruments							
Choosing difficult techniques for sonic gratification	×						
Effects of variation across register on repertoire and arrangements		×	×			×	×
Effect of playing in different registers on idiomatism	×	×		×		×	
Influence of timbral variation on repertoire	×	×	×	×			×
Instrument is designed to have a strong bottom register	×		×	×			
Micro Scale Within Macro Scale of Large Instruments							
Microscopic design that has a large effect	×						
Microscopic gestures that have a large effect	×			×		×	
Improvising or Composing with Large Instruments							
The feel of the instrument changes how I improvise		×					
What the performer doesn't play when improvising		×		×			
What the performer plays when improvising		×		×			
Idiomatic, easy, natural to perform with large instruments							
Idiomatic techniques		×	×	×			
Performance of idiomatic music	×	×			×	×	×
Composition relating to idiomatism	×	×	×	×	×	×	×
What is easy to play with the instrument	×	×		×	×		
What makes music idiomatic for this instrument	×			×		×	×
Unidiomatic, Difficult or Unnatural to Perform with large instruments							
What is difficult to play	×					×	
What makes a composition unidiomatic	×	×		×		×	×
Examples of unidiomatic compositions		×	×	×		×	×
Performances of unidiomatic compositions		×		×		×	×
What is more difficult to play than it seems		×		×			
Virtuosic or Impressive Compositions for Large Instruments							
Video of virtuosic composition	×					×	
Examples of virtuosic or impressive writing	×	×	×	×			
What makes a composition virtuosic for this large instrument		×	×	×			
Performing a Different Instrument's Repertoire on Large Instruments							
Offered examples of when performing a different instrument's repertoire is possible		×	×	×	×		
Offered examples of when performing a different instrument's repertoire is possible	×	×	×	×	×	×	

*Gyil*¹ performer P5 identified maintaining a grip on heavy sticks through long and rapid performance as a major cause of performance fatigue as the sticks used for performing *gyil* are heavier than sticks used for performing smaller tuned percussion instruments (such as glockenspiel), and as such require more muscle use and control. Her method of pushing through performance fatigue is changing her grip on the sticks. P5 elaborates ‘*I can feel after a few hours of playing “I can’t hold my sticks!” and I start using the back of my hands. So I’ve got ways. It’s a mental thing.*’

In some cases the instrument’s size and/or weight influences whether the performer chooses to perform the instrument at all. P4 commented she often opts not to perform with the contrabass flute at improvisational concerts because carrying the contrabass flute limits her ability to travel with more than one flute, whereas if she selects a smaller flute such as alto flute she has the option to also carry another flute such as concert flute or piccolo, offering her greater options at the concert. P6 said he seldom performs tuba in concert due to environmental concerns related to the need to transport such a large instrument by car.

3.4.4 Timbral variation across registers in large wind instruments

Beyond identifying the aforementioned obvious size-related affordances of large instruments, the study identified a less obvious influence of the size of large wind instruments on composed and improvised repertoire. Large acoustic wind instruments are often designed to have a rich tone in the lower register. This feature is a result of the instrument having a very large pipe (sound chamber). Activating the entire chamber will result in the lowest, most resonant tone. Playing in higher registers uses smaller sections of the chamber, resulting in more airy, frail tones in the higher registers. These unusual upper tones are more difficult to perform in tune because, due to the size of the instrument, more air pressure is required. Maintaining a steady pressure at the intensity required is a difficult task for even the most advanced players.

Although a byproduct of the instrument’s design, the unusual tones in the upper registers can become an interesting aesthetic resource to draw on when composing and improvising with the instrument. Referring back to Tuuri, Parvainen and Pirhonen’s ‘*push*’ effects (discussed in Section 2.1.2), the Scoping Study results indicate that the unique tones of both the upper and lower registers influences performer choices through embodied cognition and ‘*push*’ effects.

All performers interviewed improvise with their instrument. When asked what they often play when improvising, four out of seven interviewees mentioned

¹A *gyil* is a West African xylophone made of wood.

drawing inspiration from the timbral variation across registers. Composing and performing improvisations that are influenced by this aesthetic is an example of embodied cognition, as the performers are making specific choices based on the instrument’s affordance of different tone colours at each register.

Contrabassoon performer P1 described performing the same passage an octave higher as having *‘not the same feel at all... the more of the instrument you’re using the more of the resonance is in the sound.’*, noting that as tones are performed in higher and higher registers *‘the notes begin to get weaker’*. He often makes a compositional choice of performing in the high register to exploit this unstable timbral quality, which he describes as *‘alien’*. He said *‘In an orchestral setting, unless you want to specifically exploit this change in timbre in taking the instrument up an octave it might be better to write (the same part) for a bassoon instead... In my own music however I swap octaves a lot specifically to introduce this slightly more frail sound.’* By extending his compositions into the higher register for the purpose of utilising this *‘frail’* timbre (rather than other compositional choices such as an ascending melody), P1 is revealing the *‘push’* effects of the timbral aesthetic of the high register. This is an example of embodied cognition in that P1’s compositional choices are changed by interacting with the instrument.

P2 is another performer drawn to the timbral variation across registers with the largest version of the instrument he performs. He mentioned that the E-flat clarinet is designed to have a uniform tone across all registers. By contrast the contrabass clarinet is not, hence it affords more timbral options to the performer. He said the contrabass clarinet *‘has a lot richer sounds and things that I can really do with it, whereas the clarinet has more of a certain kind of sound and it doesn’t have the same richness and variation.’* When asked to name a composition that feels natural to play with the contrabass clarinet, P2 nominated *‘Dark Light’* by Thanos Chrysakis [30] because it *‘highlights the capabilities of the instrument.’* Composed for contrabass clarinet, *‘Dark Light’* features long tones in both the low and high registers. P2 later mentioned that performing contrabass clarinet in the higher registers is more difficult and less precise than performing in the lower registers. *‘The higher you go the more notes I have on a single fingering... so I can’t move between them as quickly as I have to do it with my mouth rather than with my fingers, so the precision isn’t the same.’* I find it interesting that even though performance of contrabass clarinet is more difficult for tones in the higher register, P2 indicated the most natural composition to perform with the instrument (in Tanaka’s terminology discussed in Section 2.2.1, an example of *‘idiomatic writing’* for contrabass clarinet) features many complicated tones in the higher registers.

Similarly, P4 said that performing the same part in different registers with

the contrabass flute *‘would probably make it more difficult. If it was going higher it would make it harder to play in tune.’* P4 said this difficulty in performing the higher register in tune is a byproduct of the contrabass flute design, which was intended to optimise the lower register tone at the expense of the higher register tone, which is rarely performed in ensemble repertoire for the instrument.

‘The smaller (flutes) are deliberately made to make them as even as possible. Whereas the bigger ones are deliberately made not to do that. Because for example if you’re playing a bass flute and you’re playing in a flute choir, what you want is a really strong bottom octave... (With the contrabass flute) you get much better resonance in the low register, but it’s possibly a bit weaker and a bit out of tune in the higher register where you’re not going to use it very much.’ - P4

Aside from causing tuning issues, P4 also indicated that performing the same passage in different registers of the contrabass flute would result in changing the character of the music. P4 said *‘the character between the octaves changes quite dramatically. They each have a very different tone colour... I think if you put it in a different octave it would definitely change the character of the music.’* When asked what types of sounds and passages she performs when improvising with contrabass flute, her responses included *‘slow melodic material, possibly in the different octaves.’*

Notably, it is not only the weaker, higher register that influences the performer’s choice to perform a tone despite its difficulty. P1 said *‘What I love on the instrument (contrabassoon) is holding the low notes for a long time. But that is very difficult.’* He explained that unlike performing a long bass tone with another instrument such as the piano which would require the relatively easy gesture of pressing a key with one finger, performing a long bass tone with the contrabassoon requires precise core control. *‘When I started playing this instrument it took me several years of doing nothing other than just playing long tones, and learning how to use one’s core muscles... The lower you get, the more control you need over a consistent flow of air.’* Yet despite the effort, what P1 enjoys performing the most with the instrument is long sustained bass tones. He regularly features them in compositions, commenting *‘if you’re using that with something on top that is such a brilliant foundation.’* When asked why he prefers to use the contrabassoon rather than for example an electronic instrument for sustaining long bass tones, P1 said *‘The performative and aesthetic element is important to me. I like using big effort instruments to make relatively reduced music. I have been using smaller instruments for ease of travel and using pitch shifting pedals to take them down an octave and although the*

end result is almost the same sonically as playing on a bigger instrument, it changes the essence of the music.’ That P1 prefers to perform such a difficult technique with the contrabassoon instead of an easier technique with a different instrument is another example of embodied music cognition as he believes that creating the (almost) identical tone with a different instrument ‘*changes the essence of the music*’, implying that the instrument, not the tone, is changing his perception of the music.

3.4.5 Microscopic performance techniques for large instruments

Three out of five of the performers of large scale brass and woodwind instruments commented that microscopic changes in the embouchure and air pressure can result in huge changes in the sound and tone quality.

Microscopic changes in air angle can have such a substantial effect on the contrabass flute’s sound that a millimetre can result in large changes and even the sound being lost altogether.

‘It’s really critical that the air goes in at the right angle. So because the instrument is so big, the air has to travel, so even something very simple like changing octaves needs very precise control of the air stream. And the distance between the octaves feels much bigger than it would do on a smaller instrument. So if you’re playing something like a normal flute it takes a lot less air, and also the notes feel much closer together because the tube length is so much smaller. So because of that, all of those intervals, everything gets expanded. So I think from that point of view you’re using a lot of precision of the airflow all of the time... Literally, if the air goes one millimetre in one way you’ll lose the sound or change the sound.’ - P4

Similarly, changes to the contrabassoon reed can cause large changes to the instrument’s tone. P1 said ‘*If we want a soft reed we can sandpaper that down for 10 seconds, that’s going to get the instrument to behave in a completely different way from not really very much of a change. So yes even though it’s very big, some of the small changes can have a profound effect on the instrument.*’

A silversmith by trade, P1 also designs custom parts for the contrabassoon. Through this practice he has discovered ways certain microscopic changes to the parts can influence the overall character of the instrument. When creating his own crooks (also known as bocals, the thin s-shaped tapered tube that the reed connects to), P1 discovered that microscopic changes to the angle of the taper result in each crook having a unique sound. When comparing one self-designed

crook to another, P1 said that in one *‘the bore inside gets bigger quicker than the other one. So this has the capability to play higher notes more reliably.’* While the other crook may be less reliable in the upper tones, P1 added it has its own characteristic that can be desirable for certain repertoire. *‘The trade off is this one has more fundamental in the low notes.’* By refining his crook-making process he can now design characteristics into the tone of the instrument. *‘If I know I want a darker sound I know what to change to make that.’*

P6 described a microscopic tuba technique he uses to create a beating sound when playing in unison with other players. *‘Other players will play a solid note and then I’ll slightly bend the pitch of my note to create beats and that’s done by a minor change in the liping... it’s really subtle. It’s probably a bit to do with the air pressure as well but it’s mostly a small deviation in the lip.’* The result is an audible beating caused by the physics of the similar length sound waves colliding at regular intervals, creating a perceived effect of the tone rhythmically starting and stopping even though each performer is playing one long tone.

3.4.6 Influence of difficulty and virtuosity on idiomatic writing

The interview data gathered from questions relating to improvisation, repertoire, gestural performance techniques and performing repertoire intended for different instruments revealed interesting insights into what makes a technique, pattern or composition more or less difficult, idiomatic, virtuosic or impressive to perform with large instruments. In many cases the results offered insights that contradict common preconceptions of idiomatic writing, such as the assumptions that idiomaticity is synonymous with ease of performance, and virtuosity is synonymous with difficulty of performance. P2 and P5 both nominated examples of compositions they consider the most idiomatic and/or natural to perform with their instruments that also contain performance techniques among the most difficult to perform with their instrument. P5 said the most idiomatic music for the *gyil* is the Degaari traditional music. As it is polymetric, the music requires the mental challenge of holding two metres at the same time, performing tones as well as silence between them - the very techniques that P5 considers the most difficult to perform with the instrument. Meanwhile, the factors that impress audiences about this music, such as its speed and use of the full range of the instrument, are not what make it difficult to perform, and the mental challenge posed by the polymetric groove is not necessarily a factor that makes it virtuosic. P5 said *‘holding both metres and being able to play between them - that’s hard for me and I don’t think that’s virtuosic... And if people thought that it was hard when they’re listening to me then I’m not doing it right.’*

3.5 Discussion

Current ongoing trends in DMI performance research include effortfulness [10], physicality and whether controllerism/laptop music engages audiences [11]. I argue that while large DMIs engage more with the body and are more physical and visible than their smaller counterparts, more research is required to fully understand ways in which their size influences DMI music and performance.

Keeping in mind Magnusson’s [104] notion of ‘*scripts*’ and ‘*material epistemologies*’, the hidden knowledge embedded in instruments that shape idiomatic writing, DMI designers can draw inspiration from the detail and variation of sonic features of acoustic instruments when creating sound design that inspires virtuosic composition with DMIs. The interviews with the contrabass flute and contrabass clarinet performers show that the varying timbral qualities afforded by large wind instruments influence performers’ choices when improvising with the instrument, as well as their decision of whether to perform the instrument at all (in place of performing the smaller version with more uniform timbres across all registers). This indicates that non-uniformity of timbres across registers is a strong aesthetic resource for compositional inspiration. DMI designers could consider implementing this characteristic not only to large DMIs but DMIs of all sizes.

The observations from the Large Instrument Performers Study show that the ‘*push*’ effects of timbrally varied tones across registers influenced performers to make use of multiple registers while improvising and composing. That the participants chose to perform within the more difficult registers even at their own discomfort and risk of error, shows the extent to which performers value these tones. I argue these findings should not only encourage designers of DMIs of all sizes to consider the value of offering simultaneous access to multiple registers and varied sound design across registers, but also probe them to consider the implementation of microscopically precise gestural controls, even those initially unnatural or difficult to perform.

In light of the study findings that reveal that large wind instruments respond to microscopic changes in gestural control and micro-scale design details, I argue that to reach new frontiers of virtuosic digital instrument performance and repertoire, large DMI designers should take into account the microscale within the macroscale and match or exceed the nuanced precision of large acoustic instruments. Scaling up the DMI to be larger is only the first step.

Exploring human interaction with an instrument too large and complex to master was an approach taken by the group Sensorband (Atau Tanaka, Zbigniew Karkowski and Edwin van der Heide) with their architectural scale instrument SoundNet [173]. In the context of researching embodied cognition and idiomatic

Table 3.3: Suggested design considerations for implementing findings into large DMI design.

Study Results	DMI Design Choices Influenced by Study Results
Impact of Size, Weight or Fatigue on Performers	
Weight	Consider ways the DMI design may decouple size from weight, such as the use of light-weight materials or a design that packs down into travel cases.
Strength required to perform instrument	Consider how a DMI that requires physical strength to perform influences the material epistemological scripts of the instrument, and what is idiomatic to perform with it, for example resulting in slower tempos or recurring clusters of tones located near one another.
Size	Consider ways to avoid the size-related constraints of large DMIs, such as open spaces/layouts that the performer can see past, or translucent materials.
Timbral Variation Across Registers	
Choosing difficult techniques for sonic gratification	Consider designing in ‘ <i>easter egg</i> ’ tones accessible via the most difficult to perform gestures at the very limit of what is performable.
Effects of variation across register on repertoire or arrangements	Consider assigning one register as the most resonant and weaker tones in other registers; offer access to many registers at once via many tones or choice of a scale with fewer tones per octave.
Effect of playing in different registers on idiomatity	Consider the ways that implementing sound design that varies across registers results may create scripts of idiomatic music for the instrument.
Instrument is designed with a strong bottom register	Consider whether the DMI is intended for performance as a solo instrument or in ensembles.
Microscale Within Macroscale	
Microscopic gestures that have a large effect	Consider DMI designs that allow for microscopic gestures to result in a large sonic effect on the overall tone or performance of the DMI.
Improvising/Composing with Large DMIs	
Feel of the DMI changes improvisations	Consider how the strength and effort required to perform the DMI may influence the performances or compositions created on the DMI.
What is Idiomatic, Easy or Natural to Perform with Large Instruments	
Idiomatic Techniques	Consider the impact of the ‘ <i>push</i> ’ and ‘ <i>pull</i> ’ effects of what tones or passages are created by the easiest to perform techniques.

writing, I argue there is more to be discovered from musical interactions with instruments designed to overwhelm the performer with their physicality. One physically overwhelming instrument discussed in The Large Instrument Performers Study was the contrabass flute. The breath support required to perform it can result in dizziness during performance and discomfort for days to follow. P4's expert insight into performing such a physically overwhelming instrument illuminated our discussion by providing a perspective from the extreme end of acoustic instrument performance.

This study has shown us that large scale instruments are more than just small instruments scaled up; rather they are highly detailed, precise instruments that in many cases offer different sonic affordances than their smaller counterpart of the same instrument family.

3.5.1 Design considerations for implementing findings into DMI design

Drawing on the findings on the study, Table 3.3 outlines a series of design features that DMI designers could consider.

3.6 Summary

This chapter presents a scoping study that examines the affordances of large acoustic instruments and their effect on performers choices. The findings reveal a series of interesting aesthetic design features of large acoustic instruments, such as the timbral variation across registers and the microscopic precision of control, that have a strong influence on performers choices through embodied music cognition and '*push*' effects. More research is required to understand the full impact of instrument size on musical performance and composition, however this research offers initial insights to consider when designing new large DMIs, and DMIs of all sizes.

3.7 Carry forward

The design considerations for designing large DMIs presented in Section 3.5.1 were put to use in the design of a new large DMI, Chaos Bells, presented in the next chapter and used in subsequent research presented in Chapters 5, 6 and 7 that explore the role of instrument size on music created with a large DMIs.

Chapter 4

The Study Instrument: Chaos Bells

Some content in this chapter appears in:

- ‘*From Miming to NIMEing: The Development of Idiomatic Gestural Language on Large Scale DMIs*’ by Mice and McPherson, originally published in the *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2020 [120].
- ‘*Super size me: Interface size, identity and embodiment in Digital Musical Instrument design*’ by Mice and McPherson, originally published in the *proceedings of the Conference on Human Factors in Computing Systems (CHI)*, 2022 [121].

This chapter describes Chaos Bells, a new gesturally performed¹ DMI, shown in Figure 4.1, that was designed with both artistic and analytical goals in mind: it is a probe [84] into the exploration of the impact of instrument size on performance, while also being a vehicle for my performance practice. To maximise its potential as a probe in each study, Chaos Bells can be constructed to various sizes and configured to different sound design and tonal layouts.

¹As opposed to robotically or remotely performed.



Figure 4.1: The study instrument, Chaos Bells, is a new gesturally-performed DMI designed for use in the studies. It is configurable to a larger version (two metres wide and tall) and a smaller version (one metre wide and tall).

4.1 Why a new instrument was necessary

Chaos Bells was designed for answering the RQ1² and RQ2³, the central research questions of this thesis.

To answer these questions I required a large DMI for use in various research studies in which musicians would create original performances with the instrument. I required the performances to be comparable. I also required the instrument to be configurable to various sizes so that smaller versions of the instrument could be created for priming the musicians for insights about how the size of the instrument influenced their performances.

I identified the following requirements for the study instrument:

- configurable to varying dimensions (including larger than the performer’s arm span) while retaining similar sonic output
- configurable to varying tunings while retaining the same physical construction
- performable with both large and small gestures
- requires new performance techniques and methods (even though the instrument may make use of certain skills and tacit knowledge developed through performance of other instruments)

Additionally, I had the following design preferences that were influenced by the findings of the scoping study (Chapter 3):

- sound design that features timbres that vary across registers (inspired by findings that performers of large acoustic instruments are drawn to the timbral variations across registers, discussed in Section 3.4.4).
- the ability for very small gestures to result in a large change to the sonic output (inspired by the finding that performers of large acoustic instruments are drawn to the ability for micro-gestures to influence the overall sound of the instrument (‘*the micro-scale within the macro-scale*’ discussed in Section 3.4.5)).

Existing large acoustic instruments were not suitable for this research as their size and tonal layouts are coupled to their acoustic tone production. The

²How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?

³By conducting research with instruments that are physically larger than the performer’s body, what can we learn about instruments of all sizes with regards to the impact that design choices have on performance and compositional choices?

instrument therefore had to be digital to fulfil the requirements of configuring the instrument to various tunings and sizes while retaining the same sonic output.

Various large DMIs were considered, such as the MOAI [11, 12], the laser harp [50] and the Big Piano⁴, however none were constructed with the desired sound design features influenced by the findings of Chapter 3 such as timbral variation across registers. For these reasons, designing a new instrument that fulfils the design criteria became necessary for this research.

In addition, since there are so few large gesturally controlled DMIs (as discussed in Section 2.4.1), designing our own created an opportunity to create one that would not only help this research but could also be adopted by composers and performers, such as myself, who are interested in performing with large digital musical instruments. As such, the study instrument is frequently performed live by myself and other members of the London experimental electronic music scene⁵.

4.2 Chaos Bells technical description

4.2.1 Physical construction

Chaos Bells is constructed from pipes and connectors made of PVC. The instrument's physical design consists of a cage-like frame with 20 identical pendulums⁶ that hang from two tiers, an upper tier and a lower tier (10 pendulums per tier). A support pole bisects the tiers horizontally, creating a visual aesthetic of four quadrants of five pendulums. The pendulums can swing freely up to 90 degrees on one axis (forwards and backwards, but not side to side). Each pendulum features a textural pattern of 10 raised rings (Figure 4.2) inspired by the Latin-American *güiro*.

4.2.2 Instrument versions

For the studies, Chaos Bells was configured to six versions (L1A, L1B, L2A, L2B, S2A and S2B), outlined in Table 4.1. The instrument versions were designed to created fertile ground for comparing compositions and performances created during the studies. Details of the versions are discussed in the following sections.

⁴<https://bigpiano.com/>

⁵A video performance of myself and Odd Lust (Alex Wallwork) performing Chaos Bells at the 2021 Oram Awards Ceremony livestreamed concert can be viewed at www.liamice.com/chaosbellsresources.

⁶The pendulums are identical so as to not offer clues to performers about which tones are assigned to which pendulums. This way tones can be reordered according to study designs.



Figure 4.2: Close-up photo of the large version of the instrument's pendulums with 10 raised rings.

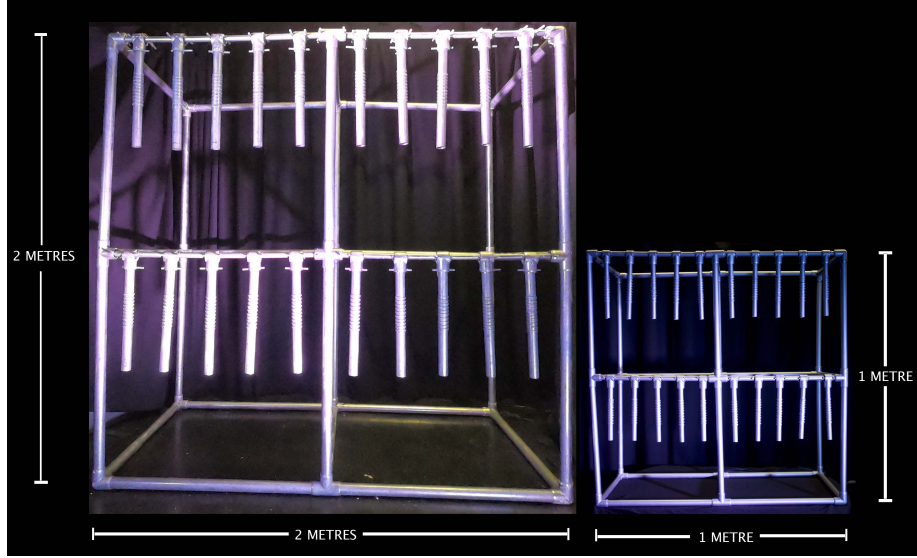


Figure 4.3: Left: The larger version of the study instrument is two metres wide and two metres tall. Right: The smaller version is one metre wide and one metre tall.

Figure 4.3 shows the larger interface (used for versions L1A, L1B, L2A and L2B) alongside the smaller interface (used for Versions S2A and S2B).

4.2.3 Hardware and software

An ADXL335 three-axis analog accelerometer is attached to the inside of each pendulum 12 centimetres from the top. Figure 4.4 shows the hardware schematic. The 20 accelerometers are connected to the analog inputs of four Bela Minis [127] coded with C++ and Pure Data [147] for sound synthesis⁷. Figure 4.5 shows a block diagram of the Pure Data synthesis code running on Chaos Bells versions L1A and L1B. Figure 4.6 shows a block diagram of the Pure Data synthesis code running on Chaos Bells versions L2A, L2B, S2A and S2B. The four audio outputs are combined via an analog mixing board and amplified by a guitar amplifier or PA.

Each accelerometer breakout board is modified by replacing the Y-axis capacitor with an SMD Multilayer Ceramic Capacitor (4700 pF, 50 V, 0603 [1608 Metric], $\pm 10\%$). As a result the Y-axis is sampled at 22.05kHz and configured to have a natural analog bandwidth of approximately 1kHz with a first order roll off. In the Pure Data code, each of the accelerometers' Y axis data (responding to the forwards-backwards angle of the pendulum motion) excites a

⁷The code running on the Bela Minis is so CPU-intensive that a maximum of five accelerometer signals can be simultaneously processed per Bela Mini.

Table 4.1: Versions of the study instrument

Version name	Frame size (width cm, height cm, depth cm)	Pendulum length (cm)	Pendulum diameter (cm)	Tuning name (scale)	Tilt mapping (description)	Tonal Layout (pattern of ascension, shown in Figure 4.8)	Which study used in
L1A	200, 200, 100	50	4.2	Tuning 1 (abstract)	Tilt Mapping 1 (longer sustain)	A (ascend L to R lower tier then L to R upper tier)	1
L1B	200, 200, 100	50	4.2	Tuning 1 (abstract)	Tilt Mapping 1 (longer sustain)	B (ascend L to R in zig-zag formation)	1
L2A	200, 200, 100	50	4.2	Tuning 2 (C# minor)	Tilt Mapping 2 (drone)	A (ascend L to R lower tier then L to R upper tier)	2a, 2b
L2B	200, 200, 100	50	4.2	Tuning 2 (C# minor)	Tilt Mapping 2 (drone)	B (ascend L to R in zig-zag formation)	2a, 2b
S2A	100, 100, 50	25	2.1	Tuning 2 (C# minor)	Tilt Mapping 2 (drone)	A (ascend L to R lower tier then L to R upper tier)	2a, 2b
S2B	100, 100, 50	25	2.1	Tuning 2 (C# minor)	Tilt Mapping 2 (drone)	B (ascend L to R in zig-zag formation)	2a, 2b

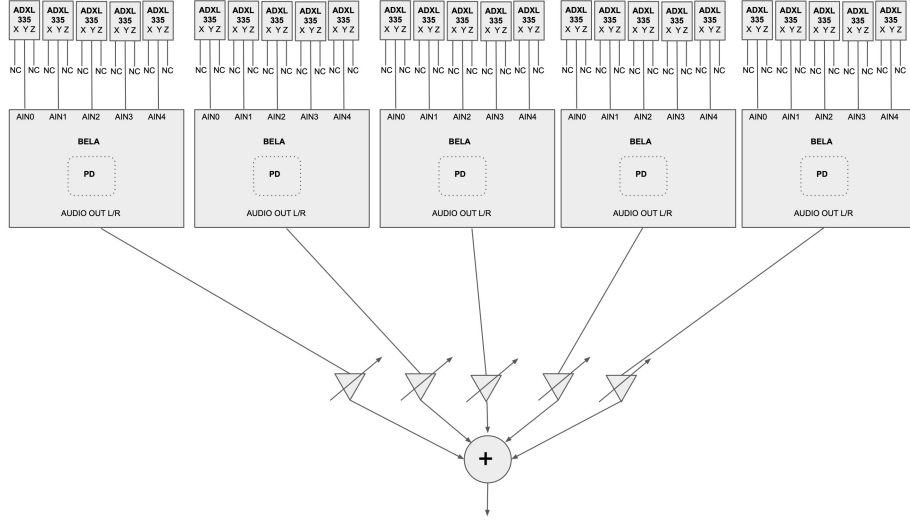


Figure 4.4: Chaos Bells hardware schematic.

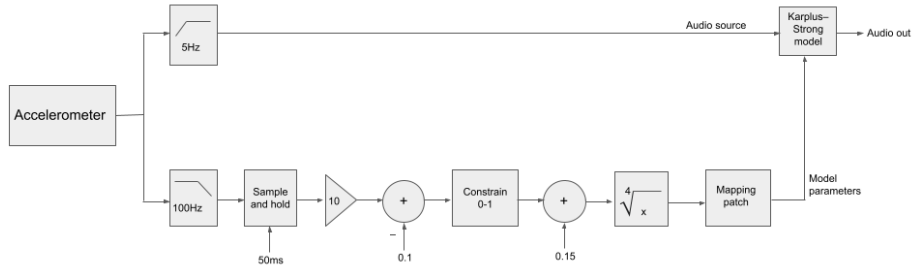


Figure 4.5: Block diagram of the Pure Data synthesis code running on Chaos Bells versions L1A and L1B.

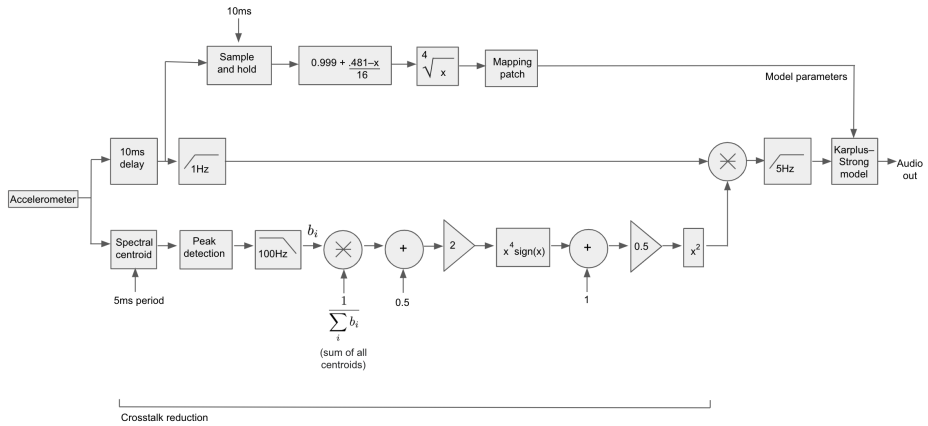


Figure 4.6: Block diagram of the Pure Data synthesis code running on Chaos Bells versions L2A, L2B, S2A and S2B.

Karplus-Strong algorithm [85], based on open source Pure Data code⁸ created by Neupert et al for Chair Audio’s Tickle instrument [133].

4.2.4 Sound design

Each pendulum is assigned a discrete tone featuring harmonics with a fundamental frequency. The characteristics of the synthesis algorithm mean that each pendulum has a distinctive timbre from slightly different combinations of harmonics and inharmonicity.

The instrument is performable by striking a pendulum or the instrument frame with the soft or hard end of a mallet, or by tapping with hands or fingers. A *staccato* (short) tone is produced by striking or tapping the instrument either on the pendulums (to create a clear tone) or the instrument frame (to create a cacophony of tones). A repeated tone is created by scraping the mallet or fingers over the raised ridges of the pendulum. A discordant cacophony of tones is achievable by interacting with the instrument frame or pendulum support pole in such a way that the frame will vibrate.

Activating the Karplus-Strong synthesis algorithm with the embedded accelerometer signal results in a nuanced sound palette that responds differently according to the input gestures, and hence can be performed with gestures ranging from very small (such as finger taps) to very large (such as striking or swinging gestures).

The sound design of the study instrument features lower register tones with clear fundamental frequencies that sound like a synthesised electric guitar, meanwhile the higher register tones contain more inharmonic partials for a bell-like quality⁹. The instrument is polyphonic up to 20 voices. The staccato strikes and drones can be performed simultaneously, including on the same tone.

Tilt mapping

The instrument was designed over two iterations. During the first iteration (L1A and L1B), the instrument sound design was configured to Tilt Mapping 1 in which the tilt angle affected the decay of the Karplus-Strong algorithm. When configured to Tilt Mapping 1, striking the pendulum while it is at an angle other than the vertical position such as while it is swinging or being held out at an angle results in a longer (less *staccato*) tone as its release time is proportional to the angle of tilt. In this configuration, swinging the pendulum without striking it does not result in a tone and therefore the tone is not directly

⁸The original Pure Data code for Chair Audio’s Tickle instrument is available at <https://github.com/chairaudio/tickle-examples>.

⁹Videos illustrating the sound design of the lower and higher registers and basic techniques and sounds can be viewed at www.liamice.com/chaosbellsresources

related to the length of the pendulum (unlike many pendulum instruments, such as those discussed in Section 4.3).

After conducting Study 1 (Chapter 5) with the instrument configured to Tilt Mapping 1, I noticed that many participants did not discover that striking a tilted pendulum results in a longer tone, and if they did the effect was so subtle they did not spend much time exploring it. After this realization the tilt mapping was iterated to Tilt Mapping 2 for use in Studies 2a (Chapter 6) and 2b (Chapter 7).

When configured to Tilt Mapping 2, tilting a pendulum produces a drone (sustained tone). The pendulum angle changes the feedback coefficient of the Karplus-Strong algorithm, thereby changing both the decay and the timbral quality of the drone¹⁰. Somewhere between 45 and 90 degrees on each pendulum, the feedback coefficient becomes greater than 1, producing an unstable system where the drone grows over time and eventually becomes chaotic and distorted as it is clipped by the digital system, finally disintegrating into broadband noise with no clear fundamental tone. In this mapping, when a pendulum swings and passes through vertical position, it depends whether the pendulum has begun from droning or not as to whether it will stop droning as it passes through the vertical position. If the pendulum had been held at an angle so as to begin droning before the pendulum is released and begins to swing, the drone will continue as it passes through the vertical position but will begin to fade as the swinging loses energy such that the pendulum no longer crosses the drone threshold. If the pendulum was not already droning when it began to swing, it will remain silent as it swings through the vertical position. If it swings high enough to pass the drone threshold, it may temporarily begin to drone until it drops below the drone threshold again and returns to silence. In this way, with enough energy in the pendulum a swinging pendulum can emit a rhythmic pattern. However, it will not emit this rhythmic pattern for long because it quickly loses energy due to air friction and gravity and no longer swings above the drone threshold.

4.2.5 Dimensions

Chaos Bells' physical interface is constructed to two sizes: one twice the size of the other. The dimensions of the larger and smaller versions are shown in Table 4.1. Figure 4.7 shows a study participant standing with arms outstretched in front of the larger and smaller versions of the instrument.

¹⁰The software codes are available for download at <https://qmro.qmul.ac.uk/xmlui/handle/123456789/90556>.

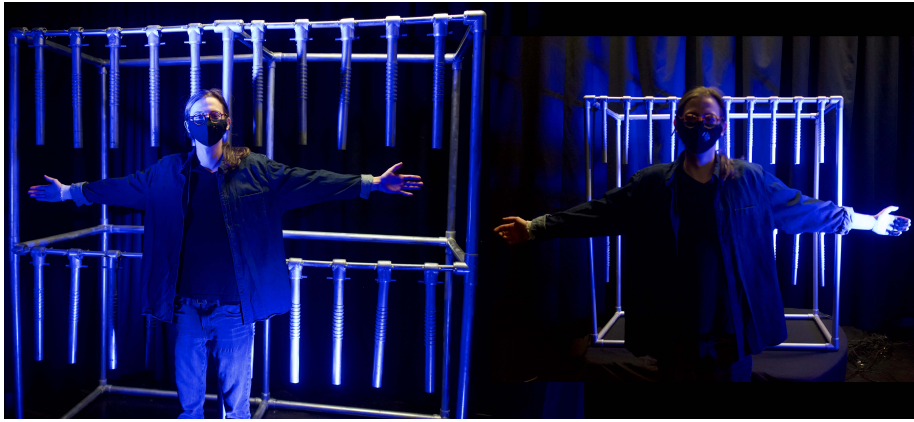


Figure 4.7: Left: A study participant stands with his arms outstretched in front of the larger version of the study instrument. Right: The same participant stands with his arms outstretched in front of the smaller study instrument.

4.2.6 Instrument tunings and tonal layouts

The instrument can be configurable to different tone mappings. For the purpose of the studies, two tone mappings were implemented: Layout A and Layout B. Both mappings feature discrete tones that ascend in order with the lowest located on the far left and the highest on the far right, however each mapping ascends in a different pattern as shown in Figure 4.8.

The instrument can be configured to different tunings. Tones included in each tuning can exist within or outside of any musical scale, and were therefore chosen for their effectiveness in creating the most useful data for each study.

Table 4.2 shows Tuning 1, a tuning created for the study instrument that is not based on any Western key signature. This tuning features fundamental frequencies ranging from 55 Hertz to 1046.5 Hertz spaced across four octaves. The frequencies of all tunings were tuned by ear in reference to a piano and are therefore approximate¹¹. This tuning is designed for use in the Study 1 (discussed in Chapter 5) that probes the participants for interactions that could identify the idiomatic gestures and patterns of the instrument.

Table 4.3 shows Tuning 2, a tuning that is based on the Western scale C# melodic minor and features fundamental frequencies ranging from 55 Hertz to 1046.50 Hertz. Melodic minor scales have been used in a wide range of Western music composition genres ranging from 19th Century piano sonatas and concertos [9, 153] to techno and pop [15]. As such, this tuning was designed for use in Studies 2a (Chapter 6) and 2b (Chapter 7) in which the participant

¹¹Due to the overtones incorporated in the sound design of each tone, digital tuning software did not accurately recognise the instrument's fundamental tones, therefore tuning the instrument by ear was more of a necessity than a choice.

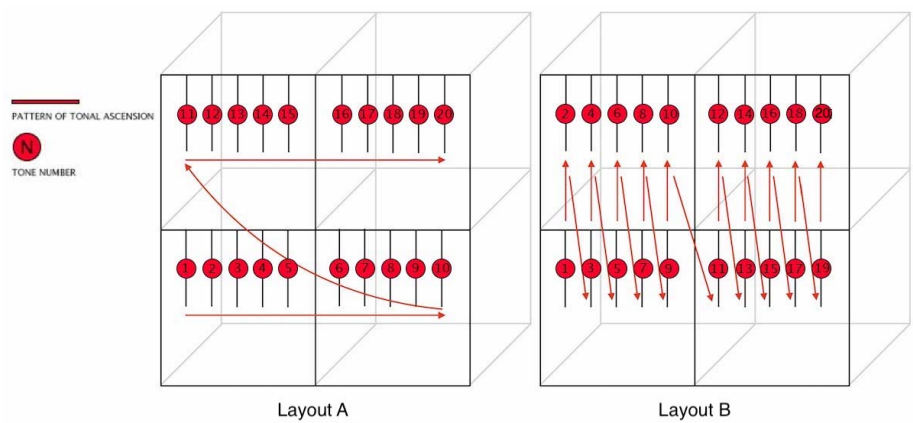


Figure 4.8: Both tonal layout mappings feature discrete tones that ascend in order with the lowest located on the far left and the highest on the far right, however each mapping ascends in a different pattern.

Table 4.2: Tuning 1

Tone Number	Hertz	Note Name	Tone Number	Hertz	Note Name
1	55.00	A1	11	164.81	E3
2	69.30	C#2	12	174.61	F3
3	77.78	D#2	13	207.65	G#3
4	92.50	F#2	14	233.08	A#3
5	103.82	G#2	15	261.63	C4
6	116.54	A#2	16	415.31	G#4
7	123.47	B2	17	440.00	A4
8	130.81	C3	18	554.37	C#5
9	138.59	C#3	19	622.25	D#5
10	155.56	D#3	20	1046.50	C6

create original performances with Chaos Bells.

Tuning 2 includes a bass register of 10 tones and a treble register of 10 tones, with a gap of more than an octave between the registers. As this tuning combines equally sized lower and higher registers, it creates a symmetrical tonal layout regardless of whether the instrument is configured to tonal Layout A or B. In Layout A, the lower register is located on the lower tier of the instrument and the higher register is located on the upper tier of the instrument. In Layout B, the lower tier is located on the left side of the instrument and the upper tier is located on the right side of the instrument. It is hypothesised that dividing the instrument tones in this way, in which half the tones are in the lower register and half are in the upper register, will be more likely to result in melodic compositions than textural compositions, and would therefore benefit the study as melodic compositions could be compared for their tonal constitution.

Table 4.3: Tuning 2

Tone Number	Hertz	Note Name	Tone Number	Hertz	Note Name
1	34.65	C#1	11	207.65	G#3
2	38.89	D#1	12	233.08	A#3
3	41.20	E1	13	261.63	B#3
4	46.25	F#1	14	277.18	C#4
5	51.91	G#1	15	311.13	D#4
6	58.27	A#1	16	329.63	E4
7	65.41	B#1	17	369.99	F#4
8	69.30	C#2	18	415.30	G#4
9	77.78	D#2	19	466.16	A#4
10	82.41	E2	20	523.25	B#4

4.3 Other related study instruments and how they differ from the study instrument

4.3.1 Other large-scale DMIs

Other research instruments have been designed with the intention of researching gestural interaction with large-scale instruments, including SoundNet (discussed in Section 2.4.1) and MOAI [11, 12]. MOAI is a research instrument that plays a different sample according to the velocity with which it is struck. Striking the box of the instrument with enough intensity results in the instrument bouncing and a sample is played back with added harmonics. The box continues to bounce after it is performed, with the sonic output changing according to data collected by an embedded accelerometer. While the design of MOAI shares some similarities with Chaos Bells, MOAI is sample-based whereas the sound

of Chaos Bells is generated by a modified Karplus-Strong string synthesis algorithm thereby resulting in different timbres and sounds depending on the performance interaction.

4.3.2 Other pendulum DMIs

Recently created DMIs that feature a pendulum in their design include the Kugelschwung [72] and the Chowndolo [101]. Performative systems that feature a pendulum include Steve Reich’s process music system for performing *Pendulum Music (For Microphones, Amplifiers, Speakers and Performers)* [150] in which four microphones are suspended above speakers and swung to create intermittent polyrhythmic feedback; and the pendulum systems performed by Aphex Twin in a two-part performance at London’s Barbican Theatre [96]. While all of these instruments feature pendulums, what makes Chaos Bells different from these examples is that Chaos Bells does not use the pendulum design for the oscillation of tones, and in this way unlike these examples, the length of the pendulums are not coupled to compositional features of the music created using them. To elaborate, while the angle of the pendulum of the study instrument influences the sustain of the tone, the free oscillation of a swinging pendulum generally has no effect on the sonic output¹², and as such the length the instrument’s pendulums are decoupled from the length of the sustained tone produced by the instrument.

4.4 Chaos Bells interface development

The study instrument design progressed over the duration of this research.

4.4.1 Material considerations

PVC was chosen as the main construction material for its lightweight nature, and its ability to be assembled at different scales, including large scales.

The pipes were painted with silver metallic paint to give the impression of metal. This was originally an aesthetic choice but evidently resulted in findings on the impact of materiality on imagined sound (Study 1, Chapter 5, Section 5.10.1).

¹²With the exception of the pendulum swinging motion described in Section 4.2.4 that results in rhythmic start and stop of the drone when pendulums configured to Tilt Mapping 2 are pushed with a lot of force.

4.4.2 Size considerations

The larger interface, which was used in Studies 1, 2a and 2b (Chapters 5, 6 and 7), was designed to be wider and taller than can be comfortably gesturally performed. At two metres wide, all pendulums are not easily accessible at the same time. The lower tier is one metre above the ground and the upper tier is two metres above the ground, placing both tiers uncomfortably low and high respectively. These design considerations force performers to make compositional choices between tones, allowing for the comparison of performer choices based on sonic output versus physical location.

By contrast, the smaller interface, which was used in Study 2a (Chapter 6), was designed to be a more manageable size that comfortably fits in front of the performer's body, allowing performers to easily reach any combination of pendulums simultaneously.

4.4.3 Unfamiliarity of the study instrument

Chaos Bells is designed to require some performance methods that do not draw on the participants' tacit gestural knowledge they have developed through performing other instruments. In this way the research instrument can be used to explore the relationships between the idiomatic gestural languages and the performances created with a large DMI. While percussionists may already have developed skills for performing with mallets, the study instrument requires performance skills that control the angle of the pendulum tilt, such as striking the pendulums in a way to maximise or minimise movement, or holding the pendulums still while striking them. Other suspended percussion instruments that can be performed with mallets (such as gongs, bells or chimes), do not require these skills as the angle of tilt of these instruments does not affect the sonic output.

4.4.4 Interface iterations

Figures 4.9 and 4.10 show early prototype sketches of the study instrument. Various versions of the interface were sketched using pencil and paper until the final version of the interface was derived. Once decided, the overall interface design did not change, however small details were adjusted during the prototyping process.

After initial prototyping, it was discovered that the design for the coupler (the part of the instrument that connects the pendulum to the support pole) contributed to acoustic cross-talk between sensors. The interface design was subsequently upgraded to feature a larger diameter coupler with adhesive rubber

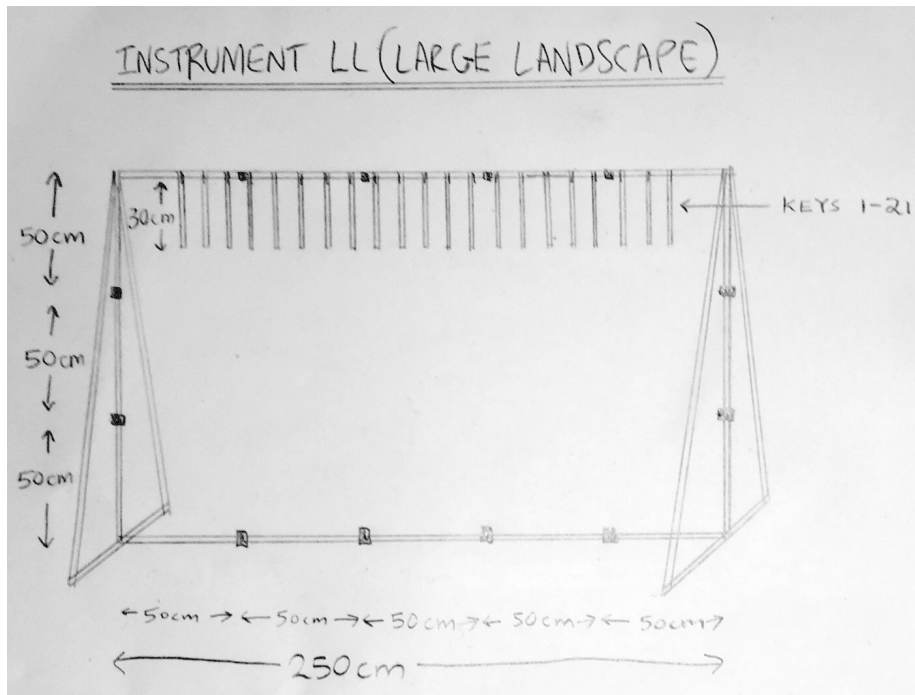


Figure 4.9: An early prototype sketch of the study instrument.

foam tape between the coupler and the support pole. The new design dampened the pendulums, reducing the cross-talk between sensors.

On the first prototype, each accelerometer was soldered directly to its audio cable. However this design was prone to damaging the accelerometers due to strain on the cable caused by the swinging pendulums. On the second prototype, a socket was soldered to each accelerometer for connecting the audio cable. This socket disconnects if strained, protecting the accelerometer from damage.

4.4.5 Influence of the scoping study on the design of the study instrument

Table 4.4 shows the ways that the design considerations for implementing the findings of the scoping study (shown in Table 3.3 in Chapter 3) influenced the design of the study instrument.

Exploring the micro-scale in the macro-scale

Chaos Bells was designed to allow for micro-gestural interaction that can greatly change the sonic output. By mapping the accelerometer Y-axis data to the decay time of the Karplus-Strong tone, the study instrument is capable of a larger range of tones and timbres than MIDI sample trigger systems. This mapping

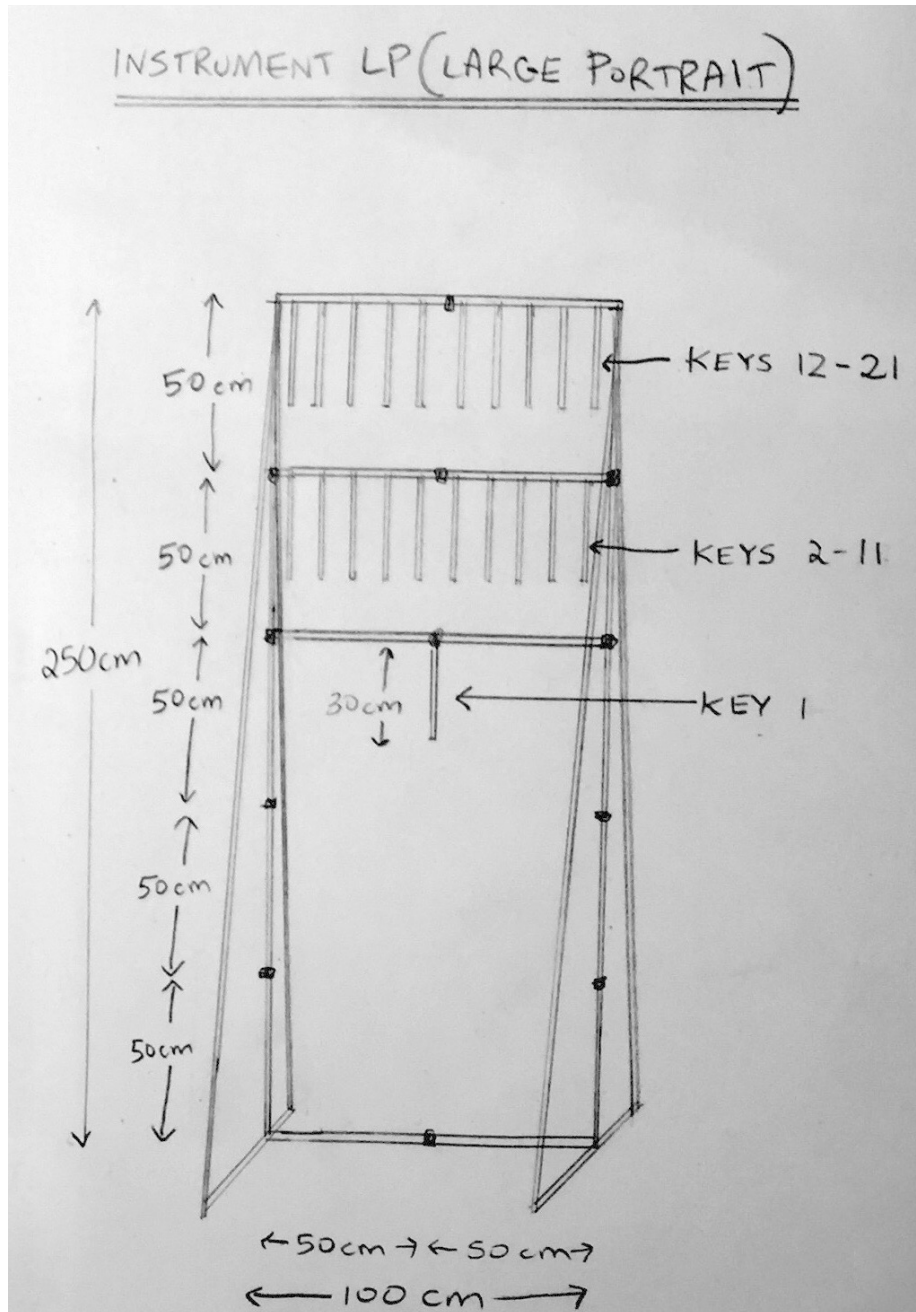


Figure 4.10: An early prototype sketch of the instrument

Table 4.4: Implementing the Scoping Study findings into instrument design

Study results	DMI design considerations inspired by study results	How the study instrument design implements these considerations
Impact of size, weight or fatigue on performers		
Weight	Consider ways the DMI design may decouple size from weight, such as the use of light-weight materials or a design that packs down into travel cases.	Constructed of lightweight PVC
Strength required to perform instrument	Consider how a DMI that requires physical strength to perform influences the material epistemological scripts of the instrument, and what is idiomatic to perform on it, for example resulting in slower tempos or recurring clusters of tones located near one another.	As the pendulums are constructed with PVC they are not heavy to raise
Size	Consider ways to avoid the size-related constraints of large DMIs such as open spaces/layouts that the performer can see past, or translucent materials.	The cage-like frame features open spaces
Timbral variation across registers		
Choosing difficult techniques for sonic gratification	consider designing in ‘ <i>easter egg</i> ’ tones accessible via the most difficult to perform gestures at the very limit of what is performable.	Performing multiple pendulums at once sounds good but is physically difficult
Effects of variation across register on repertoire or arrangements	Consider assigning one register as the most resonant, and weaker tones in other registers; offer access to many registers at once by offering many tones or choice of a scale with fewer tones per octave.	Lower register has clear tones, upper register has more harmonics.
Effect of playing in different registers on idiomatcity	Consider the ways that implementing sound design that varies across registers results may create scripts of idiomatic music for the instrument.	Layouts A and B position the registers in different relative locations for examining the impact of tonal layout on performing in different registers.
Instrument is designed with a strong bottom register	Consider whether the DMI is intended for performance as a solo instrument or in ensembles.	Lower register has clear tones, upper register has more harmonics.
Micro-scale within macro-scale		
Microscopic gestures that have a large effect	Consider DMI designs that allow for microscopic gestures to result in a large sonic effect on the overall tone or performance of the DMI.	Karplus-Strong synthesis allows for small gestures to result in large sonic changes.
Improvising or composing with large DMIs		
Feel of the DMI changes improvisations	Consider how the strength and effort required to perform the DMI may influence the performances or compositions created on the DMI.	The size requires more effortful performance.
What is idiomatic, easy or natural to perform with large instruments		
Idiomatic techniques	Consider the impact of the ‘ <i>push</i> ’ and ‘ <i>pull</i> ’ effects [179] of what tones or passages are created by the easiest to perform techniques.	The instrument is performable with many different gestures and techniques.

results in a sensitive system in which a millimetre change in gestural force or pendulum tilt (discussed in Section 4.2.4) can result in a large change in the overall tone of the instrument.

4.5 Indicators of success and points for improvement

Chaos Bells was designed as a way of probing performance practices and for this purpose it has proven a valuable tool in my investigations. This section summarises the features that indicate its success as a musical instrument. Additionally, this section details points to be improved in future iterations.

4.5.1 Value points

Flexibility

The instrument can be constructed to various design considerations including size, sound design and mappings. Changing the designs in order to meet the needs of the specific research context, something that would be impossible with an acoustic or commercial instrument, has been possible.

Additionally, this flexibility means that Chaos Bells could potentially have multiple future uses in both research and performance. While I have used this instrument to complete this research and also performed it live in various settings in the UK and internationally (see Section 8.1.11), the potential exists for the instrument to be reconfigured to meet the requirements of other artists and studies. Chaos Bells is currently being used by another Queen Mary University of London doctoral student, Teresa Pelinski, in research that explores issues of acoustic crosstalk in DMIs with multiple sensor inputs (see Chapter 8 Section 8.2).

Stability and durability

The instrument materials and components are durable and robust enough for installation and sustained performance in one location. During the 50 sessions required to conduct Studies 1 and 2, the following minor repairs were performed on the instrument:

- Aggressive performance of the pendulums with the hard end of the mallet resulted in some pendulum rings becoming loose or falling off. The pendulum rings were reattached with PVC glue which takes 10 minutes to dry.

- Aggressive rotation of a pendulum occasionally resulted in an analog accelerometer becoming detached from the instrument jack that carries its signal to the Bela Mini. The accelerometer was reconnected to the jack, a process which takes approximately one minute.

While touring with Chaos Bells outside of the laboratory environment, rough handling by shipping companies and children resulted in minor damage to the Bela Minis and accelerometers (see Section 8.1.12 for details).

4.5.2 Areas for improvement and new features

Cost effectiveness

While the instrument hardware is constructed from relatively inexpensive components (PVC pipes and connectors, analog accelerometers, audio cables and Bela Minis), due to the sheer size of the instrument and number of sensors required, the cost of constructing the instrument adds up. Disregarding the time taken to fabricate the instrument, and the four Bela Minis that both instruments shared, the materials required for the larger and smaller versions cost £814 and £575 respectively.

Improving the software code so as to reduce CPU usage would reduce the cost of producing the instrument as it could run on fewer Bela Minis¹³.

Environmental impact

Chaos Bells is constructed from PVC, the most environmentally damaging plastic [62]. This material was chosen to satisfy the following design requirements:

- Durable enough to last several years of use in 50 research studies.
- Lightweight so as not to injure study participants.
- Not emit a tone when struck so that the only tone heard by performers is the output of the digital synthesis. In this way the instrument's tonal layout can be reconfigured.

While I had ethical concerns of working with PVC, this material was chosen for this research study as it was the only material that satisfied all of the above design requirements. Future versions of Chaos Bells will not need to satisfy

¹³The most CPU-intensive aspect of the code pertains to the the reduction of cross-talk from the 20 accelerometers. However Teresa Pelinski, PhD student at QMUL, is currently using the study instrument in research to explore the reduction of cross-talk in DMIs with multiple sensors. This research could potentially upgrade the study instrument code to be able to run on as few as one Bela Mini.

these specific design requirements and therefore, to reduce environmental impact, future prototyping will explore renewable and biodegradable (though less durable) materials such as cardboard.

Portability and storage

PVC was chosen as the main construction material for its lightweight nature and its ability to be assembled at different scales, as well as disassembled for storage or transportation.

Due to its size, the larger version requires disassembling for transportation. After various design iterations the time required for assembling and disassembling the instrument has been reduced from several days to approximately one hour, and can be completed by one adult, though it is faster and easier with two.

At 0.5 cubic metres, the smaller version fits on a tabletop, and is therefore easier to store and transport in its fully constructed complete form.

In its constructed form, the larger interface requires four cubic metres of space, therefore transporting it fully constructed is not feasible as it would not fit into a car or van. The larger version is therefore built to be dismantled for storage and transport. Once dismantled the instrument parts can be transported inside two large cardboard boxes that are one metre long, 60 centimetres wide and 20 centimetres deep (Figure 4.11) and were originally designed for transportation of a bicycle frame. However these boxes are deemed oversized by airlines and shipping companies, resulting in high costs to transport by air and freight. For future iterations of the larger interface, the frame will be constructed from narrower pipes with more break-points and connections such that they can be transported in regular-sized suitcases.

4.6 Hypothesis of material epistemology of the study instrument

As discussed in Chapter 2 Section 2.2, all instruments have material epistemologies [105]. While designing Chaos Bells I hypothesised that the epistemologies of Chaos Bells likely include the following characteristics:

- Music idiomatic to Chaos Bells may include idiomatic patterns or clusters of tones located physically close to one another. Keeping in mind the large range of Western compositions that feature the pentatonic scale offered by the black keys of the piano discussed in Section 2.2.1, I hypothesised that performances with Chaos Bells will feature idiomatic pattern of tones that



Figure 4.11: The larger version of the Chaos Bells interface can be transported in two large cardboard boxes that are one metre long, 60 centimetres wide and 20 centimetres deep.

are located next to one another, and regardless of their specific tuning their physical proximity makes them easier to perform together. This hypothesis is tested in Studies 1 and 2a (Chapters 5 and 6).

- Compositions that cover many octaves. When configured in Tuning 2, the instrument offers the possibility of performance of almost four octaves of tones as well as the inclusion of timbral variation across registers. I hypothesised that these features may influence the performers to utilise all registers for their unique sonic qualities. Additionally, I hypothesised that compositions will feature both the very lowest and very highest tones available, again due to the inclusion of timbral variation across registers. This hypothesis is tested in Study 2b (Chapter 7).
- With the larger version of Chaos Bells, compositions may commonly feature slow tempos. Due to the instrument's size and layout of keys across a large area, the low pitches and long sustain might lead to slow tempos in performances created with the larger version of the instrument. This hypothesis is tested in Study 2b (Chapter 7).

4.7 Summary

This chapter has presented the design of a new instrument, Chaos Bells, that can be configured to various versions, including versions larger than the performer's body and small enough to fit on a desk top. This instrument is designed for use in research studies that will explore the influence of size and layout on performances created with a large DMI. The instrument has been designed to be expressively performed through gestural interaction. The instrument features design decisions influenced by the findings of the scoping study (Chapter 3) and the material epistemologies of designing the instrument in such a way were hypothesised. The following chapter describes the first main study of this research, Study 1, in which performers interact with Chaos Bells versions L1A and L1B.

Chapter 5

Study 1: Size and idiomatic patterns

Part of this chapter appears in ‘From Miming to NIMEing: The Development of Idiomatic Gestural Language on Large Scale DMIs’ by Mice and McPherson, originally published in the Proceedings of the International Conference on New Interfaces for Musical Expression, 2020 [120].

This chapter describes Study 1, which draws on the findings of the scoping study outlined in Chapter 3 and utilises Chaos Bells, the DMI outlined in Chapter 4, to consider the choices performers make when creating an idiomatic gestural language for an entirely unfamiliar instrument. Study 1 invited trained musicians to perform one of two versions of the same large instrument, each physically identical but with different tone mappings. The study results reveal insights into how musicians develop novel performance gestures when encountering a new instrument characterised by an unfamiliar shape and size.

5.1 Research questions and motivation

5.1.1 The problem space

This study investigates the factors that shape the idiomatic gestures and patterns of large DMIs. Every year an influx of new DMIs is created. Commercially, existing digital instruments are reissued ever smaller, requiring performance gestures that are familiar but equally scaled down. Artistically, entirely novel instruments are created that explore new realms of materiality and require original, even eccentric, performance gestures. However, with so many options available, how do instrument designers know if just because we can, we should? Are design choices such as size, shape, materiality, tonal layout and sound de-

sign influencing the music created with a new instrument in ways we had not imagined? I hypothesised that insights into the impacts of these design features can be found by examining the performances created with new instruments.

5.1.2 Idiomatic gestures and patterns

As discussed in Section 2.1.2, musical gestures that are well suited for an instrument so as to feel natural are often called ‘*idiomatic*’ [79]. All instruments have idiomatic patterns, they are a byproduct of the instrument’s idiomatic gestural language and instrument idiomatcity [173]. Idiomatic patterns play a role in shaping the repertoire composed with an instrument. What is idiomatic with new instruments by definition is as yet undefined [173]. This study investigates the factors that influence the idiomatic patterns ingrained in large DMIs.

5.1.3 Findings from the scoping study

This study takes on board the design considerations for implementing the findings of the scoping study into large DMI design (see Section 3.5.1). These design considerations were implemented into the design of Chaos Bells, the instrument designed for use in this research, as discussed in Section 4.4.5.

5.1.4 Research questions

The central research questions for Study 1 are:

- In what ways do instrument size and tonal layout and sound design influence the idiomatic gestural language of a DMI?
- In what ways does sound design and the act of sound production influence musical choices during improvisation?

The Study 1 research questions relate to central research question 1 (Section 1.3): How do the changes in physical dimensions and layout of a Digital Musical Instrument shape the gestural language of the performer, and in turn the compositions and performance created with the instrument?

5.2 Methodology

Study 1 was designed in accordance to the methodological considerations outlined in Section 1.4. During this study, I monitored classically trained musicians interacting with one of two versions (L1A and L1B) of Chaos Bells, a new DMI (detailed in Chapter 4). Both versions of the instrument are identical in physical construction and sonic affordances but feature different tone mappings (see

Table 4.1). The participants completed three creative prompts. During Creative Prompts 1 and 2 the instrument was turned off, requiring the participants to mime their performances. During Creative Prompt 3 the instrument was on and amplified through a PA.

5.3 Study design

Study 1 was a semi-structured one-to-one interview-based study. Each interview lasted one hour during which time the trained musicians were introduced to the new instrument for the first time and given creative prompts to perform with the instrument. After each creative prompt, the participants were asked to elaborate on the choices they made while completing the prompt. The participants' responses to the creative prompts and interviews were recorded with video cameras. Due to the size of Chaos Bells and the unpredictability of participants' responses to the creative prompts, to ensure that all sections of the instrument were captured, two wide-angle cameras were installed: one in front and one behind the instrument. Figure 5.1 shows the areas of Chaos Bells captured by each camera.

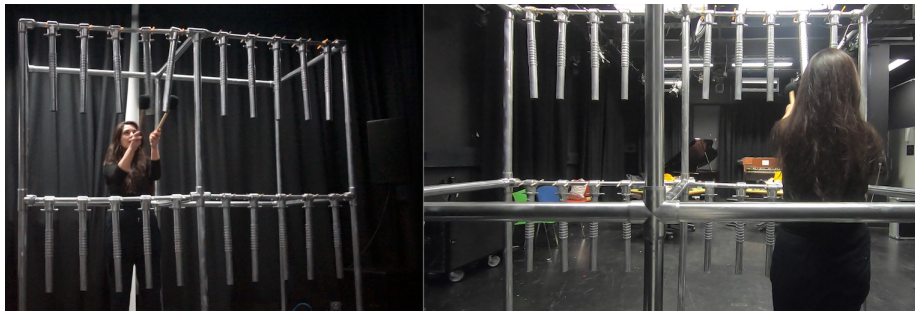


Figure 5.1: P8 performs Chaos Bells while two wide-angle cameras simultaneously capture the study session.

5.3.1 Considerations of participant selection

Participants were selected in accordance to the considerations outlined in Section 1.4.2 that include selecting participants that share similar experiences in performance and composition and musical culture (western music), but varied gestural musical skills.

An open call for participants was launched via a tweet from my personal twitter.com account that read *'I've made a new instrument. I'm looking for musicians to play it for an hour as a study for my PhD. If interested please*

fill out this form'. The tweet linked to an online questionnaire that asked the background questions outlined in Appendix C.

5.4 Selected participants

10 participants (four women, five men and one gender-fluid person) were recruited for the study. Table 6.2 shows the participants' musical backgrounds and which version of the study instrument they were assigned. Seven participants were trained pianists, five were trained percussionists and five were trained guitarists. An equal number of percussionists and keyboard players were assigned each version of the study instrument. Participants' ages ranged from 25 to 69 with an average of 38 years old. The average years of lessons they had received for their primary instrument was eight years for keyboardists, three years for percussionists and two years for guitarists. While all participants were literate in western notation, their primary musical styles varied.

5.5 Study 1 research instrument

The study instruments used in Study 1 were the L1A and L1B versions of Chaos Bells, the instrument discussed in Chapter 4.

5.5.1 Why only the large Chaos Bells interface was used in this study

Only the large Chaos Bells interface was used in this study because this study is designed to explore the development of gestural languages and patterns with a large instrument. If some of the participants were using the larger version instrument and some were using the smaller version, the findings would not be specific to large instruments.

5.5.2 Why half of the participants were assigned L1A and half were assigned L1B

As discussed in Section 4.2.6, the difference between Layout A and Layout B is the location of the tones. Both layouts feature the same tones, but they are arranged in a different pattern (shown in 4.8).

The reasoning behind assigning half of the participants Layout A and half of the participants Layout B was so that if trends of patterns performed by participants are observed to be performed by all participants regardless of which version of the instrument they are assigned, those patterns could not only be

Table 5.1: Study 1 participants.

Participant number	Gender, pronouns	Primary instrument	Years of lessons	Other instruments	Primary style	Study instrument
P1	Man, he/him	Guitar	3	Drums	Rock, popular music	L1A
P2	Man, he/him	Drums	3	Piano, tympani, glockenspiel	Prog rock	L1B
P3	Man, he/him	Bass guitar	1	Piano, saxophone, synthesizer	Rock	L1B
P4	Man, he/him	Piano	14	Trumpet	Free improvisation	B
P5	Man, he/him	Guitar	2	Drums, piano, tuned percussion	Folk music	L1B
P6	Woman, she/her	Synthesizer	10	Piano, gong, drums	Experimental	L1A
P7	Woman, She/her	Piano, keyboard	7	Guitar	Classical, popular	L1A
P8	Woman, she/her	Piano	4	Cello, synthesizer, sampler	Cinematic, electronic	L1A
P9	Woman, she/her	Guitar, piano	8	Voice, synthesizer, sampler	Post punk	L1A
P10	Genderfluid, they/them	Guitar	0	Violin, keyboards, drums, voice	Alternative rock	L1B

identified as the idiomatic patterns of the instrument, but they could also be identified as being influenced by factors other than the location of the tones, such as instrument size.

5.6 Minimising outside influence on gestural interaction

When introducing the participants to the instrument, so as not to influence the development of an original gestural language, the instrument was not demonstrated by the investigator. Instead the participant was told that the instrument can be performed using two hands and optionally two mallets.

5.7 Study session

During their one-hour one-to-one session the participants each completed three creative prompts with their assigned version of Chaos Bells followed by a semi-structured interview (refer to Appendix D for the interview questions). In Creative Prompt 1, the instrument remained turned off. The participant was given five minutes to explore the instrument, perform gestures and imagine the resulting sounds. They were told to perform a one-minute mimed improvised performance while imagining the sound of the instrument. In Creative Prompt 2, the investigator¹ performed the instrument without the participant watching, so that the participant could be aware of the range of tones and timbres the instrument is capable of producing. Participants were again encouraged to silently explore the instrument for five minutes in its turned off state, then mime a one-minute improvised performance, however this time with knowledge of the instrument's sound design. In Creative Prompt 3, the instrument was turned on and amplified through a PA. The participant explored the instrument for five minutes and then performed a one-minute improvisation.

5.8 Analysis and evaluation

The video recordings of each study session were edited so as to simultaneously show both camera angles on the screen. The editing and exporting process took approximately 20 minutes per video. The video recordings were manually transcribed and the transcription data was analyzed following a thematic analysis methodology [118]. Codes emerged through a theory driven iterative process [157], in that the raw interview data was examined for trends and correlations

¹For consistency, all study sessions were investigated by one researcher, myself.

that relate to the theories of idiomatic gestural language and experiential control. Four iterations of coding were performed resulting in a codebook that was updated and refined at each coding iteration. The video recordings of the improvised performances were analysed for performative trends by identifying gestures and patterns participants performed in each creative prompt.

5.9 Findings

The themes revealed trends across participants, regardless of their musical background and which instrument version they performed.

5.9.1 Imagined sound design of the instrument

Creative Prompt 1 required the participants to mime a performance with the instrument unaware of the digital sounds it makes, and in doing so imagine its sonic affordances. Several participants conceptualised similar sound design for the instrument. Seven of the 10 participants imagined the DMI to sound like a metal tuned percussion instrument, with several each referring to bells, wind chimes, xylophone and vibraphone. One participant, P4, chose to not imagine tones at all and only perform the instrument with knowledge of their own rhythmic input so that no matter what sounds the instrument makes the resulting music could at least be rhythmically coherent. Even so, he said he initially thought the DMI might sound like a bell until he realised the instrument is not made of metal, only painted to look that way. Four participants imagined sounds inspired by wind moving through pipes, and one imagined sound design of metal scraping on metal, such as the sound of a squeaky gate. Two participants imagined percussive tones reminiscent of a *güiro*. Four participants imagined ambient, soundscape or *found sound* samples.

Three participants imagined a deep bass tone. P7, a pianist, imagined the instrument to sound like a piano but no participants imagined the instrument to sound like a guitar. Upon hearing the DMI only one participant, P10, commented that the instrument featured a tone they had imagined, saying *‘I was really gratified that this had within it that kind of dark tone that I was hoping to hear... I was right in imagining this was a sci-fi instrument.’*

5.9.2 Familiarity of instrument

After knowing the sound of the DMI, when commenting how its sound compares to other instruments, six participants said it has features reminiscent of tuned percussion instruments such as melodic drums, thumb piano, cymbals, bells or tubular bells, and seven participants commented it has some sound design

features similar to a string or extended string instrument such as an electric guitar, sitar, saz, prepared piano or prepared harp. Six participants said the DMI is unlike any other instrument they have ever performed. Common reasons for its distinctiveness are that it is performed in a physical, percussive manner but has the detailed sonic affordances of an electric string instrument. P10 said the raised rings on the pendulums are like the coils of a guitar string if the guitar string was enlarged to the size of the pendulum.

5.9.3 Tonal layout of the instrument

In response to the first two creative prompts, all participants imagined that each pendulum has a unique tone and the tones are arranged in a predictable order. Two participants imagined the tones ascend to form a pentatonic scale, two imagined a chromatic scale and two imagined a scale neither pentatonic nor chromatic. Three participants imagined the tones to be ordered with the lowest tones in the centre and highest tones on the outside, inspired by the tuning layout of the metal tine instrument the *mbira*. When responding to the final creative prompt with the instrument turned on, five participants correctly identified that the lowest tones are located on the left and the highest tones on the right, however no participants identified the exact pattern of tonal ascension. Six participants commented that they found the pitches to be in an unexpected or confusing order.

Visually, the instrument frame creates an aesthetic of two tiers separated into four quadrants containing five pendulums each. While discussing the tonal layout of the instrument, eight of the 10 participants referred to the tiers and nine of the 10 participants referred to the quadrants in comments that revealed they assigned significance of the tiers and quadrants to the instrument's tonal layout. During the mimed tasks, four participants imagined lower tones located on the lower tier and higher tones located on the upper tier, while five participants imagined different tones and/or timbres to be located on each tier but not necessarily the low tones on the lower tier and the higher tones on the upper tier. Five participants imagined each quadrant features a different register or range of tones, and one participant (P9) imagined each quadrant features a different instrument such as a sampler in one quadrant and a synth in another quadrant.

After Creative Prompt 3, P3 said he enjoyed performing the central upper tier pendulums because he like the pitch range there. Similarly, P10 was particularly drawn to a certain quadrant because it has a '*Turkish saz vibe*' and the pitches in that quadrant are in a range similar to an electric guitar. P10 commented that pendulums in a particular quadrant '*made really outrageous*

noises’ and *‘seemed so much less melodic’* than pendulums in other quadrants. *‘I was trying to create a groove and I thought those (pendulums) are going to disrupt that’*. Both P3 and P10 performed L1B.

P5 and P8, who performed L1B and L1A respectively, both commented that they don’t think the order of the tones in the quadrants on the left follow on to the quadrants on the right, implying that the central support beam signifies a discontinuation of the tonal layout. In all, six of the participants referred to the quadrants as a way of describing groups of tones. The reality is the tones ascend in order irrespective of the quadrants.

5.9.4 Playing techniques

Table 5.2 shows emergent playing techniques and how many participants performed each technique per creative prompt. Notably, striking the instrument with the soft end of the mallet was performed by all 10 participants. Six other gestures were performed by five or more participants, including striking the instrument frame (eight participants), scraping the hard end of the mallet over the pendulum rings (seven participants) and striking with the hard end of the mallet (seven participants).

With each creative prompt the participants expanded their gestural languages. In Creative Prompt 1, by default all 10 participants performed gestures they had not performed before. In Creative Prompt 2 and again in Creative Prompt 3, seven out of 10 participants performed a new gesture they had not previously performed. It is to be expected that participants would discover new gestures in Creative Prompt 3 as a result of the sound being on, and five participants reported knowingly doing so. I find it interesting that two participants, P6 and P7, developed new gestures during Creative Prompt 2 after discovering the instrument is capable of creating more timbres than they had originally imagined.

Table 5.3 shows the number of pendulums each performer played per task. We find it interesting that each participant performed on average 18, 16 and 19 pendulums during Task 1, 2, and 3 respectively, making almost full use of the 20 tones on offer regardless of whether the sound was on.

In addition to trends of sound producing gestures, trends of compositional patterns emerged in which participants were observed to perform the same combination of tones in series. Table 5.4 shows the patterns that participants were observed to play, and how many participants performed each pattern per task. All 10 participants performed at least one of these patterns during each task.

Five of the patterns (*‘quadrant in order’*, *‘adjacent quadrant patterns’*, *‘quadrant sweep’*, *‘simultaneous or alternating neighbours’* and *‘tier in order’*) were

Table 5.2: Number of participants that performed each gesture in Creative Prompts 1, 2, 3 and all creative prompts combined.

Gesture	Prompt 1	Prompt 2	Prompt 3	All Prompts
Strike pendulum - soft end of mallet	10	9	8	10
Strike frame - mallet/hand	5	4	6	8
Strike pendulum - wooden shaft of mallet	3	4	3	7
Scrape pendulum rings - wooden shaft of mallet	4	4	5	7
Push pendulum - hand	4	6	2	6
Upward strike to pendulum - mallet/hand	4	2	3	6
Scrape pendulum rings - soft end of mallet	3	4	3	5
Scrape pendulum rings - hand	4	1	1	4
Strike pendulum - mallet, and pendulum returns to mallet	1	2	2	4
Tap pendulum - hand	1	2	1	3
Hold pendulum at an angle and strike - mallet/hand	0	2	3	3
Hold pendulum at an angle	0	2	1	2
Strike inside pendulum - hand	1	1	1	2
Strike inside pendulum - wooden shaft of mallet	0	1	1	2
Catch swinging pendulum	1	1	0	2

Table 5.3: Number of pendulums performed per creative prompt.

Participant	Prompt 1	Prompt 2	Prompt 3
P1	20	20	17
P2	19	20	20
P3	11	6	18
P4	20	20	20
P5	20	18	20
P6	20	20	20
P7	20	13	20
P8	14	13	20
P9	16	10	13
P10	20	18	20
Mean average	18	16	19

Table 5.4: Patterns of tones performed in order and how many participants performed each pattern per creative prompt.

Pattern	Prompt 1	Prompt 2	Prompt 3
Quadrant in order: 5 pendulums located in the same quadrant performed in order, strike gestures	8	8	7
Adjacent quadrant patterns: a sequence of pendulums in a quadrant repeating in another quadrant	8	7	4
Quadrant sweep: 5 pendulums of same quadrant, 1 arm motion	8	3	3
Simultaneous or alternating neighbours: performing 2 pendulums next to one another	4	6	5
Tier order: 10 pendulums located on the same tier consecutive order, strike gesture	3	4	4
Tier sweep: 10 pendulums of same tier, 1 arm motion	4	1	1
Furthermost stretch: performing the furthermost left and right pendulums on one tier simultaneously	2	0	0

performed by participants on both versions of the instrument during Task 3 with the sound on, thereby resulting in different sonic output. The most performed patterns are achievable with relative ease, such as the sweeping motions that results in many notes performed in order with the one arm gesture. By contrast, the least frequently observed pattern was the most difficult to perform (*‘furthermost stretch’*).

5.9.5 Physicality of the instrument in relationship to the performer’s body

Five participants remarked on how large the instrument is, saying *‘it’s easily the biggest instrument I’ve ever played’* (P3) and *‘I can’t believe how large it is, and I think that could be slightly intimidating’* (P6). Two of the participants commented on its potential to be dangerous, with P2 demonstrating *‘if it’s swinging like this you have to be careful it doesn’t hit you in the face’*².

Three participants commented that they chose to perform pendulums that were more ergonomically suited to their body. Five participants said they re-

²While I acknowledge that the pendulum swinging *could* hit the performer in the face, no participant of any study was hit in the face or elsewhere by a swinging pendulum. Regardless, this possibility is not considered a danger as the instrument is constructed out of lightweight PVC. If the instrument were constructed from a heavier material such as wood or metal this would be a concern and is something to keep in mind when future iterations of the instrument are constructed, such as those made out of eco-friendly materials, as discussed in Section 4.5.2.

located themselves to a different part of the instrument to perform pendulums that were in their preferred tonal range.

Seven out of 10 participants consistently performed from outside the instrument's frame (Table 5.5). Of these participants, three performed only ever facing the pendulums, without exploring the side or back of the instrument.

Table 5.5: Participants who performed from each location per creative prompt.

Performer location	Prompt 1	Prompt 2	Prompt 3
Outside frame, facing pendulums	P1, P2, P3, P4, P5, P7, P9, P10	P1, P2, P3, P4, P5, P7, P10	P1, P2, P3, P4, P5, P7, P10
Inside frame, facing pendulums	P2, P6, P8, P9, P10	P6, P8, P9	P6, P8, P9
Left, right and/or behind frame	P4, P5, P10	P6	P1, P2

Three participants chose to complete all creative prompts from inside the instrument's frame (Figure 5.2) with one (P8) not even exploring the options of performing from any other location. All three complained that the instrument design features horizontal support beam dividing the left and right sides of the instrument, restricting their access to each side as they would need to duck below it to cross the divide. This resulted in them either focusing their improvisations on one half of the instrument, or choreographing ducking movements into their performance. Ironically if they had chosen to perform from the outside of the instrument they would not have been restricted by the support beam.

5.10 Discussion

It is evident that the instrument's materiality, aesthetics and sound design influence the emergent gestural language and in turn the initial music improvised with the instrument.

5.10.1 Impact of materiality on imagined sound

When given the task to imagine the DMI's sound, one of the participants declined to imagine any sound. Of the participants that did imagine sound, all nine were influenced by the instrument's materiality such as the pendulum rings that brought to mind *güiro*-inspired sounds and the metallic aesthetic that evoked sounds and tonal layouts of metallic instruments. Additionally, during the interview it was learned that the participant that did not imagine any sound during the creative prompt had already begun imagining the sound of the instrument before the session began, and at that time he had imagined bell-like sounds influenced by the materiality of the instrument. These results reinforce Pigrem



Figure 5.2: Three participants completed all creative prompts from inside the frame even though this restricted access to the other side of the instrument.

and McPherson’s findings that performers’ expectations of a DMI’s sound and function are fundamentally linked to their tacit and cultural knowledge of materiality [145].

5.10.2 Impact of sound design on development of gestural language

Participants discussed ways in which the sound design influenced their methods for developing performance gestures. P3 and P5 discussed abandoning previous gestures when they discovered they did not result in sound. P2 described changing to easier techniques that result in the same sound. For instance, when he discovered the swing of a pendulum does not emit a tone he left pendulums swinging, when previously he tried to stop each pendulum. P4 and P10 both described their techniques as trying every gesture then focusing on those that result in sound, *‘eliminating movements that are not useful, and trying to find the ones that were’* (P10). With the sound on, P10 played with more precision and variation, explaining *‘I was testing much more subtle kind of movements, when originally I thought they might just make one sound but it seems that they’re more interactive with velocity.’* These comments illustrate Jack, Stockman and McPherson’s research into musicians optimising their gestures to match the sensing modalities of instruments [83].

5.10.3 Impact of sound design on improvisation

During Creative Prompt 1, P8 imagined the instrument’s tones would sustain so she performed gestures at a slow tempo. During Creative Prompt 2, after hearing the shorter-than-expected instrument tones, her gestures sped up. She said her decision to increase the tempo was based on a preference for tones to finish before new ones begin. This demonstrates how an instrument’s sound design can impose *‘pull’* effects that control the performer to change the speed of their performance.

5.10.4 Impact of instrument physicality on compositional choices

P6 commented that she was unsure whether she played a pendulum because she likes its tone or whether she likes its tone because it is in an ergonomically convenient location. Meanwhile, P8 justified moving around the instrument a lot by saying *‘you’ve got this big machine, you don’t want to just stay there. You want to... use the breadth of the machine.’* These examples illustrate Tuuri, Parviainen and Pirhonen’s research on experiential control [179] as the physical

size of the instrument in relationship to the performers' bodies results in '*pull*' effects that control which pendulums the performers play and in turn how they move their bodies.

Impact of tonal layout on improvisation choices

Identical patterns of successive tones were observed to be performed by different participants. As these compositional patterns were performed with both instrument versions regardless of tonal layout, therefore resulting in different sonic output, I propose to identify them as the instrument's idiomatic gestural patterns.

Patterns occurring across more than one quadrant more frequently combined quadrants located above or below rather than beside one another. Performing quadrants side by side requires much more movement than performing quadrants above one another. This trend indicates that what is idiomatic to this instrument has less to do with sound design and more to do with the instrument's physical layout and its relationship to the body.

Beyond influencing emergent idiomatic patterns, the visual aesthetic of the quadrants even influenced the performer's perception of the tones themselves. This is illustrated by the examples of the participants that performed version L1B of the instrument who were drawn to certain quadrants and avoided others. Version L1B features a zigzag tonal layout such that the upper and lower tiers have a similar range of pitches and timbres. Therefore the quadrants above and below each other have similar pitches, yet participants described preferring one quadrant of tones over another.

5.11 Summary

This chapter introduced Study 1, a study that observed the initial reactions of trained musicians when encountering a new, unfamiliar, large scale DMI for the first time. The study resulted in the identification of several idiomatic gestures and idiomatic patterns of the instrument as well as new insights into how the layout, materiality, sound design and size of an instrument govern performance choices.

This study investigated and revealed insights into the following questions:

In what ways do instrument size and tonal layout and sound design influence the idiomatic gestural language of a DMI?

While there is an influence of sound design on performance techniques, as evidenced by participants narrowing their gestures to those that produced or ef-

affected the sonic output of the instrument, the idiomatic gestures and patterns that emerged seem to be strongly dependant on the relationship between the instrument's physical layout (a combination of the tonal layout and size) and the performer's body, resulting in strong influence on the improvisations created and moreover even resulting in musicians changing their perception of the sound.

In what ways does sound design and the act of sound production influence musical choices during improvisation?

The study revealed that sound design influences both idiomatic gestures and idiomatic patterns, yet some idiomatic patterns are so inherent to an instrument that if disrupted by replacing tones with other tones, musicians perform the idiomatic patterns regardless of the tones and even perceive the tones differently which in turn influences their use in performance.

5.12 Carry forward

These findings illuminate how the size and layout of a DMI influence the instrument's idiomatic gestures and idiomatic patterns, which in turn influence improvised performances created with the instrument. However the effects observed reflect only a short term engagement with the instrument. The research in the following chapters explores the continued development of gestural languages over time and the impact of size on fixed performances of musicians familiar with the instrument through long-term engagement.

Chapter 6

Study 2a: Entanglement and size

This chapter is built on significant material from ‘Super size me: Interface size, identity and embodiment in Digital Musical Instrument design’ by Mice and McPherson, originally published in the proceedings of the Conference on Human Factors in Computing Systems (CHI), 2022 [121].

In this chapter I describe Study 2, and present the Study 2a findings which examined the impact of instrument size on the co-constitution of humans and technology ¹.

In Section 6.2 I detail the research questions explored by this study and how they relate to the central research questions of this thesis.

In the following section (Section 6.3), I describe the study design and process, including a description of each study session.

The results are detailed in Section 6.4. This section presents the outcomes of the thematic and interaction analyses.

Finally, in Section 6.5 I relate these back to the frameworks of the ‘*Entanglement theories of HCI*’ (discussed in Section 2.2.4).

6.1 Findings from Study 1 and the problem space

Study 1 examined the impact of an instrument’s size and layout on the initial gestural languages used to perform a large DMI during a limited one-session exploration of the instrument. Study 1 monitored musicians during their first encounter with a new large DMI. The Study 1 findings, outlined in Section

¹The Study 2 data will be further examined and presented in Chapter 7 (Study 2b: Exploring motivic analysis)

5.9, show that the idiomatic gestures and patterns that emerged were strongly dependant on the relationship between the instrument's physical layout (a combination of the tonal layout and size) and the performer's body. The idiomatic patterns that emerged were not influenced by the tonal layout of the instrument. This is proven by the discovery that the same idiomatic patterns emerged across all participants even though half were assigned a version with a different tonal layout, and that none of the participants fully understood the tonal layout of either version of the instrument beyond knowing the locations of the lowest and highest tones. Questions remain surrounding the impact of these idiomatic gestures and patterns on fixed performances composed with a large instrument.

6.2 Study 2a research questions and motivation

Advancements in digital technology allow for the design of ever smaller interfaces, while human bodies remain stubbornly the same size. This chapter presents Study 2a in which I investigate the role of interface size on both the compositional choices of musicians and the creation of user identities. In Study 2, 10 musicians performed with a very large DMI (two metres wide and tall). Based on the actions and comments of the musicians, I reflect on the diversity of embodiment relationships and explore how designing a musical instrument might shape the personal identity of the musician who plays it.

Ideas around the trend of shrinking interfaces in DMI design are discussed in depth in Section 2.3, and in this section I summarise these ideas as well as present concepts that directly influence this research.

While large DMIs have been designed for public interactive installations [143, 53], the lack of widespread availability of large DMIs makes them a fertile ground for exploring the role of size in technology design and its ensuing impact on human perception and creative output.

Considering entanglement HCI in a musical context, following on from Section 2.2.2 (Bodies, interfaces and size), particularly [167, 77], Section 2.2.3 (Size, effort and context in musical interfaces), particularly [156, 184, 92, 188] and Section 2.2.4 (More-than-human bodies and entanglement), particularly [77, 52, 4] the instrument does not become an instrument until it is played by a performer [66], and conversely, a performer only acquires that identity in relation to their instrument. But how does this act of co-constitution impact human experience and identity? And what does it mean for the music being created? Costello [33] poses these questions as being central to the perspective of Entanglement HCI: *'this perspective asks design researchers to focus on how designs become different things, to focus on processes of emergence and re-configuration, and to focus on what humans and designs become as they are entangled together'* [33].

What role, then, does size play in this entanglement? Prosaically, it ought to have an effect on human bodies: larger instruments will engage different muscular groups (requiring arm span rather than finger span), will require different amounts of force and have differing requirements in spatial precision. But changing the instrument size will also affect the performer's experience of their own body and their own musicianship. In turn, this entanglement also encompasses the diversity of individual bodies, considering physical health, gender, race and (dis)ability [167], prior experience on other instruments, and cultural contexts and priorities [188].

Time is also a factor in musical entanglements: instruments require time for musicians to develop the skills for performing them [155, 113]. Therefore, to understand the role that size plays on the entanglement of players learning instruments, I designed a study that tracks 10 musicians as they learn to perform a large digital musical instrument over a period of four weeks. During this time the musicians attended four sessions (one per week). I embarked on a study that is longitudinal, exploratory, pluralistic (admitting a diversity of individual perspectives rather than seeking universality) and experience-oriented rather than music-theoretical. In contrast to traditional HCI in the workplace, musical performance is essentially a taskless interaction [155]. On that basis, if performance is embodied and features an entanglement between performer and instrument, we should see a few features:

- The patterns of performance should reflect the physical or gestural affordances of the instrument in relation to the particular body of the player. In other words, the musical patterns will not be explainable by music theoretical notions alone such as harmony, melody, rhythm.
- We may see bodily interactions that are ancillary to the ostensible goal of producing sound, which have a personal or communicative purpose rather than simply enabling sound production.
- Each performer will approach the instrument differently in relation to their stylistic background but also in relation to other instruments they might play, as those other instruments have shaped their bodily experience.

The above effects should not be entirely arbitrary but should be traceable to particular relationships between bodies and technologies. If indeed the performer and the instrument are inherently entangled, then we may also see an influence of the instrument on the player's self-perception of their own body: not just what they do, but how they experience themselves.

6.2.1 Research questions in this study

The central research questions for Study 2a are:

- What is the relationship between the instrument's physical design and the music performed with the instrument? What role does size play in this relationship?
- How does a difference in the size of an instrument influence performer identities?
- Which factor exerts a greater influence on motivic patterns, physical layout or sonic features?

I hypothesised that the physical design of the large study instrument would influence what is idiomatic to perform with the instrument. I hypothesised the emergence of physical performance patterns that trend across performers regardless of the resulting tones which may influence the tone selection of composers performing with the instrument.

6.2.2 How the Study 2a research questions relate to the central research questions

The Study 2a research questions relate to both central research questions shown in Section 1.3):

- RQ1²: The DMI designed for the purposes of this experiment was Chaos Bells, an instrument produced in various versions (described at length in Chapter 4. For this study each participant composed with one of the large versions (half received L2A and half received L2B) for three sessions. During the 4th session, each participant performed with the smaller version of their larger version (those who composed with L2A performed with S2A, those who composed with L2B performed with S2B). Analyses of the participants' performance and interview data revealed ways that physical dimensions shape the performances created.
- RQ2³: While the participants of this study were all trained in Western music, their musical background including primary instruments and styles varied. The performance and interview data was explored to understand the impact that replacing a musician's primary instrument with a new

²How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?

³By conducting research with instruments that are physically larger than the performer's body, what can we learn about instruments of all sizes with regards to the impact that design choices have on performance and compositional choices?

instrument that is unfamiliar in size and form factor has on musical entanglements. The findings of this investigation are relevant to instruments of all sizes.

6.3 Study design

Study 2 is an exploratory study that uses size as a probe, deliberately inverting the prevailing trend toward smaller, more portable, more general-purpose interfaces. I invited musicians to create new performances with a large-scale digital musical instrument over the course of the first three sessions of the study. Participants were instructed to create compositions that are repeatable and that represent themselves musically, and were informed that a video-recording of their final composition would be broadcast on a public online concert⁴. During the fourth and final session, the participants were introduced to a smaller version of the large-scale instrument – half the size of the original version – and were invited to perform their composition with it. In this way, the smaller version of the instrument probed the participants to consider ways the size of the large-scale instrument influenced their compositional choices. For consistency, one investigator (myself) administered all sessions.

The study was reviewed and approved by the Queen Mary University of London ethics board (ethics approval reference #2393) prior to research commencing⁵.

6.3.1 Study 2 instrument

The instrument designed for this study is called Chaos Bells. An in-depth exploration of the design approach, process, sound design, tonal layouts and size considerations can be found in Chapter 4. The versions of the instrument used in this study were L2A, L2B, S2A and S2B (detailed in Table 4.1). Figure 6.1 shows a participant with her arms outstretched in front of the larger version of the study instrument interface (used for versions L2A and L2B).

Tuning

The instrument is tuned to Tuning 2 (shown in Table 4.3), an ascending C# melodic minor scale (C#, D#, E, F#, G#, A#, B#). The lower register

⁴The purpose of this methodology was to ensure that participants authentically engaged with the study. Creating repeatable compositions ensured that the performers were indeed composing rather than improvising. Broadcasting the performance gave the participants incentive to invest genuine artistic effort in the process and attempt to create a composition that authentically reflected their musical priorities.

⁵While the instrument is large in size it is lightweight and therefore does not put participants at risk of injury, hence the ethics facilitator deemed the study extremely low risk.



Figure 6.1: A performer with arms outstretched in front of a large digital instrument.

consists of 10 tones spanning from C#1 to E2 and the upper register consists of 10 tones from G#3 to B#4. The characteristics of the synthesis algorithm mean that each pendulum has a distinctive timbre from slightly different combinations of harmonics and inharmonicity.

Instrument versions

The instrument versions differ in size (L2A and L2B are twice the size of S2A and S2B) and tonal layouts (L2A and S2A are configured to tonal layout A, while L2B and S2B are configured to tonal layout B).

Half the participants received Layout A and half the participants received Layout B for the duration of the study. Figure 6.2 demonstrates the location of tones when the instrument is configured to layouts A and B with lower register tones shown in blue and higher register tones shown in yellow. Layout A features lower register tones that ascend left-to-right across the lower tier, and higher register tones that ascend left-to-right across the upper tier. Layout B features lower register tones that ascend in a zigzag pattern (inspired by the chromatic layout of piano keys) on the left and higher register tones that ascend in a zigzag on the right⁶.

⁶The tuning of the instrument was designed to encourage composition of melodic, tonal music so that the compositions could be compared. By creating a gap of over an octave between the lower and higher registers, the instrument features distinct lower and higher registers. Meanwhile, having two layouts allowed comparisons which reveal tonal versus ergonomic effects on the choice of musical material. These design choices created fertile ground for comparing compositions and performances created during the study.

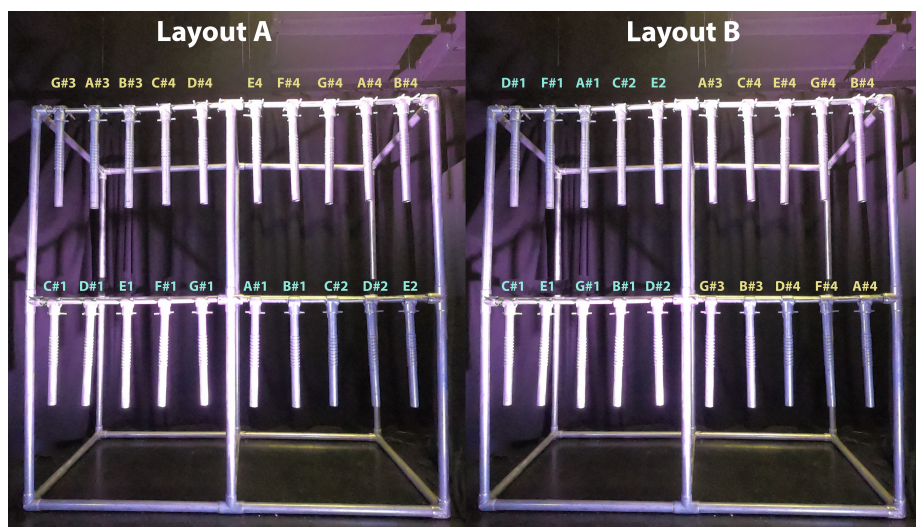


Figure 6.2: Location of tones on instrument layouts A and B with lower register tones shown in blue and higher register tones shown in yellow.

6.3.2 Selection of participants

An open call was circulated on social media for musicians to perform a new musical instrument in an upcoming online concert as part of an instrument design study. All 10 participants that were available for the study sessions were accepted for the study, regardless of their musical backgrounds, customary genres and primary instruments⁷.

6.3.3 Study sessions

As I was interested in comparing performances created by musicians familiar with the instrument, I designed the study to take place over four sessions. During each session, the musicians privately engaged with the study instrument for one hour. They were instructed to complete several compositions in response to various creative prompts (shown in Table 6.1), and perform each composition twice to ensure that they were indeed composing rather than improvising. Each session concluded with a semi-structured interview. The interview questions for each session are shown in Appendix E. The musicians were told that the final three minute performance would be broadcast on an online streaming concert.

⁷While some musicians in the study have lived experience of conditions that may impact music performance, the call for participants did not target such musicians.

Table 6.1: Creative prompts

Session	Creative prompt	Instrument version
1	Create a 1 minute composition that is dynamic in its registers	Larger interface (L2A or L2B)
2	Create a 1 minute composition that is an exploration of rhythm	Larger interface (L2A or L2B)
3	Create a 1 minute composition that is an exploration of texture, Create a 3 minute composition that shows your favourite aspects of music created with the instrument	Larger interface (L2A or L2B)
4	Perform the 3 minute composition on the smaller interface	Smaller interface (S2A or L2B)

Session 1

Initially, the investigator introduced the participant to the study instrument and explained to them that the instrument is safe to perform as long as the participant does not attempt to climb the instrument. Having seen the instrument, the participant confirmed that they would participate in the study and completed a consent form.

The investigator then explained the instrument's tuning and pattern of tones, and demonstrated how the instrument may be performed. The following gestures were demonstrated: striking the pendulum with the soft and hard ends of a mallet so as to create clear tones; scraping the pendulum rings with the hard end of the mallet so as to create repeated tones and textures; striking the instrument frame with the mallet so as to create a cacophony of tones; raising the pendulum to create a drone; raising the pendulum above the chaos threshold to create white noise; dropping the pendulum to demonstrate the slow release of the drone/white noise. The participant was given five minutes to explore performing the instrument, after which time they were given 40 minutes to compose a short one-minute sketch of a composition that responds to the creative prompt of being 'dynamic in its registers' in that it makes use of the range of tones afforded with the instrument. Upon completion, the participant performed the one-minute dynamic registers sketch twice and answered questions about their musical background and experience with the instrument during this session.

Session 2

The second session began with the participant performing their one-minute dynamic registers sketch (that they composed in their previous session) twice.

They were then given 40 minutes to compose a different one-minute sketch of a composition which responded to the creative prompt of being an exploration of rhythm. The participant performed the one-minute rhythm sketch twice and answered questions about their experience with the instrument during this session.

Session 3

The third session began with the participant performing their one-minute rhythm sketch (that they composed in their previous session) twice. They were then given 10 minutes to compose a different one-minute sketch of a composition that responded to the creative prompt of being an exploration of texture. The participant performed the one-minute texture sketch twice. They were then given 30 minutes to compose a 3-minute composition that responds to the creative prompt of showing their favourite aspects of music created with the instrument. They were told that this final composition would be recorded for broadcast on an online streaming concert. The participant performed the 3-minute concert composition twice and answered questions about their experience with the instrument during this session.

Session 4

The fourth session began with the investigator introducing the study participant to the smaller instrument. The investigator explained that the smaller instrument is exactly the same as the larger instrument but half the size, and due to the difference in size, requires different performance techniques. The investigator demonstrated how the small instrument may be performed to create the same tones as the large instrument. The participant was given 10 minutes to explore the smaller instrument and rehearse their concert composition to make it as similar as possible to its performance on the large instrument. The participant then performed the concert composition twice on the smaller instrument and answered questions about their experience performing the smaller instrument.

Finally, the participant was given five minutes to explore performing the larger instrument again and to rehearse their concert composition on it. Upon completion, the participant performed the concert composition twice on the large instrument and answered questions about their experience performing the instruments during this session. Participants were instructed to watch the videos of the concert composition performed on the large and small instruments and choose which video they would like included in the live-streamed public concert.

6.3.4 Data collection and analysis

Each time a participant performed a composition the performance was captured on video. The interviews were also captured on video. Two wide-angle video cameras simultaneously captured the performances and interviews. One camera was placed on a tripod in front of the instrument and a second camera was hand-held by the study investigator. Using the hand-held camera the investigator reacted in real time to capture on video the participants' responses to the creative prompts. Using a hand-held camera in this way removed the time-consuming step of editing together the videos that captured multiple angles that was required during Study 1, discussed in Chapter 5, Section 5.8.

The performance videos were manually analysed for gestural interaction following a method in which I logged all performance gestures as well as the corresponding locations of the instrument performed by participants (outlined in Section 1.4.3), as well as the presence of the the physical performance patterns observed in improvised performances with the instrument during Study 1 (Chapter 5 Table 5.4).

The audio of the recorded interviews was automatically transcribed using *otter.ai*, an online automated transcription tool, and manually corrected. The interview data was analysed following a thematic analysis methodology [41] that took both an inductive (from the data) and a priori approach [157] (see Section 1.4.3). The thematic analysis codebook (Appendix F) features 1338 coded segments clustered into the codes: *effort*; *entanglement*; *characteristics of the compositions*; *reflections on the instrument*; *gestures and techniques*; *performing perception*; *performer's body*; *movement*; *learning the instrument over time*; and *'edge-like interactions'*⁸ [131].

6.3.5 Participants

10 participants (three women, four men and three gender-fluid people) who have been trained on a variety of instruments and have varying musical backgrounds and genres participated in the study. Three of the participants (P3, P7 and P10) had previously participated in Study 1 (Chapter 5). Table 6.2 shows information pertaining to the participants' bodies including heights (ranging from 157 centimetres to 186 centimetres), arm spans (ranging from 153 centimetres to 191 centimetres), ages (within the age ranges of 25 to 54) and self-identified conditions that may impact musical performance. While all participants have a formal Western music background, and are established composer-performers within the experimental electronic music scene of London, their primary instru-

⁸'Edge-like interactions' is the term used by Mudd to describe exploratory performance interactions at the boundary between stability and instability.

ments and styles vary. Table 6.3 shows the participants’ musical backgrounds and the layout they were assigned.

Table 6.2: Participants’ bodies

Participant number	Gender, Pronouns	Age range (Years)	Height, Arm span (cm)	Conditions that may impact music performance
P1	Man, he/him	25-34	180, 180	Occult ganglion (right wrist and shoulder)
P2	Man, he/him	35-44	186, 181	Neurodiverse
P3	Woman, she/her	35-44	163, 167	N/A
P4	Gender-fluid, they/them	35-44	175, 170	Neurodiverse, Chronic anxiety, Memory issues
P5	Gender-fluid, she/her	25-34	157, 153	Hyperventilation syndrome (HVS)
P6	Woman, she/her	25-34	168, 166	Dyspraxia
P7	Man, he/him	25-34	184, 191	N/A
P8	Gender-fluid, She/They	35-44	167, 168	Performance anxiety
P9	Woman, she/her	25-34	173, 172	N/A
P10	Man, he/him	45-54	175, 172	Pulled arm muscle

6.4 Results

6.4.1 Longitudinal performance data

Completion of compositions

All 10 participants completed the four sessions. During each session all participants confirmed that they succeeded in completing each composition according to the creative prompts, and, despite only the final composition being featured in an online concert, participants acknowledged that all compositions created during the study represent themselves musically in that they would be happy for them to appear in an online concert. In response to each creative prompt, all participants created fixed compositions that were repeatable twice with only minor performance-related differences. The participants all successfully created the compositions during the allotted times and were not drawing on previous compositions or ideas, with the exception that for the final 3-minute concert composition all participants included segments from at least one of their one-minute compositions.

Table 6.3: Participants' musical background and study instrument layout

Part- icipant	Primary instru- ment	Other instru- ments per- formed	Perform- ing in- stru- ments (total years)	Primary genre	Secondary genre	Layout (A/B)
P1	Piano	Guitar, Synthe- sizer, Drums, Bass	23	Electronic, New Psyche- delic, Ambient	Noise, Drone, IDM, Shoegaze	A
P2	Cello	Synthesizer, Handmade electronic instru- ments	25	Improv- isat- ion	Avant garde, Classical	A
P3	Piano	Synthesizer, Gong	20	Electronic	Experi- mental pop	B
P4	Piano	Viola, Gui- tar, Bass, Recorder, Harmonica	19	Noise	Industrial, Punk, Metal, Avant garde	A
P5	Guitar	Photo- phonics, Recorder, Electro- magnetic frequen- cies, Voice	18	Experi- mental electron- ics	Irish folk	A
P6	Piano	Computers, Guitar	21	Experi- mental electronic	Dance, Pop, Classical	B
P7	Saxo- phone	Bass guitar, Synthe- sizer	29	Rock	Electronic	A
P8	Piano	Bass, Vi- olin, Syn- thesizer, Organ, Guitar, Recorder, Congas, Triangle	40	Electronic, Avant garde	Baroque, Singer- song-writer, Kraut-rock, Contempo- rary classical, Latin, Rock, Pop, Disco bass	B
P9	Piano	Synthesizer	20	Electronic	N/A	B
P10	Drum kit	Snare drum, Tympani, Piano	36	Rock	Jazz, Elec- tronic, Ambi- ent, Classical	B

Only one participant, P8, mentioned that the request for compositions to be repeatable may have resulted in minimising the compositions and range of performance techniques. *‘I think I put a bit more restraint on things so that they could be repeated’*, P8 commented. When comparing the goal of creating repeatable compositions to their regular improvisation-based practice they said *‘when I go do some crazy stuff, it departs quite radically. But then can I remember that? Sometimes I don’t actually often want to remember it. I just go with it like you do in improvisation or something.’*

Evolution of performance techniques

As the participants became familiarised with the instruments over the course of the three sessions, they added new gestures and performance techniques. The gestures used to perform the instrument included those that the investigator demonstrated to the participants, such as striking the instrument with fingers, the soft or hard ends of the mallet, and tilting the pendulums to create a drone, as well as original gestures and techniques created by the participants.

In the second session, seven participants (P1, P2, P4, P5, P6, P8, P9) performed new sound-producing gestures or techniques. Some new techniques were creative gestures developed to perform the instrument with fine control. P1 used the soft end of a mallet to plug the opening of the pendulum and used the mallet to raise the pendulum. He commented that using this technique he had more control changing the angle of pendulum while making a drone.

During the third session, in which the participants composed both a short texture composition and their final concert composition, all 10 participants added new sound-producing gestures or techniques at some point during the session. One participant (P3) performed new gestures only in their texture composition, three participants (P2, P4, P9) performed new gestures only in their concert composition, and six participants (P1, P5, P6, P7, P8, P10) added new gestures during both the short sketch and the concert composition, indicating that the process of creating a new composition encourages the development of new performance methods. P10 commented *‘there are lots of other sounds that I haven’t really gotten out of this (instrument) yet. You know, maybe if I kept on doing this (study), I would explore more’*.

Some of the techniques developed in the third session resulted in radical shifts in instrument performance. For instance P5 changed from performing the instrument with mallets to solely using her hands. During the fourth session, when the participants repeated their concert composition on the large instrument, no participants expanded their performance gestures or techniques and instead continued performing the piece with the gestures and techniques

developed during the third session.

P3 explained how the Session 3 creative prompt (to create a sketch of a composition that explores texture) led her to try out new gestures during this session which ultimately led to new gestures and performance techniques in her compositions such as striking the pendulum support pole and scraping the pendulum rings. Elaborating on the process of developing these performance techniques, P3 said *because it was texture, I wanted to experiment with playing in a different spot that I hadn't touched yet before. So that's why I picked in between (playing on the support pole between the couplers that attach each pendulum)*'.

Tables 6.4 and 6.5 show the progression of gestures and techniques performed by the participants during each session. Table 6.4 shows the sessions in which participants first performed techniques demonstrated by the investigator, and Table 6.5 shows the sessions in which participants first performed techniques that they developed themselves.

Some of the more inventive performance gestures created by the participants involved using their legs. Figure 6.3 shows P7 performing his concert composition during Session 3 balanced on one leg so as to use the other knee to raise a lower-tier pendulum to create a drone, a technique that freed up his hands for performing other gestures. Similarly, during the first session P9 used an extended leg to push a pendulum and sustain a drone. During the third session P10 used his hands to raise a lower-tier pendulum to create a drone and sustained the drone by resting the pendulum against his leg. P3 reported attempting to perform the pendulums with her leg but moving on from the idea without including it in her composition.

Other creative performance methods included inserting a finger (P5) or the hard end of the mallet (P5, P7, P8) into the pendulum and rattling it like a bell, a technique that P5 further extended by additionally using the hard end of the mallet to raise the pendulum to create a drone.

Some participants spoke of not performing certain techniques because they did not have enough time with the instrument to practice those techniques to get good enough at them. P10 said he avoided performing the *güiro*-esque pendulum rings because *'it's a bit hard to get yourself in exactly the right position and use them. As a drummer, my inclination is always to sort of try and get a controlled movement on them, and I'd have to practice very hard'*. Meanwhile P5 opted for performing the instrument with her hands during the third session because she was dissatisfied with her abilities with the mallets. She said *'I feel like there's a skill to be learned in how one holds them. Like, do you hold them at the fulcrum? How tight, how loose, whereabouts on the stick? And then also, you've got a hand eye coordination situation with this extra long bit. Whereas when it's your own hands, you can stop looking and not need to be quite so accurate*



Figure 6.3: Photos of the large instrument with participants P7 and P2 performing gestures they created themselves: P7 sustaining a drone with his knee, P2 waving arms towards the pendulums in an ancillary gesture.

and still get what you want to achieve’.

P8 (the third-shortest participant) opted to perform the instrument with mallets rather than her hands because at 41.5 centimetres in length each, the mallets substantially add to her 168 centimetre arm span.

Although all participants understood that the instrument is digital, various participants said they had uncanny, disorienting experiences with the instrument because the instrument creates the convincing effect of being acoustic. During the second session, P2 (who regularly performs bass guitar) said that due to the ‘*physical*’, ‘*acoustic*’ presence of the instrument, without thinking he grabbed a pendulum to try to mute it, as one would a vibrating string or drum skin. Also during the second session, P3 (who is trained on piano and gong) said she felt disoriented because the instrument sounds like a string but is performed like a drum. *‘It kind of took me out of my head for a while, which was really nice. And then I came back and I was like “Wow, that was a really interesting experience”. You know, that’s what happens when you play music, you get lost in it. But this was quite a different experience, because I was standing up with sticks. But it sounded like a piano. Like it was quite disorienting in a really nice way’.*

Aside from sound-producing gestures, participants also incorporated into their performances exaggerated ancillary (non-sound-producing) gestures [37], however only when performing the larger version of the instrument. Table 6.6 shows the number and description of ancillary gestures performed by participants with the larger version of Chaos Bells. These gestures ranged from freezing

Table 6.4: Performance of sound-producing gestures and techniques initially demonstrated by the investigator (Larger version of Chaos Bells)

Sound-producing gesture or technique that was originally demonstrated by the investigator	Participant that first performed this gesture in Session 1	Participant that first performed this gesture in Session 2	Participant that first performed this gesture in Session 3	Participant that first performed this gesture in Session 4
Raise pendulum tube to create a drone	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10	None	None	None
Strike pendulum tube with soft end of mallet	P3, P4, P5, P6, P7, P8	P1, P9	P10	None
Strike pendulum coupler with soft end of mallet	P3, P5, P6, P7, P10	P1, P4	None	None
Raise pendulum tube to create a drone including chaos	P2, P4, P5, P7, P9	P1	P10	None
Strike pendulum support pole with soft end of mallet	P4, P6, P9	None	P3, P5, P6, P7, P8	None
Scrape pendulum rings with hard end of mallet	None	P1, P9	P3, P5, P6	None
Strike pendulum tube with hard end of mallet	None	P9	P6	None
Strike instrument frame with soft end of mallet	None	None	P6, P8	None

Table 6.5: Progression of sound-producing gestures and techniques that were developed by the participants

Sound-producing gesture or technique that was developed by the participant	Participant first performed this in Session 1	Participant first performed this in Session 2	Participant first performed this in Session 3	Participant first performed this in Session 4
Finger tapping on pendulum coupler or instrument frame	P4, P10	None	P1	None
Rattle hard end of mallet between 2 neighbouring pendulums to repeatedly strike pendulums	P5	None	P3, P9	None
Strike pendulum tube or coupler with soft end of mallet while holding 2 mallets in 1 hand	P6	None	P1, P4	None
Rotate pendulum coupler to create a drone including chaos	P2	None	P5	None
Strike pendulum tube, coupler or support pole with hand	P4	None	P5	None
Scrape pendulum rings with fingers or jewelry	P8	None	P5	None
Push pendulum with foot or knee to create drone	P9	None	P7	None
Rattle finger or hard end of mallet inside pendulum tube opening	None	P5	P5, P7, P8	None
Hold already sustaining pendulum with other hand or rest on knee	None	P6	P5, P10	None
Scrape pendulum rings with soft end of mallet	None	P8	P6	None
Forcefully release pendulum to make it swing	None	P2	None	None
Rattle hard end of mallet inside pendulum tube opening, use same mallet to raise pendulum to create drone and chaos	None	P5	None	None
Raise pendulum to make a drone while striking the same pendulum with soft end of mallet	None	None	P1, P3, P10	None
Raise pendulum to create a drone and scrape rings of the same pendulum with hard end of mallet or finger	None	None	P3, P5	None
Raise pendulum to create drone using hard end of mallet or finger	None	None	P5, P8	None
Raise pendulum to create drone while using same hand to strike the same pendulum or another pendulum with soft end of mallet	None	None	P6, P9	None
Use soft end of mallet to plug the end of pendulum to control changing the angle of pendulum while making a drone	None	None	P1	None
Use forearm to raise multiple neighbouring pendulums to create drones	None	None	P2	None
Foot tapping on instrument frame	None	None	P5	None

in place at the end of the composition (P10) to exaggerated, performative gestures such as waving arms in the air while a drone sustains as though conducting the sound (P3, P4, P5), skipping or dancing when moving between locations of the instrument (P5), and moving between performing from the inside to the outside of the instrument (P3, P6).

When describing one of their ancillary gestures that is part of their concert performance, P4 highlighted ways that ancillary gestures not only add to the performance but also allow the performer to engage differently with the performance.

‘The bit right at the end, where I hold (pendulums) sort of for a longer period of time than the other ones. And I sort of let my hand slide down the full length of the pendulums. And then let them go and just wait for it to ring out. I think that was very effective. And it was it was nice to do that as well... The fact that it’s still the performance, but you’re also just sort of waiting and posing and listening to it ring out and trail down... It adds a different performative element of it in so much as something is happening, but you’re not doing anything anymore. And you just sort of stand there, and it gives you a chance to just breathe and listen to what’s happening. And just let it happen. Let the instrument do its thing.’ - P4

P8 developed various gestures that created sounds in an exaggerated performative way that could have otherwise been performed with less effort: she performed two drones simultaneously in an overly complicated way (shown in Figure 6.4) pulling one pendulum forward and pushing one backwards; and she performed the frame of the instrument in various locations even though she recognised it sounds approximately the same regardless of where it is struck. P8 explained that they incorporated these exaggerated gestures into their composition because of the way an audience would view the performance: *‘you can drone in each direction, so it looks nice when you do like this. I mean, you can work with the aesthetics of the droning as much as with the sounds’*. Three participants (P1, P5, P9) said they enjoy the feeling of moving around the large instrument as part of the performance.

Once familiarised with the instrument (during the second and third sessions), nine participants (P2, P3, P4, P5, P6, P7, P8, P9, P10) stated that the fact that the pendulums all look the same does not affect their ability to remember the location of the tones. P8 and P9 commented that they consider the large gestures in relation to their own body to help with their memory of the location of tones. P8 commented that remembering the location of tones is *‘actually not as difficult as I thought. I think it’s partly because you start associating*

Table 6.6: Ancillary gestures performed by participants during each session

Ancillary gesture	Partici- pant that per- formed this gesture in Ses- sion 1	Partici- pant that per- formed this gesture in Ses- sion 2	Partici- pant that per- formed this gesture in Ses- sion 3	Partici- pant that per- formed this gesture in Ses- sion 4
Performing from inside the instrument	P3, P6	None	None	P3
Exaggerated side bend with body while finger tapping on instrument frame	P4	None	None	None
Looking up to the ceiling in an exaggerated way while raising a pendulum to create a drone	P5	None	None	P2
Standing on 1 leg in a performative way for no sound-related reason	P5	None	None	None
Holding mallets frozen in mid-air at the end of the composition	None	P10	None	None
Exaggerated hand movements while a drone fades out as though conducting the drone	None	None	P4, P5	P2
Moving from performing inside the instrument to outside the instrument	None	None	P3	P3
Exaggerated arm gesture to indicate letting go of pendulum	None	None	P3	None
Looking up at the ceiling in an exaggerated gesture as final drone fades out	None	None	P4	P2
Exaggerated arm and head movements while raising pendulums located on upper tier	P4, P5	None	P4	P4
Pushing a pendulum and pulling another at the same time to create drones in an overly performative way	None	None	P8	P8
Striking the frame of the instrument in different locations	None	None	P8	P8
Swinging mallets in a circle to indicate start of performance	None	None	None	P4



Figure 6.4: P8 performing 2 drones simultaneously by pulling one pendulum forward and pushing one backwards. Photo used with permission from the participant.

them with a sound. And also you have this body gesture and maybe because the gestures are quite large as well... If you are struggling to memorise you could also use your body to measure, I guess. But I didn't find it that difficult'. P9 said '(b)ecause the gestures are so big for each note and it's so physically in front of you, you quickly get to realise what's what'.

Effort and performance

Participants commented that performing the larger version of the instrument requires effortful concentration (P8, P10) and the effort of reaching or stretching (P1, P4, P6, P8, P10). Describing the effort required for her to perform drones with pendulums located on the upper tier, P8 said *'let's say I was doing a drone on this top right one (the pendulum located on the far right of the upper tier), then I have to go on my tiptoes almost if I want to go all the way up.'*

P2 spoke of creating different gestures for performing drones with the pendulums on each tier, opting for gestures that required him to move his arm the least and therefore did not require effortful reaching. For the lower tier pendulums he tilted the pendulums by holding the pendulum coupler (the part of the instrument that connects the pendulum to the support pole), whereas for the upper tier pendulums he tilted the pendulums by holding on to the pendulum tube.

Meanwhile P4 spoke of enjoying the effort required for performing the large instrument.

‘It’s a good sort of effort. It’s not strenuous. It’s good and it works somehow for the physicality of what it is and how it works. I mean, just the fact that levering (the pendulum on the upper tier) is so satisfying on (the larger version) because of the way you have the stretch up. And the way you have to sort of shift your stance with each one. I really liked doing that’. -P4

Although the larger version of Chaos Bells requires effort related to its size, some participants had suggestions for the design of the instrument that would result in requiring *more* effort to perform the instrument. P5 (the shortest participant) suggested adding a 3rd tier that could be performed by climbing⁹. P7 suggested that the large instrument could be doubled in size, requiring stairs to access. P2 (the tallest participant) suggested adding more mass to the pendulums to create more inertia when swinging. P4 also said they would prefer the pendulums to weigh more, but specifically for the reason of requiring more effort to perform them.

‘It’s like playing on gym equipment. I’d almost like it more if they (the pendulums) were weighted. So you really had to work out with it somehow. Because you were saying about “Does it take strength?” And no it doesn’t because everything on it is very, very light. But it might be nice if everything was actually really heavy when you have to play it and you really feel the difference. Because it’s like having a weighted keyboard versus an unweighted one. It does feel very different when you’re playing it. And it is like a different instrument. Like if you’ve always trained on just playing a normal keyboard, even a weighted one, and then you go to a piano it’s a very different experience. And it is basically, even though you still have the keyboard set up in exactly the same way in the 12 tone sequence of Western music and all that. It’s still a different instrument... I’ve played weighted keyboards, and they still don’t sound or feel like quite the same instrument as the piano... It’s almost like these two (the larger and the smaller versions) they feel like the difference between a piano and a harpsichord, almost but not quite.’ -P4

I find these suggestions interesting because they would both result in the instrument requiring more effort to perform.

⁹ ‘I think I would want one further storey so that it became a bit of a heart in mouth kind of situation when someone was watching you play it. I don’t know why. I like adding danger to my set apparently.’ - P5

Gestural explorations of millimetre control

A trend emerged showing that participants found that the most difficult technique of performing the study instrument was controlling the drones because the drone feature of the instrument is very sensitive and a small change in gesture can result in a large sonic change. Participants commented on the challenge of maintaining a drone without accidentally creating white noise (P1, P2) or keeping the drones in the *'sweet spot'* (P1, P3, P4, P9, P10). P2 likened the millimetre control required to perform the drone to *'walking on a tightrope'*, saying *'sometimes I can't stop it from feeding back. It's like getting that balance right. Sometimes I don't get it right'*.

Other aspects that make the drones difficult included starting them on time as they may not start when expected (P1) or accidentally stopping a drone before intended *'because that would be quite anticlimactic'* (P1). P3 pointed out that maintaining more than one drone at a time is particularly difficult because of the size and the spacing of the pendulums.

Even though participants identified performing the drone as a difficult performance technique to achieve with the study instrument, various participants (P1, P2, P5, P9) commented that they enjoyed playing with the changing timbres of the drone, such as exploring how micro-movements of the angle of the pendulum can result in large changes in the sonic characteristics. P1 said *'just finding that sweet spot, and then being able to subtly move your hand and drastically change the phasing of the tone. That sounds awesome'*.

6.4.2 Characteristics of the compositions

Each participant had been instructed to create compositions that represent themselves musically. During the interviews, three participants (P1, P2, P9) commented that the compositions they created were reminiscent of the kind of compositions they create on their primary instrument. When discussing her concert composition, P9, whose primary instrument is synthesizer, said *'I think I've made synthscaapes that have that same kind of expansive, rolling, slow feel'*. P2, a cello player, said that his method of composing with the study instrument was inspired by *'not necessarily cello, but the way I play cello'*. Meanwhile P8, a piano player, commented that their compositions created on the large instrument are *'quite representative of my solo stuff that I normally write on the piano'*.

For the concert composition, three participants (P1, P6, P10) created compositions that were intended to be performed metronomically in their entirety, three participants (P2, P5, P8) created compositions with no fixed pulse, and four participants (P3, P4, P7, P9) created compositions that move between a

fixed pulse and more flexible time keeping. The resulting concert compositions spanned various tempos from compositions without a discernible tempo (P2, P5, P8) to tempos spanning 80 BPM (P1) to 174 BPM (P10).

When reflecting on how they chose the tempos of all compositions created during the study, participants reported various methods including what felt ‘*natural*’ or ‘*intuitive*’ (P2, P4, P8, P10); the speed that they can move their fingers or hands (P1, P7); the physicality of the instrument such as the speed at which the pendulums can swing (P2, P6); choosing a tempo at random (P10); and fitting their musical ideas within the length of the composition requested by the investigator (P1, P3, P5, P10). When describing how the study requested a one-minute composition influenced the composition tempo, P5 said ‘*I set a timer a couple of times to get a feel for how long a minute was. And I would play with different sections within it. And if I’ve got to a point where the timer was going off and I hadn’t quite got everything done then I knew I needed to speed that bit up, and vice versa*’. During the first session, P10 figured out a tempo that would fit his composition idea within the requested time-limit of one minute. ‘*It was about 71 BPM or something so that enabled me to get pretty much the exact number of bars at that speed in the space of a minute. It happened to work out. Four beats in a bar, I think it worked out, you know. I had sort of four complete cycles, each taking 15 seconds*’.

Seven participants (P2, P3, P5, P7, P8, P9, P10) considered that it was the same composition when played on both instruments, and three participants (P1, P4, P6) said it is not the same composition. P1 and P6 perceived their compositions as different because they sound differently when performed on the small instrument compared to the large. Meanwhile P4 considered it a different composition because gestures they had created for the large instrument were less performative when playing the smaller instrument. He elaborated that ‘*on (the large instrument), there’s a much larger performative aspect of it. And there’s a particular part where I do a particular set of motions that I tried to do on the smaller one but it doesn’t feel the same. So I felt like that was actually an important aspect of (the composition)*’.

Effort and compositional features

A trend emerged in which most compositions featured extended periods in which the participant stood still, punctuated by moments of moving to other parts of the instrument, rather than continuous motion back and forth around the instrument.

Regardless of which tonal layout version participants performed, 73% of all compositions created during the study featured only tones within the width of

five pendulums (100 centimetres), compared to the full width of the instrument: 10 pendulums (200 centimetres). This was a width in which all pendulums are located in front of the performer's body and are therefore reachable without much effort. This is interesting because the tones located within the width of five pendulums on Layout A are different from those located within the width of five pendulums on Layout B, indicating that the performer's compositional choices of which tones to include were influenced more by physical location than pitch.

Regardless of the instrument layout version performed, 88% of all compositions featured tones located in both the upper tier and lower tier, and only 27% of tones chosen to be included in the compositions were located on the upper tier. This is interesting because on Layout A the upper and lower tiers are different registers, whereas on Layout B they are adjacent tones. That this trend emerged in all performers regardless of instrument layout indicates that the extra physical effort required to raise the arms to perform the pendulums located on the upper tier resulted in participants performing fewer tones located on the upper tier in their compositions.

P8 commented that when choosing which pendulums to include in a composition she favoured pendulums within her reach. She performed instrument layout B, and said *I was going to try and use (the bass) side a bit more and other low notes than the ones I was playing, and I didn't end up, I just kept it to (the right) side. It always depends on what pattern I start with. I find something and then I have to find stuff that sonically goes with it and that I can reach in time as well*'. Additionally, a comment from P9 (who at 173 centimetres tall is the 5th shortest participant and performed layout B) indicated that between the instrument size and it only featuring tones within a scale, she may have not prioritised choosing the best tones for the melody of her composition and instead opted for the easiest to perform. P9 said *all the notes sound good together. So I was kind of just reaching for notes that were convenient, as opposed to thinking more about the melody. So I'm not sure that I found exactly the right combination*'.

P6 (who performed layout B) noticed that her concert composition is performed mostly on pendulums located on the lower tier of the instrument - a realization she came to during the final session when performing the composition on the large instrument after performing it on the smaller instrument. She noticed that the few pendulums she performed on the upper tier took a lot more effort to perform than the ones located on the lower tier due to physical exertion reaching them, and commented that her compositional choices may have been subconsciously influenced by not wanting to exert the extra effort of reaching up to perform pendulums located on the upper tier. She said *I think maybe*

your composition shapes around the instrument that you make it on. You end up finding weird niches that make the most physical sense and musical sense at the same time.' P9 offered a similar line of thought: *I feel like the composition was shaped by how big this instrument is - big body movements.*'

P4 (who performed Layout A, in which the higher register tones are all located on the upper tier) was reminded of a famous anecdote by the Velvet Underground drummer Moe Tucker. *'She had this thing of saying that the ride cymbal should be used very, very rarely. So she would sort of hide it slightly above where she could reach so if she wanted to use it, she had to really feel like it was necessary.'* In a similar way, P4 considered the effort required to perform the upper tier tones was beneficial to their composition as this way they would not play the tones more than necessary. *'(The upper register tones are) too high pitched. Too high pitched to have all the time. Like occasionally it makes a nice protrusion into the piece. It sharpens it up just a bit.'*

P4 composed a section of their concert composition based around an effortful motion of using their arms to raise alternating pendulums on the upper tier. They referred to this section of the composition as the *'gym equipment move'*. They commented that they created it based on the way their body felt, rather than because of the sound it produces, and said it is their favorite part of the composition.

Some participants were aware that, as a by-product of the effort it takes to perform pendulums that are located far away from each other, their compositions were made up of smaller parts, each located within easy-to-reach sections of the instrument. P2 (who performed layout A) commented: *'It's quite hard to get to different bits of it at the same time... Because of the size of the (large instrument), I ended up almost separating sections of the piece into physical sections of the instrument.'*

Similarly, P8 mentioned that their compositions included moments of pause (which would appear in music notation as a *fermata*) during which time they could move to another part of the instrument. P8 explained *'You need a gap. It's like when, on piano, you go to a different register... You just work with the instrument, and even if it's not mega sophisticated, that's how it came out. I'm kind of applying a bit of classical training to it'*. P4 also spoke of the pause of sound while relocating their body to another location of the instrument, pointing out that this influences not only the music composed but also the audience experience of the performance. P4 said *'you can't necessarily smoothly go from doing one thing to the next. It does put this more performative aspect in it of you having to switch around like that. And I enjoyed it'*.

P6 reflected less positively on the realisation that relocating her body to different parts of the instrument to more comfortably perform a musical phrase

creates pauses in the repertoire. P6 performed instrument Layout B in which the lower register tones are all located on the left hand side of the instrument, and the higher register tones are located on the right hand side. P6 said *‘say I was playing a melody down here (in the lower register) and I went to repeat it in the higher octave, you kind of have that gap between, like “I’ve finished here, and I have to go over there and play it”. You get a bit of incongruity then.’* Likewise, P7 (who performed layout A) expressed frustration that due to the size of the instrument, reaching to play certain pendulums can result in playing tones out of time.

P5 described how she uses the chaos sound in her composition as a way to sustain a tone while she relocates to another part of the instrument. This works because once the pendulum creates the chaos tone, it takes seconds after releasing the pendulum for the tone to decay back to silence. P5 said *‘you leave (the pendulum) to swing, it takes a little while to come back (to silence). So you’ve got a moment to compose yourself, get to another part of the instrument and start playing’.*

6.4.3 Reflections when primed with smaller version

During the fourth session, participants were told to rehearse and perform their concert performance with the smaller version of Chaos Bells with the intention of their performance sounding as close as possible to their performance with the larger version. After performing the concert composition with the smaller version, participants returned to the larger version to rehearse and perform the concert performance two final times.

Introducing the participants to the smaller version of Chaos Bells in this way was not intended to result in a scientific comparison between the participants’ performances with both sizes, rather this was to encourage more performer awareness and discussion surrounding their experiences of creating a performance with the larger version of the instrument. Due to the nature of our methodology I cannot present a scientific comparison of the performer engagement with the larger and smaller versions of Chaos Bells, however the performers were clearly comparing the two versions in their mind and their comments are interesting. Likewise, the introduction of the smaller version primed the participants to further consider the size of the larger instrument now that they had spent four sessions with it.

After performing the smaller version and returning the larger version, P8 discussed the ways that, compared to the smaller version, the larger version requires more effort to perform. *‘I think it’s definitely more physically demanding. I didn’t remember so much how actually you have to stretch and look more for*

things. And then because it's not so much in your line of sight. Whereas with the other one (smaller version) everything is pretty much in your line of sight.' They went on to explain that performing with the larger instrument requires more consideration of choreographic gestures to result in the intended musical performance.

'You do have to go over there and then go back. And sometimes you wonder, you know with a piano when you put your finger on the (key) to get the octaves and stuff. And here (with the larger version of Chaos Bells) you almost have to think "Should I not hit it with the right hand, but with the left hand, then it will save me time. But will that then mess up the composition? Because it's also movement based as well as sound based." So you have to make these considerations that you don't have to make so much on the other one (the smaller version).'' - P8

When introduced to the smaller version of the instrument P9 commented *'It's like playing with a toy. Just because it's so small.'* She added that the smaller version makes her feel *'really tall. Yeah, I mean, compared to playing (the larger version) it felt like I was a child playing with a toy. I also felt like I was having to be a little bit... I felt more delicate playing it... It felt as if I sensed each of my movements a lot more closely, as opposed to this big one (the larger version), which is very much like just hit it.'*

Returning to the larger version of Chaos Bells after performing the smaller version, P4 commented that they also feel differently when performing the larger version due to its size and speculated ways that this feeling may have influenced their compositional choices.

'There's something nice about the chunkiness of (the larger version). There's something nice about the way some of (the pendulums) shimmer in the light. There's something nice about the size of it, and the fact that it does feel so different to anything else and I get a completely different feeling from the smaller one... It feels smaller and cuter and more somehow aesthetic. It has that that certain something in and of itself. It's just a very nice object. Whereas (the larger version) is more a nice thing to play and to perform with. It feels more rough and tumble where as (the smaller version) is more delicate and almost like a more sculptural aestheticified version of (the larger version)... Where (the larger version), it's very different. And that feeling sort of continues when you're playing it because of just the sheer scale of it, and how different it is to other things...

*The size has a bigger impact than just being big. It's almost spiritual somehow. It has an effect on you and it affects the way you play it, the way you **can** play it, there's something about having something this size that maybe makes you think about it differently. Like I think if we had done (the study) with just the small one from the get go, I might have made different compositions for all sorts of reasons, including the size of it. I mean, in particular, that part (the "gym equipment move"), I did fall in love with it not specifically because of the sound, but because of the motions that I was making. I just thought "This is brilliant!". And obviously I wouldn't have had that with (the smaller version). But I might have done something different.'* - P4

P4 and P10 also considered the larger and smaller versions to be altogether different instruments ('size does have such an impact that it does actually make it a different instrument' - P4).

P3 and P6 said they were static when performing the smaller version. P9 said '*I feel like the composition was so shaped by how big the instrument is - big body movements - that it felt kind of a little bit restricting to be using smaller movements to make the same sounds.*' Participants spoke of using performance gestures that are '*delicate*' (P8) compared to the larger version, which many participants commented they can strike with more force (P3, P4), in a more carefree manner (P1, P8), compared to the smaller instrument which required '*more fine control*' (P2, P4). P1 elaborated that performing the smaller instrument is '*a little bit more fiddly. Whereas with (the larger version) I can sort of be standing away from it and hit it more randomly and get a nice note out of it*'.

When reviewing the concert compositions as performed on each version of the instrument, I noticed that the size of the instrument influenced the timing of the performance. For instance, when P4 performed their concert composition with the large instrument there is a one second *fermata* (musical pause) between each section of the performance while P4 relocated to another location of the instrument. However during their concert performance with the smaller instrument there is no gap between sections because P4 can reach the pendulums required for all sections without relocating.

When they returned to performing the larger version of Chaos Bells, no participants used the new sound-creating gestures they had developed for the smaller instrument with the larger instrument. Instead they returned to the performance gestures they had previously developed for performing the larger version. Additionally, after returning to the larger version, only one participant

(P4) had an idea for performing the smaller instrument after returning to the larger instrument. The gestural trends indicate that the performers consider the larger and smaller versions as *different* instruments and that performing one version does not offer ideas for performing another version.

Only one participant (P10) attempted to perform a compositional idea he had had on the small instrument when he returned to the large. P10 had mentioned when he was playing the small instrument he considered adding in a bass note to his composition. He thought it sounded great however he decided not to include it as he wanted the performance to stay as true to the large version as possible. Then when he returned to playing the large instrument, he tried to go for the bass note and realised he couldn't even reach it if he tried. It was at that moment that he realized that he hadn't had the idea to include the bass note previously because the note was out of his reach.

Some gestures and techniques that work with the larger version do not work with the smaller version due factors related to its smaller size. For instance, the instrument is smaller in relation to the performer's body (and therefore there is less space to put hands and mallets between the pendulums); and the smaller version is constructed from smaller diameter PVC pipes, which make it less structurally stable than the larger version, resulting in more vibrations (and therefore tones) created from the same amount of force when compared with the larger version. For these reasons, while both instruments were nominally capable of creating the same sounds, the performance gestures to do so were different. Additionally, the smaller instrument was placed on a table, which raised the lower tier pendulums to higher above the ground than the lower tier pendulums on the large instrument. This made certain gestures more effortful to achieve, such as using one knee to push and hold forward a pendulum to create a drone - a technique used by both P7 and P10 in the concert performances.

No participants created exaggerated ancillary gestures (gestures that do not create sounds) while performing the smaller instrument, and to at least one participant (P4) the composition was incomplete without such gestures despite commenting that it sounded the same.

While performing their concert performances with the smaller instrument, nine of the 10 participants developed new gestures and techniques that they had not used during any of their compositions performed with the larger version. P3 and P10 changed their mallet technique from striking with the soft end to striking with the hard end because the small instrument is more responsive to the hard end of the mallet than the soft end of the mallet. P5 used their fingers, specifically rings on their fingers, to tap the instrument because the mallet technique which previously worked on the large instrument no longer worked because the pendulums on the smaller instrument are closer together.

Conversely, P1 had been using a finger-tapping technique when performing the larger version and did not find this technique as effective with the smaller instrument and so changed his concert performance to feature drones instead of tapping when performing it with the smaller instrument.

P1 indicated that moving around the larger version of the instrument not only felt good but shifted his attention from perfect performance to a more enjoyable musical experience.

‘I definitely feel more like I’m moving around while I’m playing (the larger version). Whereas the little one, I’m much more worried about “Am I getting the right note?”. Whereas with (the large version) I’m sort of like walking. Like it feels good to sort of walk around. Which is like not what I would normally do. Playing keyboards or something like that you want to be quite rooted and have your little zone where you’re working. But (with the larger version), it’s nice that I can be like “I’m over here now”’ - P1

6.4.4 Edge-like interactions and composition

Four participants (P1, P2, P5, P9) enjoyed exploring the point where the tone degrades into white noise, which led to developing moments in their compositions based around these ‘edge-like interactions’ [131]. P9 said *‘I really like how you can play with the distortion. So like pulling (the pendulum) up and down, just kind of playing with where the breaking point is’*. P2 said *‘the edge of feedback sort of thing, I find that’s where it’s got all the really nice interactions... It’s kind of a subtle bouncing thing.’* P5 said *‘playing with that moment when it’s just about to go mad, but not letting it, if you can, is fun... The resonance noise that it makes before it goes into white noise and trying to play with just the cusp of that, which was something I did try and play with previously, but with the stick (mallet) I found it harder to control. Whereas (with hands) you’ve got almost millimeter control.’*

P2 commented that the fine control required to perform the drone resulted in him accidentally performing white noise, which then resulted in him improvising around the mistake and creating a performance he preferred to his intended approach. P2 said *‘It just sort of ended up kind of going a little bit more into feedback when I didn’t mean it to. But I still played with that and liked it.’* Similarly, during another performance, P2 had a compositional idea after unintentionally ending a drone. *‘Something cut short, and then I kind of went “Oh, actually, let’s put a bit of space in it!”’*

6.4.5 Participants' reflections on their own bodies

During the course of the study, I noticed examples of participants feeling differently about their bodies while performing the larger version of the instrument. Some comments were overwhelmingly positive, for example participants said the larger version make their body feel powerful (P5), '*energised*' (P9), and accomplished (P10), while other comments implied that participants would like to change their bodies to be more suitable for performing such an oversized instrument. P5 said performing the instrument '*makes me want more arms*', and P8 commented '*I need bigger arms*' and '*more body extensions*'. P9 said '*I wish I had three hands.*'

I found four examples of musical composition that the participants created despite causing discomfort or pain to themselves. P10 and P7 incorporated a gesture in their concert compositions in which they used their leg to sustain a drone by using a knee to push a pendulum forward (P7) or by resting a pendulum on the upper leg (P10). They both reported that maintaining these postures during performance were effortful to the point of extreme discomfort.

For almost the entirety of his concert composition, P1 performed a finger drumming gesture which he said was tiring but liked the sound it created so much that he was willing to perform it. (*'Finger drumming is great because you can get more interesting rhythms than I probably could playing it with drumsticks.'*) Additionally, P1 has a wrist and shoulder injury that makes performing the pendulums on the upper tier more painful. Despite this, he still opted to perform the high-pitched pendulum on the upper register in his sketch in session 1¹⁰. He said pain is '*something I live with*' and he chose to play the high pendulum for the sake of improving the composition, saying '*I wanted the polyphony of the low and high notes.*'

During the first session, P7 (the participant with the longest arm span) repeatedly performed a pendulum on the upper tier using a striking gesture which he said '*kills*' his hand due to the height of the pendulum. (*'It was really high and it was really hurting my shoulder.'*) He later reported that his arm was sore for several days afterwards. The pain P7 encountered due to performing the upper-tier pendulums led him to suggest that the tones of the instrument be rearranged so that he could perform the upper-tier tones on the lower tier instead, or that the upper tier be lowered. (*'It can be at least 20 centimetres lower. But it's also nice, the "big" thing. It's a big instrument, like, it has the presence of something large. So trying to keep the same sound or something and*

¹⁰At the start of Session 1 all participants were shown various performance methods for performing the instrument, and were told all techniques are optional, as is all participation in any aspect of the study. Subsequently, P1 performed the upper pendulum in this way. It was only later in the session that he disclosed his long-term condition (occult ganglion of the right wrist and shoulder) to the investigator.

make it smaller would make it a different thing.’)

Body movement as a tool for memory and composition

Four participants (P4, P5, P8, P9) commented that using their bodies while performing the instrument helped them remember the compositions, describing this as ‘*body memory*’ (P8) or ‘*muscle memory*’ (P4, P5, P9). P8 said ‘*I think a lot of music is body memory... I think once you’ve played it a few times then the body remembers as much as the mind. That’s how I tend to remember things.*’

Beyond considering his body as a tool for remembering the composition, P10 additionally recognises that when performing this oversized instrument, as opposed to smaller instruments, his body movements in themselves become the process of creating the compositions in the first place, as he engages with the instrument on a spatial, topological level. ‘*If you say make a piece of music, I’m just going to try and come up with some melodic pattern where it’s not really about trying to remember which order to put my fingers anywhere, it’s more a spatial problem about where am I going next? Everything is sort of enlarged. This is a very enlarged instrument compared to something very fiddly, or that you’ve got to blow in or whatever. I mean, those are all very tiny areas of working compared to this. You just think “Okay, the next one’s over there.” And in a way, it’s possibly easier to remember “okay, I’m going there next” because then it becomes sort of a topological thing.*’

6.5 Discussion

Here I explore the findings of our study in relation to the three conceptions of bodies in HCI identified by Homewood et al. [77]: *body* (embodied interaction), *bodies* (plurality) and *more-than-human bodies* (entangled assemblages). I draw a path from specific interactions between performers and instruments to a wider reflection on the way that the design of interfaces is also implicitly the design of bodies.

The shift from user to body (also referred to as the somatic turn [162]) was motivated by the recognition that everyone is embodied [77]. Through embodied interaction the instrument becomes an extension of the performer [137], shaping their choices through its affordances and constraints [105] and transforming the instrument to ‘*ready-to-hand*’ [71] as the performer shifts focus from the instrument to the act of musicking [104]. I found examples of how embodied interaction created the codependency between the instrument and the composition: the instrument size and effort required to perform it resulted in specific performative and compositional choices. Performers largely narrowed

their performances to tones that are located in front of the performers' bodies, prioritising tones that were comfortable to reach over melodic or harmonic considerations. The compositions are mostly performed by a musician standing still, with musical pauses to accommodate the musician relocating their body to another location of the instrument.

6.5.1 Bodies: Significance of plurality of performers in the context of interface size

Homewood et al. [77] and Spiel [167] adopt tenets of feminist HCI [7] of epistemological plurality, arguing for the singular '*body*' in embodiment to be replaced with a recognition of the diversity of bodies. In our study, although all 10 participants identified as able-bodied, their bodies varied in physical proportions (height and arm span), gender identity and impacts of health and cognition-related conditions. The participants were also diverse in musical training, tastes and practices, and approached the creative prompts with different priorities. The product of these pluralities – bodies, interfaces and musical tastes – results in the diverse musical performances that were observed.

My methodology is deliberately explorative and qualitative: in embracing the diversity and pluralism of bodies as physical, musical and cultural entities, I am more interested in the breadth of outcomes and notable particulars as opposed to '*average*' behaviour across all participants or predictive statistical models.

Interface designers have a responsibility to people's bodies. I find it interesting that only one participant (P7) suggested rearranging the tones of the instrument or lowering the height of the instrument to better suit his body, whereas three participants (P5, P8, P9) made comments about changing their bodies to better suit the instrument size. I found examples of participants that chose to perform tones and musical phrases that incurred pain, with the potential for injury, such as P1 who has an occult ganglion of the wrist yet performed an upper-tier pendulum, suffering through the discomfort because he wanted that particular tone in his performance¹¹. On the other hand, some participants recognized ways in which the large size of the instrument governs their movement and commented that they enjoy the way these movements made their bodies feel. These participants enjoy taking large steps (P5), moving around the instrument, exploring space and creating large gestures. P9 said '*it feels really nice to be using physicality to play an instrument*', finding enjoyment in the change of perspective created by interacting with a large instrument compared

¹¹On the topic of performing through the pain of his injury, P1 said '*at the end of the day, I will play regardless of the injury. I was definitely stopped for two years there, but now if I had to play, I'd just keep playing.*'

to her usual desktop music practice. (*‘When you’re like doing tiny movements on Ableton or a synthesizer it’s very much in a tiny world.’*) I acknowledge that performing with large instruments may be enjoyable to some users (such as those in our study who found the instrument performative, unique, and enjoyed creating large, forceful gestures), and exclude others. If the diversity of bodies means there cannot be a *‘universal user’*, then perhaps there should not be a universal interface size. In fact, two participants suggested that the instrument could be modified to require *more* effort to perform by adding extra weight (P2, P4) or height (P5, P7). I can only speculate on whether an even larger version of the instrument would result in even more characterful repertoire.

6.5.2 More-than-human bodies: Size, entanglement and assemblages

Homewood embraces entanglement theories of HCI [52, 77] to argue that bodies are always more-than-human. I suggest that in musical performance, the instrument co-determines the very identity of the performer: an instrumentalist only acquires that identity in relation to an instrument, and conversely the status of an object as a musical instrument heavily depends on its relationship to a musician [66]. Thus, when designing instruments we are also designing performers.

This is a significant responsibility. Redström argues that user-centred design often devolves into *user design* [149]: *‘we risk trapping people in a situation where the use of our designs has been over-determined and where there is not enough space left to act and improvise.’* An over-determined design might also privilege certain bodies or musical cultures over others.

P10’s description of his process of composing with the instrument (quoted in section 6.4.5) provides insight into how a large instrument can shape a performer’s identity. He said unlike his compositional approach when composing with smaller, *‘fiddly’* instruments, due to the *‘enlarged’* size of the study instrument he approached the composition of melodic patterns from the perspective of a *‘spatial problem’*, in which he engaged in a *‘topological’* partnership with the instrument. From the perspective of the entanglement theories of HCI, P10’s comments reveal that the composer that P10 becomes when composing with this large instrument is one who prioritises physical location of his body as a solution to the creation of melodic patterns.

P2’s description (quoted in section 6.4.4) of creating a preferred version of a composition after improvising around a drone that mistakenly turned to white noise elucidates the positive impacts that errors and *‘happy accidents’* can have on performance and composition [29, 13]. In this moment, composing with the

study instrument shaped P2’s identity as a composer from one that does not include white noise to one that does.

To understand how our instrument might form part of a more-than-human entanglement, it is perhaps more productive to consider the instruments that each participant *usually* plays. P10, a drummer, described how his years of performing the drum kit informed his approach to composition with the study instrument, with which he performed a maximum of eight pendulums per composition. *‘A more adventurous composition would go all over. And maybe a player of tonal instruments would do that. I’ve never really done that as a player. I’m used to sort of sitting in one spot and then things all being there and making their individual sounds.’*

P9 said her concert composition has an *‘expansive, rolling, slow feel’* similar to compositions she has created with the instrument she most frequently performs and composes on, the synthesizer. Meanwhile, P2 described his compositions as something he would typically create on his primary instrument, the cello. Just as Sudnow’s *‘piano-knowing hand’* finds keyboards everywhere [166], our participant P2, who has played cello for 25 years, found a cello in the large instrument. P2 commented that the music he composed for the study instrument was inspired by the way he plays the cello.

We might say that P2 and the study instrument are entangled into a more-than-human assemblage. On the other hand, we might instead focus on what has been *removed* from such an entanglement: the cello. Removal of technology has previously been studied as an HCI research method [76]. In this case, after many years of intimate familiarity with a particular instrument, removing it leaves a peculiarly-shaped hole in a performer’s (more-than-human) body. Our study instrument partially fills that hole, as seen by repertoire that bore the resemblance of the participants’ primary instruments and musical styles. In recognition of the implications of the formation of performer identities through musical entanglement, I acknowledge that no instrument can be ideal for multiple users. As Homewood et al. put it, *‘once bodies are understood as more-than-human assemblages, then designing a technological device for more than one person becomes difficult’* [77]. Is the instrument a cello-like instrument? And in which case would it be improved if it were bowable (as was suggested by P8)? Or is the instrument a piano-like instrument, and in which case would it be improved with the addition of a sustain pedal (as was suggested by P9)? Or is the instrument an organ-like instrument in which case would it be improved with the addition of foot-operated bass pedals (as was suggested by P7)?

6.5.3 The value of continued explorations of interface size

The findings of this study have shown how large-scale interfaces produce distinctive relationships to bodies which depend strongly on the individual, and can sometimes result in conflicting feelings. P8 said *‘I think it would be cool to have more bigger instruments, and also electronic instruments because most of the bigger instruments tend to be acoustic... But if I had it as my own instrument, then it would be a problem with the storage.’* Meanwhile, P5, the shortest participant, reported that performing such a large-scale instrument makes her body feel powerful, that she would like to climb on the instrument, and that it also makes her want more arms.

In commercial practice, the economic reasons for favouring small interfaces are obvious, but HCI research does not need to adopt a fixation with miniaturised technologies. There is a whole constellation of entanglements to explore, yet the musical instrument industry at large is preoccupied with creating smaller instruments that serve an entanglement centred on using the fingers, which is tied in with precision and fine control [115]. I ask who is being favoured by the preference for this specific type of interaction.

Small interfaces are also associated with perceived immediacy of ease of use, which may just be a guise for instrument companies to push products with a reduced manufacturing cost [115].

6.6 Conclusion

This chapter describes the second study in the thesis. This explorative study invited musicians to perform with four versions of Chaos Bells, a DMI designed and built for this study at two different sizes. 10 musicians completed four one-hour sessions with Chaos Bells (three sessions were with a larger version of Chaos Bells and one session with both the larger and smaller versions of Chaos Bells). The participants each composed an original three minute performance with the larger version of the instrument for broadcast on an online concert.

This study investigated and revealed insights into the following questions:

What is the relationship between the instrument’s physical design and the music performed with the instrument, and what role does size play in this relationship?

Large architecture and landscapes have the ability to impart a sense of awe. They remind us of our human scale within an incomprehensibly large universe. Some participants in this study felt a similar sense of this awe when engaging with the large version of Chaos Bells. Participants acknowledged that this

feeling, eloquently described by P4 as ‘almost spiritual’, influenced their compositions by altering the way they interacted with the instrument (for example performing showy ancillary gestures) and the way they perceived their own bodies.

Due to the size of Chaos Bells proportional to their own bodies, participants discussed approaching the act of composition from the perspective of their spatial relationship with the instrument.

Some participants highlighted ways that the additional effort required to perform the larger version of the instrument influenced their compositional choices, such as performing sequences because they feel good, for example P4’s ‘*gym equipment*’ move. By contrast, other participants discussed less enjoyable ways that the larger version of Chaos Bells required additional effort to perform, such as the extra effort required of trying to see the various parts of the instrument or navigating their bodies around the instrument, which resulted in considerations that ultimately shape the musicality of the performances.

How does a difference in the size of an instrument influence performer identities?

While performing the smaller version of Chaos Bells, participants were proportionally larger than the instrument and as a result felt taller. Conversely while performing the larger version, participants became proportionally smaller, and as a result a trend emerged of participants feeling that they could benefit from longer or more limbs. Beyond changing perceptions of their own identities, the size of the instrument also changed the performer’s perceptions of traits of the instrument itself such as its sturdiness, as evidenced by participants describing the larger instrument as more ‘*rough and tumble*’ (P4) and the smaller instrument as more ‘*delicate*’ (P9). Ultimately, most participants considered the larger and smaller versions of Chaos Bells as different instruments altogether.

The findings of this chapter also reveal that performing with the unfamiliar Chaos Bells highlighted the *absence* of the familiar instruments the musicians already played, with musicians attempting to adapt their familiar playing techniques to an unfamiliar context.

Which factor exerts a greater influence on motivic patterns, physical layout or sonic features?

The findings reveal that both physical layout and sonic features influence motivic patterns and which of these exerts more influence is dependent on which aspect of the performance is the focus. For instance, the choice of pitch material is influenced more by the layout as it is driven primarily by physical factors.

Therefore due to the physical size of the instrument, performers exhibited a penchant for tones located comfortably in front of their bodies. Meanwhile the performers' common interest in the timbral qualities of the drones is driven by sonic features. So both physical layout and sonic features are influential over the motivic patterns found within idiomatic writing with the study instrument, but they are influential over different aspects of the music.

Collectively, these results highlight the complex entanglement of bodies, instruments, social and cultural contexts which are present in musical performance, and shows how exploring music performance with an oversized instrument can perturbate this entanglement in sometimes idiosyncratic ways. This work is intended to open up avenues of exploration rather than focus on one. I acknowledge that the performances created during this study were diverse, and that repeating the study with different performers may result in different findings.

6.6.1 Carry forward

Three important findings emerged from this study. First, Chaos Bells, the instrument designed for the purpose of this research proved to be a successful tool for delivering comparative results.

Secondly, the insights into ways an instrument contributes to performers' identities shed light onto the role instruments of all sizes play in musical entanglements.

Finally, the finding that musicians favour tones located comfortably in front of their bodies builds on the findings from Study 1. To more thoroughly investigate the research question *Which factor exerts a greater influence on motivic patterns, physical layout or sonic features?*, I wanted to further explore the data gathered in Study 2 from another angle: musicological analysis of the performances.

Chapter 7

Study 2b: Exploring motivic analysis

This chapter is built on significant material from ‘From Miming to NIMEing: the Development of Idiomatic Gestural Language on Large Scale DMIs’ by Mice and McPherson, originally published in the proceedings of the International Conference on New Interfaces for Musical Expression (NIME), 2022 [122].

In this chapter I describe Study 2b, the final study of this thesis. This study illustrates the value of a musicological approach to HCI musical interaction research, suggesting the need for a broader conversation about a musicology of performances with new instruments, as distinct from instrument evaluations. While the value of new DMIs lies to a large extent in their music-making capacity, analyses of new instruments in the research literature often focus on analyses of gesture or performer experience rather than the content of the music made with the instrument [151]. This chapter presents a motivic analysis of performances made with Chaos Bells. In the context of music, a *motive* (or motif) is a small, analysable musical fragment or phrase important to or characteristic of a composition [134]. In this chapter, I outline my method for identifying and analysing motives in music made with new instruments, and display its use by using it to examine the Study 2 concert performances. I present new findings of the impact of instrument size of music made with DMIs and make a case for the value of musicological approaches in DMI research.

7.1 Study 2b motivation

NIME is the quintessential HCI community dedicated to the exploration and design of new instruments. Every year at the NIME conference new instruments

are performed. Practice-based research, in which performances and compositions form a core part of the intellectual contribution, is well-established at NIME [168, 61, 27, 38, 180]. However, musicological analyses of music made with new instruments feature far less in the NIME literature, with evaluations more often focusing on the experience of performers, audiences or other stakeholders [151, 5, 23]. While musicological analyses may be inappropriate for some NIME research, such as short-term investigations with non-functional instruments or technology probes not intended for music making [84, 130], I argue that in the context of new instruments that are intended for performance, much can be learned from adding musicological performance analysis to the evaluation methodologies commonly used at NIME [75] including thematic analysis [41] and cataloguing gestural interaction when a participant encounters a new instrument [82, 63, 170], all of which involve capturing data via a range of methods including recording, field notes, interaction logs, interviews and questionnaires.

Musicology is a broad term [20], encompassing amongst other things music theory and analysis, music history and ethnomusicology; the field grapples with tensions between text and practice, between musical and social factors, and with persistent debates over what music should be privileged for study. Aside from scores and performances, instruments are also an important area of musicological study [177, 144, 44]. It is beyond the scope of this thesis to try to unpack the differing priorities and contributions of various areas of musicology, but in the context of musical instrument design, some musicological discussions include identifying the artistic affordances of different acoustic, electronic and digital musical instruments and their critical reception in cultural contexts [44], updated expansions to traditional organology [177] and the examination of historic new instruments in wider cultural contexts [144].

Within the context of HCI, I propose that analysis of musical performances with new instruments provides a different set of intellectual perspectives and insights compared to HCI-derived or practice-driven methods more commonly used to evaluate new digital instruments. In this chapter I begin from a specific and limited subset of music analysis, *motivic analysis*, focusing on patterns of musical sound as distinct from the physical movements that performed them. While motivic analysis is commonly found in traditional score-based music analysis, the non-score-based context of our study perhaps has more affinity with the field of performance studies [36].

The techniques in this chapter are intended to complement, rather than replace, other established forms of evaluation of new instruments, and might serve as a modest starting point for deeper conversations about the analysis of music performed with new DMIs.

7.1.1 Idiomatic music and new instruments

Following up on the idiomatic writing section (section 2.1.3, particularly [104, 43, 173, 170]), while the potential of any tool to generate its own idiomatic patterns has been noted, the specific way those patterns manifested in composed or performed repertoire has received less attention. Examining musical motives that performers employ when playing an instrument can offer clues about what kind of music is idiomatic to an instrument and why.

7.1.2 The musical motive

As ‘*the smallest structural unit possessing thematic identity*’ [189], a motive can be *any* element of music. Table 7.1 shows examples of elements of Western music, any of which could form part of a motive.

Table 7.1: Some elements of Western music

Element	Basic related terms
Rhythm	Beat, Meter, Tempo, Syncopation
Dynamics	Forte, Piano, Crescendo, Decrescendo
Melody	Pitch, Theme, Conjunction, Disjunct
Harmony	Chord, Progression, Consonance, Dissonance, Key, Tonality, Atonality
Tone colour	Register, Range, Instrumentation
Texture	Monophonic (1 tone at a time), Homophonic (2 or more tones at a time: a melody and a less complicated harmony), Polyphonic (2 or more independent melodies), Imitation (melodies echoed in different voices or registers)
Form	Strophic (the same music in different verses), Through-composed (non-repeating sections), Binary (2 sections that both repeat), Ternary (same beginning and end with a contrasting middle section)

7.2 Research questions in this study

The central research questions for Study 2b are:

1. What is the relationship between the instrument’s physical design and the music performed with the instrument? What role does size play in this relationship?
2. Which factor exerts a greater influence on motivic patterns, physical layout or sonic features?

I hypothesised that the physical design of a large instrument would influence what is idiomatic to perform with the instrument. I hypothesised that physical

performance patterns may trend across performers (regardless of the resulting tones) which may influence the tone selection of composers performing with the study instrument.

To test these hypotheses, I examined the concert performances created by participants in Study 2a presented in the previous chapter (Chapter 6). Refer to Chapter 6 for the study design.

The Study 2b research questions lend insight into both central research questions shown in Section 1.3:

- RQ1¹: The first research question of Study 2b explores the role that size plays in the relationship between the instrument’s physical design and the music performed with the instrument. This study was performed using Chaos Bells (detailed in Chapter 4), a DMI designed and built for this study at two different sizes.
- RQ2²: The second research question of Study 2b examines whether instrument physical layout or sonic features exert a greater influence on motivic patterns. Although this research is conducted with the larger version of Chaos Bells, the findings are relevant to instruments of all sizes.

7.3 My method of motivic analysis

I developed a method of motivic analysis for examining music and performances created with new instruments. Similar to thematic analysis, which analyses text through the discovery and prioritisation of themes in text [157], my method of motivic analysis analyses music through the discovery and prioritisation of motives in music. Where thematic analysis builds hierarchies, or ‘*code books*’, of themes that can then be linked into theoretical models, my method of motivic analysis organises motives into a catalogue, or ‘*code book*’, of motives based on the elements of Western music.

New instruments commonly have no notation system, or one that captures a limited subset of the instrument’s salient musical features. Rather than examining notated scores, which has long been common practice for musical analyses of established repertoire, my method of motivic analysis examines the audio of the performance. Therefore, my method is also applicable to studying improvisation.

¹How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?

²By conducting research with instruments that are physically larger than the performer’s body, what can we learn about instruments of all sizes with regards to the impact that design choices have on performance and compositional choices?

Given that a motive is an element of music that is characteristic of a composition, selecting the motives for motivic analysis is not a catalogue of *all* elements of music present in the performance. Rather it is a catalogue of the elements that are *characteristic* to the performance. I identify the motives in a 2-step process. I first catalogue all elements of music present in the performance. From this catalogue, I select only elements that are characteristic of the performance to become the motives for use in my motivic analysis. The question ‘*would the performance be recognisable as the same performance without the inclusion of this element?*’ helps me identify which elements are motives of the performance.

Identifying motives is not an either-or process. Many conflicting motives may be simultaneously present and equally characteristic of the performance. The juxtaposition of conflicting motives may be a motive in itself.

7.4 Analysis of Study 2 concert performances

The Study 2 concert performances were created by the participants during the third study session in response to the prompt to compose a three minute performance that showcases their favourite music performable with the instrument. All participants created new performances and performed them several times with both the larger and smaller versions of Chaos Bells, demonstrating that the performances were fixed (as opposed to improvised). All versions of the concert performances were video recorded. In this chapter I analyse only the performance that each participant self-nominated as their favourite version of their concert performance that they performed with the larger version of Chaos Bells, as chosen by the participants after watching all video recordings of the various performances of their concert composition.

The concert performances were analysed using my method of motivic analysis. An additional interaction analysis was conducted in which the video performances were logged for location and identification of musical gestures and *performance patterns*, that is repeat performance of pendulums in sequence such as sequential performance of pendulums above or below one another; sequential performance of pendulums on the same tier in ascending or descending order; and alternating or simultaneous performance of neighbouring pendulums beside one another.

In addition to the thematic analysis [41] of the transcribed interview data from all Study 2 sessions that was already conducted during Study 2a (Chapter 6, discussed in section 6.3.4), another iteration of thematic analysis was performed with a focus on new codes based on my method of motivic analysis: *rhythm, dynamics, melody, harmony, tone colour and texture*.

7.5 Outcomes

Here I combine the interaction, motivic and thematic analysis of the three minute concert performances to explore the factors that resulted in the instrument's idiomatic writing, such as the relationship between the instrument's physical design and the performances created with the instrument.

7.5.1 Outcome of the interaction analysis

Figure 7.1 shows the outcome of the interaction analysis.

7.5.2 Outcome of the motivic analysis

Figure 7.2 shows the outcome of the motivic analysis. I present the findings in the categories of my motivic analysis based on the elements of Western music: rhythm, dynamics, melody, harmony, tone colour and texture. I argue that the motives that make up idiomatic writing for this instrument are those that appear in over half the performances, not only because they appear most frequently in the performances made with the instrument, but in keeping with De Souza's [43] definition of idiomatic music (discussed in Chapter 2, Section 2.1.2): music that features '*distinctive musical dialects made of seemingly prefabricated patterns*', the '*distinctive musical dialects*' DeSouza is referring to are musical motives common to repertoire created with an instrument.

The motivic analysis revealed that the following motives appeared in over half the performances: the juxtaposition of high and low registers (nine performances); melodies created by alternating between two tones (seven performances); extended drone/s in the lower register (nine performances); and homophonic textures (nine performances).

Rhythm

No rhythmic motives were identified as characteristic of idiomatic writing for this instrument. The performances were a mix of metronomic, part-metronomic and non-metronomic and tempos spanned from 80 BPM (P1) to 174 BPM (P10).

In the thematic analysis I found an interesting correlation between the instrument's sound design and P6's relaxed approach to metronomic performance.

'I'm hitting it like 1-2-3-4. But I feel like it's not a strict adherence to a 4/4 (time signature). You're allowed to be a bit looser, because of the sound being a bit wonkier and weird. Do you know what I mean? It feels a bit more loose.' - P6

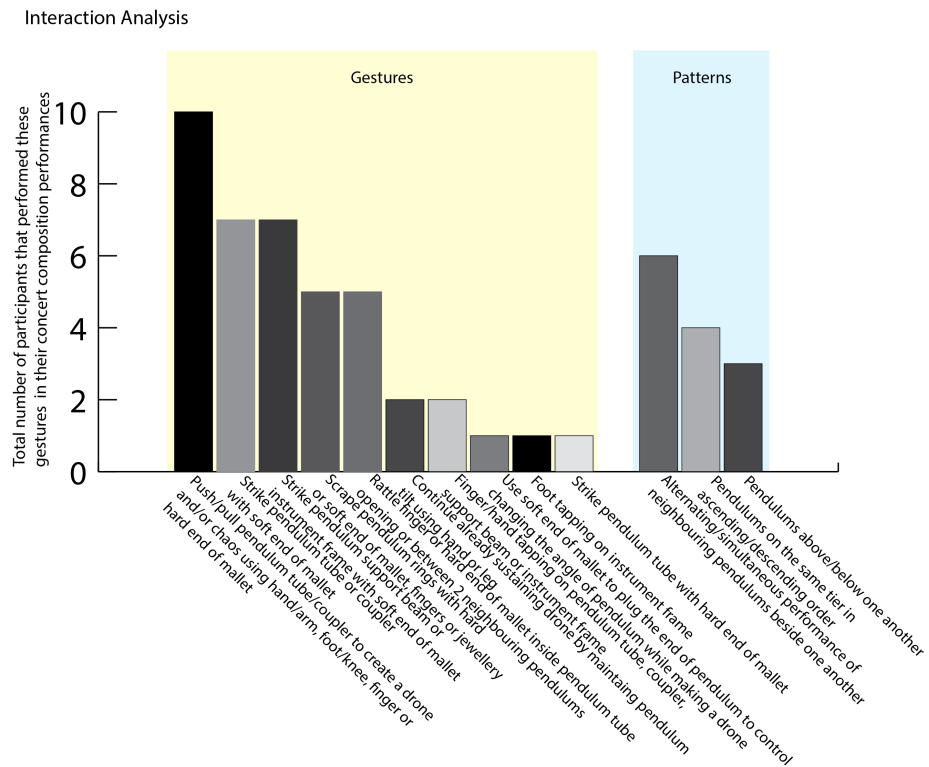


Figure 7.1: The outcome of the interaction analysis revealed that the most common gestural interactions across all participants were tilting the pendulums to create a drone (all 10 performances); striking a pendulum tube or coupler with the soft end of the mallet (seven performances); striking a pendulum support beam or the instrument frame with the soft end of the mallet (seven performances); scraping the pendulum rings with hands, fingers, jewellery or soft end of the mallet (five performances); and rattling fingers or the hard end of the mallet inside the pendulum tube (five performances). The most common performance pattern was alternating or simultaneous performance of neighbouring pendulums (six performances).

Motivic Analysis

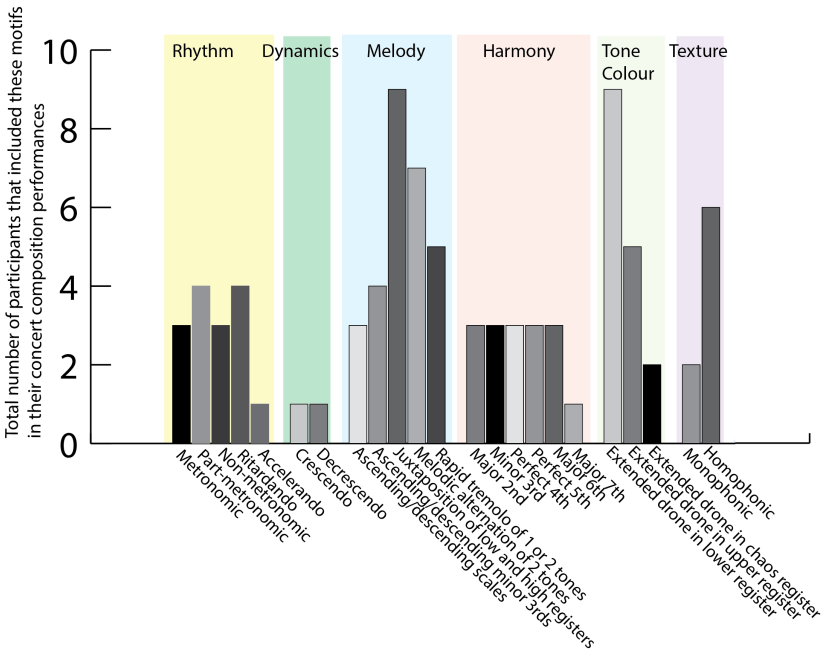


Figure 7.2: The outcome of the motivic analysis revealed that the most common motives included extended drones in the lower register (nine performances); the juxtaposition of tones located in the lower and higher registers (nine performances); melodic alternation of two tones (seven performances); homophonic textures (six performances); rapid tremolo of two tones (five performances); and extended drones in the upper register (five performances).

Dynamics

The motivic analysis did not identify any dynamics-related motives that make up idiomatic writing of this instrument. The thematic analysis shows that two participants (P1 and P4) commented that the dynamics of the instrument were unpredictable. Therefore participants may have been less likely to use dynamics as a structural or foreground element of their performance.

We observed that the unpredictable nature of the dynamics had the potential to influence compositional choices. For instance, rather than trying to control the dynamics as part of his performance, P1 allowed the unpredictable dynamics to shape his performance.

‘I just lean into it for the musicality of the piece. So if you get a slightly louder note, then that’s the dynamic and yeah, you just kind of go with the unpredictability. It’s like its own random source which is good.’ - P1

Melody

The juxtaposing of low and high registers is a motive of nine concert performances.

Participants may juxtapose lower and higher registers as influenced by their musical backgrounds. P1, whose primary styles are electronic, new psychedelic and ambient, said *‘If I had a keyboard or guitar pedals or something like that, I would normally have a low note playing off against a high melody and drones. Stuff like that’*.

The melodic alternation of two tones³ is a motive of seven concert performances. This is interesting because the thematic analysis offers no data on this happening. While the *melody* code was assigned to 33 interview segments, when the participants discussed melody in the interviews they only broadly mention melody, rather than detailed descriptions of melodies. For instance, P8 described playing *‘more melodic kind of stuff’* during their concert composition. The motivic analysis reveals that the *‘melodic kind of stuff’* they were referring to was in fact the performance of melodic alternation of two tones, however there was no way of knowing that from the interview data. Similarly, when commenting on his concert composition P7 said *‘there’s a kind of a living melody towards the next chord’*. This abstract description of melody offers no musical detail, however the motivic analysis reveals that melodic alternation of two tones is a motive of P7’s concert performance. Meanwhile when P2 described how he composed the concert composition he said *‘I just tried to use a little bit of different registers, a bit more variety of registers, and sort of melodic*

³I define this motive as an alternation of two tones that is repeated at least twice, for example A B A B.

structures a little bit in between them as well.' The motivic analysis revealed that P2's '*melodic structures*' were not melodic alternation of two tones.

Four interview segments were assigned the code '*alternating or simultaneous pendulums - neighbouring or otherwise*'. Again, performers discussed this topic without much detail, for example while describing their sketch that was composed with a focus on being dynamic in the registers, P5 said '*there was a bit of this sort of alternating bells with a bit of a drone going.*'. Additionally, all of the interview segments that made up the code '*alternating or simultaneous pendulums - neighbouring or otherwise*' were from interviews conducted during the first two sessions, not during the third or fourth session in which the concert performances were composed and performed. Therefore without the motivic analysis I would not have been aware that the melodic alternation of two tones is a trend in the concert performances.

Harmony

The motivic analysis of intervals of two pendulums played simultaneously either as strikes or drones reveals that across all performances no specific intervals trended more than others. Figure 7.3 shows which harmonic intervals were performed simultaneously and how many performances they were featured in. The harmonic intervals major second, minor third, perfect fourth, perfect fifth and major sixth were each featured in three performances, and featured in performances by both those participants assigned instrument Layout A and those assigned instrument Layout B. The harmonic interval major seventh only featured in P7's concert performance, who was assigned Layout A.

Tone colour

Extended droning in the lower register was a motive of nine concert performances.

All 10 participants included drones in their concert performance. The drone was P1 and P3's favourite aspect of the instrument. P1 commented '*If I had to do one thing, it would be that.*' P3's performance began with 47 seconds of short drones followed by three extended low drones, each ranging from 22 to 33 seconds.

'The task was basically to use your favourite parts of what you liked about instrument. So that's where I began and went to the drone sounds. Initially I was going to start there with a long drone, but I decided I would explore just making short drones first and then leading up into the longer one.' - P3

The participants' musical backgrounds may contribute to whether they enjoyed the drones. Commenting on the section of her concert performance that

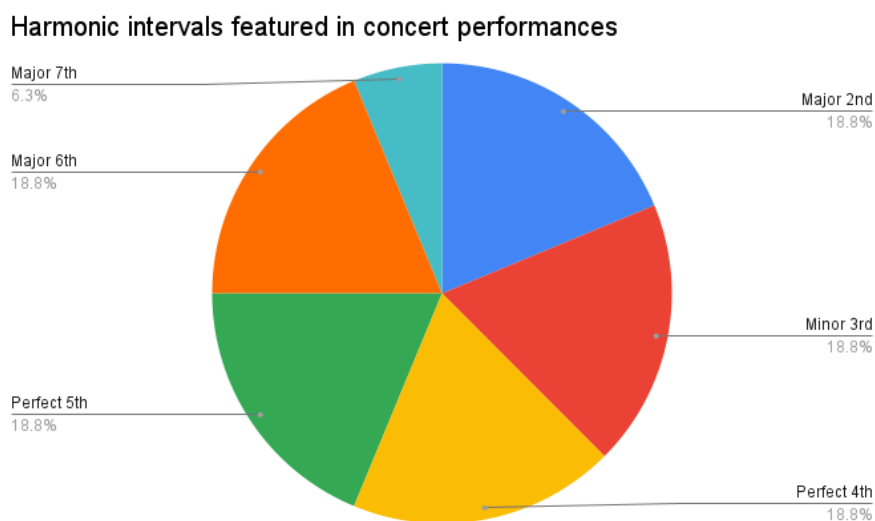


Figure 7.3: The harmonic intervals major second, minor third, perfect fourth, perfect fifth and major sixth were each featured in three performances. The major seventh harmonic interval only featured in one performance.

is made up solely of drones, P9 said *‘I think I’ve made synthscapes that have that same kind of expansive, rolling, slow feel’*. P8 commented that they enjoy *‘spacing out to drones’* in general, not just when performing with the study instrument. Meanwhile the thematic analysis offers a clearer view, revealing that seven participants simply enjoy playing the drones. Four participants (P1, P2, P5, P9) were specifically drawn to the *edge-like interactions* [131] in the drone, exploring the edge of the sustained tone disintegrating into *‘chaos’* (broadband noise), while six participants (P1, P2, P4, P5, P9, P10) spoke of finding the *‘sweet spot’* in the drone, the point of sustaining the drone to their desired timbral quality.

But why are extended low drones a motive that forms idiomatic music for this instrument, and not extended high drones? P1, who performed Layout A in which the higher register is on the upper tier, commented that performing the higher register drones requires more effort than the lower register drones. He said *‘tilting to create those drones is really nice. Although it’s quite tiring on your arms because your arm is up high’*. However the additional effort to perform upper tier tones does not explain the trend of participants preferring extended low drones over extended high drones because on Layout B, upper register tones are equally dispersed across both tiers.

The thematic analysis suggests that the participants simply like the sound of the lower register tones, and the drone allows for exploration of various timbres

within each tone. P1 said he enjoys *‘the ambiguity of these [low drone] sounds, because it’s got so many tones mixed in. The amount of variation just in that small space is really interesting’*. P9 commented *‘I like the really big resonant bass sounds’*. P7, a bass player who performed Layout A in which the lower register tones are all located on the left side of the instrument, commented that the lower register tones *‘fits better’* with the *‘physicality’* of the instrument.

Texture

The compositions were explored for presence of monophonic textures (one tone at a time), homophonic textures (two or more tones at a time: a melody and a less complicated harmony), polyphonic textures (two or more simultaneous independent melodies) and imitative textures (melodies echoed in different registers). All concert performances featured sections of monophonic textures as well as sections of homophonic textures. Half the concert performances featured majority monophonic textures and half featured majority homophonic textures. As all performances featured both monophonic and homophonic textures I consider these textures motives of idiomatic writing with the instrument.

None featured sections of polyphonic textures, and only three featured imitative textures. I therefore do not consider polyphonic and imitative textures motives of idiomatic writing with the instrument. A comment from P6, who performed Layout B, indicates that navigating the large size of the instrument results in a temporal gap when performing imitative textures (melodies echoed in different registers) and may be why imitative textures are not part of the instrument’s idiomatic music.

‘I was playing a melody down here [gestures to the left side of the instrument] and I went to go and try and repeat it in the higher octave. And you kind of had that gap between “Right, I’ve finished here, and I have to go over here and play it”. Like, you get a bit of incongruity there. But maybe again, that’s a case of working out compositional techniques for a larger instrument saying “Okay, if I’m moving, and I want to have sound, maybe I could forfeit this drone to continue the sound. So it’s a bit more smooth and continuous”.’ - P6

7.5.3 Outcome of the thematic analysis

The Study 2a thematic analysis resulted in a code book that featured 1338 coded segments clustered into the codes: *effort; entanglement; characteristics of the compositions; reflections on the instrument; gestures and techniques; performing perception; performer’s body; movement; learning the instrument over time; and ‘edge-like interactions’*. After the Study 2b additional thematic analysis the codebook featured 1669 coded segments with the additional codes relating

to motivic analysis *rhythm, dynamics, melody, harmony, tone colour and texture*, and the additional codes relating to performance patterns *alternating or simultaneous pendulums - neighbouring or otherwise, pendulums above or below one another* and *pendulums on the same tier in ascending or descending order*. Refer to Appendix F for the final version of the code book.

7.5.4 The relationship between instrument layout and melodic motives

The above findings illuminate the origins of motives of idiomatic music. A further dimension of findings was revealed by comparing the motivic and gestural analysis of each instrument tonal layout (shown in Figure 8). This is because depending on the instrument tonal layout, the performance patterns result in different melodic output. Nine performances featured performance patterns, with five performances featuring performance patterns during at least 62% of the composition.

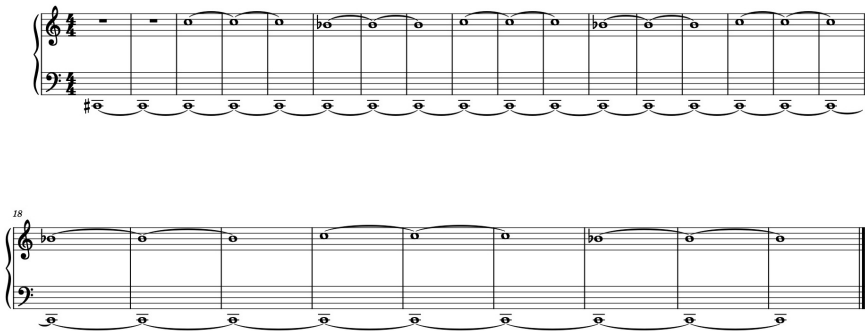
When comparing the motivic analysis to the instrument tonal layout assigned to each participant, I noticed that all three participants whose concert performances feature the melodic motive of at least three ascending or descending tones in order of the scale were assigned Layout A, in which the tones ascend left-to-right along each tier. Similarly, of the four compositions that feature melodies made up of at least three minor thirds in order, three were performed by participants that were assigned Layout B, in which tones on each tier ascend left to right in minor thirds.

7.5.5 Comparing specific performances

The first minute of the concert performances by P1 and P2 (both performing Layout A) are almost identical in melody and tempo, as evidenced in Figure 7.4 which shows the first minute of each performance transcribed in Western music notation. Both performances feature a repeating upper register melody that descends in order of the scale (B#4, A#4, G#4) accompanied by an extended low drone (C#2). P2 additionally drones (D#2) to create a beating between the drones due to their major 2nd interval. The performances differ gesturally: P1 performs finger-tapping and striking whereas P2 tilts the pendulums to create drones.

While the similarity between the two performances is interesting in itself, I also find it interesting that I had watched the participants' performances several times both during the study and after without noticing the similarity. It was while transcribing the performances for the interaction analysis that I discovered the similarity. This indicates to us that the process of transcribing the

First minute of P1's concert performance



First minute of P2's concert performance

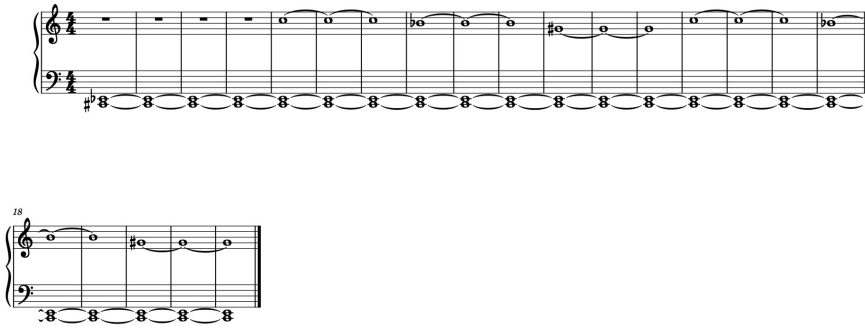


Figure 7.4: The first minute of the concert performances by P1 and P2 shown in Western notation.

performances allowed us to make connections between the performances that we as audience members were not already making.

7.5.6 Fallibility of interview data

Beyond the lack of clarity and detail about the compositions provided by the musicians during interviews (see Sections 7.5.2 and 7.5.1), the participants can misrepresent their actions during interviews. When asked if there was anything new he tried on the instrument this week, P2 said *‘Not really. I’ve sort of refined what I’ve been doing a bit, I think.’* However the gestural analysis showed that P2 had in fact developed a new gesture for maintaining droning neighbouring pendulums: balancing two tilted pendulum on his forearm. The gestural analysis showed that he had not performed this gesture in previous sketches performed with the instrument. This incongruity between P2’s interview responses and what he actually did shows that interview data can be fallible and should therefore be supplemented with other forms of documentation and analysis.

7.6 Discussion

7.6.1 The role of size in music performed with Chaos Bells

By including motivic analysis in the evaluation methodologies I gained a clearer understanding of the relationship between the instrument’s physical design and the performances created with the instrument. The least performed harmonic interval, the major seventh (which is also the interval that requires the most effort to reach: 80 centimetres on Layout B and 120 centimetres on Layout A) only appeared in the concert performance by P7 whose arm span of 191 centimetres is the largest of all study participants. Additionally, while monophonic and homophonic textures were discovered to be motives of music idiomatic to Chaos Bells, imitative textures (in which melodies are echoed in different registers) are not. P6’s comments in Section 7.5.2 indicate that the size of the instrument resulted in less satisfaction when composing imitative textures due to pauses in the music being introduced while she navigated to another part of the instrument to repeat a melody in a different register. These discoveries back up the Study 2a (Chapter 6) findings that show the large size of the instrument influenced the music created with it.

7.6.2 The value of motivic analysis in the Study 2b findings

Some insights gained from the motivic analysis, such as the features of idiomatic writing for the instrument, would not have been discovered through other methodologies such as surveys, because we cannot rely on musicians to accurately describe their own performances.

Comparing the motivic analysis to the instrument tonal layout revealed that the physical layout of tones influenced the melodies featured in performances. These findings show that the study instrument's idiomatic patterns are a product of the location of tones in combination with the size of the instrument, because due to the size of the instrument tones located on the upper register or further away from one-another require more effort to perform. These examples indicate that performers are more likely to compose melodies constructed from tones located on the lower tier and pendulums located adjacent to one another.

With the addition of motivic analysis, the discoveries made through thematic and interaction analysis gained more dimensions and clues to their origins. For instance, while the interaction analysis revealed that all 10 compositions featured drones, and the thematic analysis revealed the musicians *enjoy* performing drones, the motivic analysis revealed what *kinds* of drones the participants performed.

Upon discovering in the motivic analysis that extended drones in the lower register were characteristics of idiomatic writing for the instrument, I reviewed the gestural analysis with fresh insight to notice that two participants developed their own techniques for extended sustain of drones such as resting the tilted pendulum on the upper thigh (P10).

When I returned to the thematic analysis after doing the motivic analysis I noticed more in the interview data than I had noticed previously. For instance, I noticed that I had not coded the thematic analysis for the elements of music or the identified motives. After adding the codes pertaining to the elements of Western music (rhythm, dynamics, melody, harmony, tone colour and texture) to the thematic analysis I noticed that the participants rarely discuss the elements of music. No interview data at all discussed the melodic alternation of two tones, that I identified in seven performances. This shows that motivic analysis has the potential to identify aspects of performances that the performers themselves may not even be aware are part of their performances let alone characteristic of them.

I consider the similarity of P1 and P2's performances a result of idiomatic writing. Given that three other performances with Layout A did not feature a similar phrase, I cannot claim that the instrument design strongly suggests this

musical phrase, however more research may reveal that the similarities of P1 and P2’s performances may be an example of Magnusson’s concept of a ‘*script*’: the knowledge contained in an instrument that influences compositions created with the instrument (discussed in Chapter 2, Section 2.1.3).

I had watched all performances during the study and after, I only made the realisation that P1 and P2 had composed similar musical passages while completing the interaction analysis (which I performed before conducting the motivic analysis). This indicates that transcribing the gestural interaction allowed me to make connections I was not already making. It is unknown whether I would have made the realisation if I were analysing the performances with motivic analysis alone. I argue that the more analysis methodologies that we included in our research the more likely we are to notice connections between the data.

7.6.3 The case for musicological approaches to HCI explorations of new instruments

Numerous musicological perspectives have been written on instruments and music technologies past and current (for example [44, 46, 21, 176]). In a reversal of the situation with pre-20th-century Western art music, ethnomusicological perspectives are arguably more established in the NIME community than traditional music-theoretical analyses of NIME performances [19, 27, 70, 3]. Additionally, music-theoretical analysis has been applied to electronic music genres both popular and experimental (for example [22, 47, 42, 32]).

In this chapter I argue for elevating the music performed on new instruments as a subject of research rather than as a separate siloed element of HCI instrument design research. Creating a musicology of new instrument performance would draw together those already bringing such analytical perspectives to HCI [65, 170, 182, 14] while encouraging a closed loop between performances and written publications. This stream of work would sit alongside, but distinct from, gestural and experiential analyses deriving from HCI traditions. No single analytical approach can be appropriate to all music made with new instruments, nor can any single analyst claim a definitive interpretation of artistic works in the community, so a musicology of new instrument research within HCI ought to emerge from an inclusive conversation amongst researchers, scholars and artists.

7.6.4 Limitations of my method of motivic analysis

My motivic analysis methodology has some limitations. First, it is based in Western music. In this study, mine and the participants’ musical backgrounds are in Western music, so it made sense to construct this motivic analysis around

the elements of Western music. However, I acknowledge that both participant selection and analysis method could be seen to continue a post-colonial tradition of elevating a Western musical canon. I hope this methodology inspires future work that uses motivic analysis of new instrumental performances within a variety of cultures and genres.

Second, a musical motive is an element deemed characteristic to the composition. It follows that the integrity of a motivic analysis relies on the subjective judgement of what is important to the composition. In my methodology, motive selection and motivic analysis were both executed by me without consulting the participants. Although it is common for music analyses to be conducted by someone other than the composer or performer, the process is subject to influence from my musical judgments and biases [103].

Third, a motivic analysis focuses on music made regardless of physical gestures and techniques performed with the instrument and could therefore be conducted using as source material any method of recording including video, audio or music notation. The varying nature of notation and scores for new instruments could make comparing data difficult. Meanwhile, coding motivic analysis from audio or video recordings has its own limitations, for instance audio compression may influence perception of dynamics.

Finally, as my method of motivic analysis is based solely on audio, I acknowledge it does not show the full picture of a performance. The existence of ancillary gestures reveals that the music is not the whole performance, performance, as further illustrated by P8's comments that visual aesthetics influence their choice of performance gestures. This raises the question how much are the performances created with new instruments solely about the music? And how much is about body movement and the aesthetic show put on for the audience?

7.7 Conclusion

This chapter describes Study 2b, an explorative study that uses a new method of motivic analysis to further explore Study 2 (discussed in Chapter 6). A new DMI, Chaos Bells, was designed for this investigative purpose (described in Chapter 4). The findings presented in this chapter relate to RQ1⁴, the first original research question of this thesis. Additionally, the results suggest the value of traditional musicological analyses of the music made with new instruments. Using motivic analysis in conjunction with thematic analysis, I discovered insights into the relationship between the instrument's physical design and musical performances. I found that with Chaos Bells, the physical layout of tones influences

⁴How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?

the melodies that are characteristic of each performance.

Study 2b investigated and revealed insights into the following questions:

What is the relationship between the instrument's physical design and the music performed with the instrument? What role does size play in this relationship?

The findings reveal that the harmonic intervals that are commonly featured in the concert performances are those that fit comfortably in front of performers' bodies, backing up the findings presented in Study 2a (Chapter 6) that show that performers are more likely to compose melodies constructed from tones from pendulums comfortably located in relationship to performers' bodies such as those on the lower tier and those adjacent to one another. Similarly, the findings reveal that less performances featured imitative textures, which require navigating the instrument to repeat a melody in a different register.

Which factor exerts a greater influence on motivic patterns, physical layout or sonic features?

The Study 2b findings reveal that some motivic patterns are more influenced by the instrument's physical layout and by the instrument's sonic features. Of the four motives that I propose are characteristic to the instrument's idiomatic writing, one is clearly more influenced by the sonic features: extended drones in the lower register. Meanwhile, three of the five participants assigned Chaos Bells configured to Layout B in which the tones ascend left to right in minor thirds included melodies made up of minor thirds in their concert performances. By comparison, only one of the five participants assigned Layout A included melodies made up of minor thirds. This finding illuminates that the physical layout of the instrument has the potential for strong influence on harmonic and melodic motivic patterns of this large instrument. Additionally, I found examples in which the instrument's layout influenced why some elements of music *are not* motives of the idiomatic music of Chaos Bells. For instance, participants indicate that imitative textures is not a common motive of the concert compositions perform because physically relocating their bodies to another part of the instrument often results in a musical pause that can disrupt the flow of the performance.

7.8 Carry forward

Motivic analysis has the potential to identify aspects of the music that performer-composers may not have been aware of themselves. This research illustrates the value of a musicological approach to HCI research, suggesting the need for a broader conversation about a musicology of *performances* with new musical instrument, as distinct from instrument interaction research.

In the following chapter, I will conclude this thesis with a summary of the original contributions of the studies, and discuss how the scoping study and Studies 1, 2a and 2b result in new knowledge about large DMI design and research, as well as ways that this research benefits researchers of instruments of all sizes.

Chapter 8

Discussion and conclusions

This chapter is built on significant material from ‘Chaos Bells: Instrument size and entangled music performance’ by Mice and McPherson, accepted for publication in Contemporary Music Review, 2023 [124].

The previous two chapters detailed Study 2 which attempted to explore the impact of instrument size on musical entanglements with Chaos Bells. In this chapter, I discuss and expand on the outcomes of Studies 1 and 2 and consider the impact of foundational work done in the literature review and Scoping Study.

This chapter begins with a summary of the research conducted for this PhD. Next I recount key issues related to instrument size which were developed during the literature review (Chapter 2). I then reflect on the original investigations conducted for this research: summarising the methodologies used, and presenting the findings of the two instrument studies in the context of how they relate to the original research questions. I conclude this chapter with some considerations and implications surrounding performing and touring large DMIs within the greater music industry, and reflections on the wider themes of instrument size within the instrument design industry and how this research has impacted my own perspectives as a multi-instrumentalist, composer, artist and researcher.

8.1 Summary of the research

This thesis comprises original contributions resulting from two studies and a scoping study, and the presentation of key approaches and frameworks in the background literature review. In this section I summarise this work to contextualize the discussion that concludes this chapter.

8.1.1 Method of Study 1

In Study 1 the participants were asked to improvise with Chaos Bells twice while the instrument was not turned on: once before and once after hearing the types of sounds the instrument creates. Subsequently the participants improvised with Chaos Bells in its turned on state, amplified through a PA.

8.1.2 Results of Study 1

Study 1 revealed ways that the instrument sound design, and production of sound at all, influenced performer's gestural interactions with the instrument. Performers played the instrument twice with the sound off: first without knowledge of the instrument's sound, and then with knowledge of typical sounds the instrument makes. Finally the performers played the instrument with the sound on. During each phase of the study performers reshaped their performance gestures, each time eliminating gestural interactions that do not result in changing the sonic output of the instrument, reinforcing similar findings by Jack, Stockman and McPherson [83].

The relationship between the instrument's physical layout (a combination of the tonal layout and size) and the performers' bodies influenced the musical gestures and compositional patterns that emerged, impacting the improvisations created. Moreover I noticed examples of the physical design of the instrument resulting in musicians changing their perception of the sound, as evidenced by examples of participants commenting that they prefer the tones in one particular quadrant even though they were assigned Chaos Bells configured to Layout B in which the tones ascend in a zig-zag pattern (see Chapter 5 Figure 4.8) resulting in quadrants of pendulums above and below each other that produce a similar range of tones and timbres.

8.1.3 Method of Studies 2a and 2b

In Studies 2a and 2b the participants completed four private one-hour sessions with Chaos Bells, during which time they were instructed to create various one-minute fixed (non-improvised) performances with the instrument. In the third session they were instructed to create a three-minute performance with Chaos Bells for broadcast on an online concert. In the fourth session they were introduced to a smaller version of Chaos Bells (half the size of the larger version) and invited to perform their concert composition with both the smaller and larger versions as a method of priming the performers for further insights into how the size of the larger version impacts their performances.

8.1.4 Results of Study 2a

The Study 2a results reveal the complex role of instrument size in musical entanglements. In this study I found examples of the large size of the instrument influencing the tonal choices of composing performers as they preferred performing tones located comfortably in front of the body. Some even considered their spatial relationship with the instrument as a new compositional approach that they would not use when creating performances with a smaller instrument. I noticed examples of participants enjoying the extra effort and larger gestures required of performing the oversized instrument, and as a result incorporating large and effortful gestures and musical patterns into their compositions. When performing the larger version of Chaos Bells, some performers changed perceptions of their own bodies, including feeling powerful and desiring longer or more limbs. Inverse changes in bodily perception were noticed when participants performed the smaller version, which resulted in some participants feeling tall or like ‘*a child playing with a toy*’ (P9). I also discovered that musicians bring musical entanglements that they have developed through years of training with other instruments to their approaches to performing new unfamiliar instruments such as Chaos Bells.

8.1.5 Results of Study 2b

The Study 2b findings revealed that the size of the instrument influenced the formation of various motives found within the idiomatic writing of Chaos Bells, such as the inclusion of harmonic intervals that are conveniently located comfortably in front of the performers’ bodies and the exclusion of those that required more effort to reach, backing up the findings presented in Study 2a (Chapter 6) that show that performers are more likely to compose melodies constructed from tones from pendulums comfortably located in front of their such as those on the lower tier and those adjacent to one another. Imitative textures were also uncommon in performances with Chaos Bells as participants noticed that relocating their bodies to another part of the instrument resulted in an undesired pause in their performance.

Sonic features of the instrument also influenced the idiomatic writing of Chaos Bells, such as the motive of extended drones in the lower register which appeared in nine of the 10 concert performances.

The idiomatic gestural patterns in combination with the physical layout of the instrument were also seen to influence melodic composition as three of the five participants assigned Chaos Bells configured to Layout B included melodies made up of minor thirds in their performances, a trend that emerged because in this layout tones ascend in minor third intervals.

8.1.6 Findings from the literature review and Scoping Study

Large DMIs: the state of the art

The literature review showed that within the commercial instrument design industry, instrument and interface sizes are shrinking resulting in a trend of ‘*desktop*’ instruments. Outside of the commercial industry, interest has increased in recent years among independent artists and builders in designing large DMIs however these examples are few and far between. Within this niche field of large DMI design, these instruments tend to take the form of pre-programmed musical installations, or performed robotically or mechanically via smaller control interfaces, revealing a gap in the construction and exploration of gesturally performed large DMIs.

Insights from the Scoping Study

In Chapter 3, I interviewed seven performers of large acoustic instruments. This study revealed that the size of large instruments contributes to musical features and interactions that are not possible with smaller versions of the instrument. The performers discussed ways that the feel as well as the sonic affordances of the large instruments influence their improvisations. Several performers of large wind instruments discussed ways they are drawn to the timbral variations across registers, a by-product of the instrument size that results in a rich and clear lower register and an airy upper register that is more difficult to perform. The musicians spoke of choosing to perform difficult techniques that are risky to accomplish for the gratifying result of the ‘*frail*’ upper register tones. This study also revealed that a feature of large acoustic instruments is the ‘*microscale within the macroscale*’ in that despite their large size, a millimetre change in performance can result in a large change to the overall sonic output of the instrument. These interviews resulted in a set of design considerations for designing large DMIs inspired by the insights of performers of large acoustic instruments.

8.1.7 Review of contributions

While conducting these studies, it has become apparent that instrument size can impact performer choices, and furthermore research conducted with large DMIs can reveal findings that are relevant to the design of instruments of all sizes. I hope that through documenting my research approaches and critically reflecting on the methods and outcomes, I can offer new knowledge into instrument design practices that are relevant to designers of both large DMIs and instruments of all sizes.

The overall goal of this thesis is not to prescribe guidelines for designing

large DMIs, but to highlight the constellation of entanglements that contribute to music making as revealed through the lens of large instruments. In doing so I argue that investigation of niche musical practices that are under-explored in academic research and commercial industries can result in knowledge that benefits the broader HCI field.

In this section I present the contributions of Studies 1 and 2 in the context of the central questions guiding this research.

RQ1: Findings regarding the impact of instrument size on musical performance

The below findings relate to RQ1¹, the first original research question of this thesis.

Highlighted the role of instrument size on compositional choices:

The Study 1 (Chapter 5) findings revealed that identical patterns of successive tones were performed by different participants regardless of which instrument tonal layout they were assigned. These findings indicate that what is idiomatic to Chaos Bells has less to do with tonal layout and more to do with the instrument's physical layout and its relationship to the body. Participants reflected that the size of the instrument can influence their movements in ways that influence their compositions, as illustrated by one participant of Study 1 who commented that the size of the instrument encouraged her to move around the instrument to make use of more of the tones on offer.

Highlighted the role of instrument size on performers' musical perceptions:

During Study 1 (Chapter 5), I found examples in which the size of the instrument influenced performers' perceptions of tones, an example being when a participant observed that she was unsure whether she played a certain pendulum because she likes its tone or whether she likes its tone because it is located on the lower tier which she found to be an ergonomically convenient location.

Highlighted the role of size-related physical effort on music performance: The Scoping Study (Chapter 3) revealed that that the physical effort of performing large instruments can result in fatigue, and the effort of traveling with a large instrument can result in performers opting to perform live concerts with smaller versions of their instruments or choosing not to perform concerts at all. Transportation of Chaos Bells was not a factor in Studies 1, 2a and 2b. During Study 2a (Chapter 6) some participants suggested modifications to Chaos Bells that would result in requiring *more* effort to perform the instrument, such as adding extra weight or height. These findings reveal that physical effort is not

¹How do physical dimensions of a digital musical instrument shape the gestural language of the performer, and in turn the compositions and performances created using the instrument?

always a deterring factor for musicians and in fact can add to the enjoyment of musical interaction with large instruments. Participants spoke of enjoying creating large gestures, taking big steps and moving around the instrument as part of performing with Chaos Bells. The strongest indicator that the physical effort of performing a large DMI can impact compositional choices was revealed in the Study 2b (Chapter 7) findings. I observed that due to the physical size of Chaos Bells, extra effort is required to perform tones located on the upper tier or further away from one-another performers. As a result performers are more likely to compose melodies constructed from tones located on the lower tier and pendulums located adjacent to one another.

Highlighted the role of instrument size on the formation of performers' identities:

During Study 2a (Chapter 6), I observed examples of the influence of instrument design on the co-constitution of performers' identities as illustrated by an example in which a composer changed his approach to melodic composition due to the size of Chaos Bells. While composing with Chaos Bells he becomes a composer who prioritises physical location of body as a solution of creating melodic patterns. I noticed examples of participants who felt taller when playing the smaller version of Chaos Bells, and participants who wished they had more or longer limbs when performing the larger version of Chaos Bells.

RQ2: Findings regarding the impact of design choices of instruments of all sizes on musical performance

The below findings relate to RQ2², the second original research question of this thesis.

Highlighted that instrument designers have a responsibility to people's bodies: Through the lens of Entanglement HCI [52], the Study 2a (Chapter 6) findings reveal that the physical design of an instrument can influence performers' identities that are formed in the moment of music making. I observed examples of participants commenting about wanting to change their bodies to better suit the instrument size and examples of participants that chose to perform musical gestures that incurred pain (and may even potentially cause injury).

Highlighted the role of an instrument's sound design on compositional choices:

During Study 1 (Chapter 5), one performer's improvisations increased in tempo after she realised the instrument's tones sustain for a shorter duration

²By conducting research with instruments that are physically larger than the performer's body, what can we learn about instruments of all sizes with regards to the impact that design choices have on performance and compositional choices?

than she had initially expected. Further illustrating ways that sound design can influence compositional choices, during Study 2a (Chapter 6), a musician who accidentally performed white noise while rehearsing his performance changed the composition to purposefully include performing white noise in that section during renditions of the performance. These examples highlight the relationship between sound design and material epistemologies of instruments.

Highlighted the role of musical instruments in more-than-human assemblages:

During Study 2a (Chapter 6), I observed examples of Chaos Bells partially filling the void left behind by musicians' regular instruments in their more-than-human assemblages. I discovered examples of musicians composing with, and performing, Chaos Bells the way they would ordinarily perform their primary instruments, such as a synthesizer performer whose performances were reminiscent of her regular synthscares. Furthermore, the participants' ideas for improving the instrument commonly related to their primary or secondary instruments, such as a violin who suggested the instrument could be bowable and a piano player who suggested adding a sustain pedal to the instrument.

Highlighted the role of an instrument's visual aesthetic on music performance:

During Study 1 (Chapter 5) I observed that Chaos Bell's visual aesthetic in which the 20 pendulums are presented in four quadrants influenced performer's perception of the tones themselves. We found that some participants were drawn to certain quadrants while avoiding other quadrants that offered a similar range of tones. Additionally, a majority of participants commented that tones do not follow on in a pattern that crosses from one side of the central vertical pole to the other, incorrectly giving significance to the vertical pole which does not subdivide the layout of tones in any way.

Reinforced that performers are drawn to edge-like interactions:

As mentioned in Study 2a (Chapter 6), *edge-like interaction* [131] is the term used by Mudd to describe exploratory performance interactions at the boundary between stability and instability. During Study 2a I observed that while performing Chaos Bells, participants were specifically drawn to the edge-like interactions in the drone, exploring the edge of the sustained tone disintegrating into 'chaos' (broadband noise). This observation backs up findings made by Mudd that present the value of nonlinear dynamical processes and interface complexity to musical tools and creative HCI applications.

Reinforced the role of an instrument's sound design on emergent gestural languages:

During Study 1 (Chapter 5) performers were invited to play Chaos Bells first with the sound off and later with the sound on. Once the performers heard

the instrument they optimised their gestures to those that result in creating or changing the instrument’s sonic output, reinforcing similar findings by Jack, Stockman and McPherson [83].

8.1.8 Research artefact

Chaos Bells: a new large DMI

Chaos Bells, a new DMI with 20 performable pendulums discussed in Chapter 4, has been the focus of much of this research. While Chaos Bells has been configured to various versions for the studies, I consider the final version to be the larger two metres wide and tall version configured to Tilt Mapping 2. Chaos Bells uses 20 analog accelerometers (one embedded per pendulum) to excite a digital model of a string (a modified Karplus-Strong algorithm). A key development here is the use of the accelerometer y-axis signal to generate a sustained ‘*droning*’ tone. The result is the angle of the pendulum controls the timbre of the drone, allowing for the performance of ‘*microscale within the macroscale*’: gestures at millimetre scale that result in a large change in the sonic output of this oversized instrument.

In recognition of its innovative design, Chaos Bells was awarded the Highly Commended award in Best Innovation of a Sound Tool or Technique in the 2021 Sound of the Year Awards³, and was a finalist in the 2023 Guthman Musical Instrument Competition⁴.

8.1.9 Motivic analysis

I developed a method of motivic analysis (presented in Chapter 7) for analysing the music made with new instruments. A musical motive is a small, analysable musical fragment or phrase that is important in or characteristic of a composition. Using my method of motivic analysis, I explored the concert performances created by participants in Study 2b for musical motives, which could be any element of music such as rhythm, dynamics, melody, harmony, tone colour, texture and form.

Motivic analysis added clarity to the findings that the thematic and interaction analyses provided. For instance, while the interaction and thematic analysis revealed that participants liked performing drones, the motivic analysis revealed that they particularly liked performing extended drones in the lower register, as they appeared in nine of the 10 of the concert performances. The motivic analysis also revealed moments when the musicians’ descriptions of their

³<https://www.soundoftheyearawards.com/>

⁴<https://guthman.gatech.edu/>

own performances were lacking detail, such as when common motives of performances with Chaos Bells are not mentioned in the interview data, for example melodies that alternate between two tones was a motive of seven concert performances yet no participants spoke of this melodic approach during interviews. Furthermore, the motivic analysis can even reveal when interview answers given by participants are incorrect, as seen when a participant claimed to have not created a performed a new gesture meanwhile the interaction analysis confirmed that he did. This example highlights the need for additional methods of analysis such as motivic analysis, because we cannot trust musicians' own recollections of their own performances.

8.1.10 Methodological reflections

The methodologies of Studies 1 (Chapter 5), 2a (Chapter 6) and 2b (Chapter 7) are deliberately explorative and qualitative. Beyond just recognising trends among musicians interacting with the study instrument, these methodologies embrace the diverse perspectives of the participants, who each bring their unique physical, musical and cultural experiences and skills.

Findings were achieved through the study design of interacting via creative prompts with an instrument designed for study purposes. In Studies 1, 2a and 2b, the comparison between interactions and compositions by musicians assigned Chaos Bells Layout A and those assigned Layout B allowed me to find examples of similar compositions that occurred irrespective of instrument layout and therefore build findings that are a product of the size (not tonal layout) of the instrument.

In Studies 2a and 2b, musicians composed original performances with the large version of Chaos Bells during three sessions. During the fourth and final study session, the musicians were prompted to play their concert performances with a smaller version of Chaos Bells as a method of probing the participants to consider ways the size of the larger version of Chaos Bells impacts their compositional and performance choices.

8.1.11 An account of touring with Chaos Bells

Laboratory-based studies cannot show the full picture of the role of instruments in musical systems within the wider context of music culture. Instrument designers and researchers recognise that more discoveries can be made about instruments when laboratory-based findings are supplemented with explorations within music communities [112, 68].

After completing the research studies in London, I presented Chaos Bells

at an interactivity session at CHI '22⁵ in New Orleans USA, and embarked on a short tour of the UK performing electro-pop tracks from my solo album *Sweat Like Caramel*⁶. My live performances with Chaos Bells were not part of the research studies, but taking Chaos Bells out of the laboratory environment reminded me of the pragmatic considerations of touring artists: considerations that are different to those of non-touring music producers, instrument design companies and installation artists, and therefore offer additional insight into the role of instrument size in music performance. In this section I give an account of my experiences and insights gained through touring with Chaos Bells.

The performance set-up

A 45 minute live set of electronic music was performed as a live duo featuring electronic musician Odd Lust⁷ performing with Chaos Bells, and me performing with an eight-track sampler (for live-sampling her voice and triggering stems of drum machine beats and synthesizers) and a mixing board for controlling the volume of the sampler tracks and Chaos Bells.

Rehearsals

In advance of the tour, Odd Lust and I rehearsed the performance once for two hours. As Chaos Bells features only tones within the scale of C sharp melodic minor, during the rehearsal, Odd Lust identified which tones work in which songs with the intention to improvise with those tones during the concert performances. It was decided that Chaos Bells would only feature on five songs in the nine song set because the rest of the songs did not fit with the C sharp melodic minor tones.

Concert performances

While performing the concerts, I performed the sampler, opting to include less synth stems and vocal sampling than usual to make sonic space for Chaos Bells to be prominent in the mix. Aware that the audience was intrigued by the large instrument on stage, and that audiences of live electronic music already find it difficult to identify the source of sounds within the music, I turned Chaos Bells up in the mix to a volume that was louder than I would ordinarily mix a synthesizer part. In this way I aimed to make it obvious to the audience which tones were being created live with Chaos Bells.

⁵<https://chi2022.acm.org>

⁶<https://liamice.bandcamp.com/album/sweat-like-caramel>

⁷<https://soundcloud.com/oddlust>

I noticed that even though Odd Lust had identified multiple suitable pendulums for each song, when performing live he largely focused his improvisations with one or two pendulums. This is interesting because the laboratory studies had identified that performers had, for the sake of convenience, narrowed their performances to pendulums that are located comfortably in front of their own bodies. Performing live, Odd Lust also narrowed his performance to only one or two pendulums per part but for a different reason: within the genre of techno and electro-pop, synth parts are commonly simplistic, repetitions of one or two tones, rather than complicated melodies of multiple tones.

8.1.12 Insights from touring with Chaos Bells

Through navigating the logistics of touring and presenting Chaos Bells, as well as showing the instrument nationally and internationally at interactive sessions, we discovered additional implications of performing with large DMIs that we had not previously considered.

Tuning

If Chaos Bells had been designed specifically for touring to perform electronic music other design choices would have been made such as being tuned to different pitches and/or scales. It may have even been designed specifically for performance on one song in line with Cook's design principle 'make a piece, not an instrument or controller' [34, 35].

Fatigue

The physical demands of touring with Chaos Bells were much more than touring with my previous live set-up (a sampler, microphone and vocal effect unit) and therefore resulted in fatigue during and after the event.

Although constructed of lightweight plastic, the large, cumbersome boxes that transport Chaos Bells weigh 13kg each and require two people to move. Carrying these boxes in and out of venues, which often requires climbing and descending stairs, is a physical workout. Additionally, the instrument requires constructing before the event and breaking down afterwards, work that requires lifting arms overhead, hammering, untangling and winding long cables, and ascending and descending step stools for approximately 15 minutes (breaking down) to 30 minutes (construction). As it was economically unfeasible to bring additional roadies on this tour, this physical labour was conducted by me and Odd Lust each performance day. Combining this physical labour with the regular demands of a live show, such as soundcheck (30 minutes) and the live

performance itself (45 minutes), resulted in a huge output of energy. Sometimes Odd Lust and I did not sit down the entire event.

Transport costs

Touring with Chaos Bells made touring substantially more expensive. Before incorporating Chaos Bells into my live show, I toured alone via train (my preferred mode of transport for environmental reasons) or plane, with all luggage and equipment in one small carry-on-sized suitcase. Adding Chaos Bells to my setup however required touring by van to accommodate the additional luggage such as the Chaos Bells interface (two large boxes each one metre long and 60 centimetres tall) and microcomputers and mixer (one large suitcase). For international events, Chaos Bells was posted in both directions.

These additional expenses were not offset by higher performance fees. The higher transport costs of performing such a large instrument were not recognised by promoters as the performance being of higher value than other performances. The promoters of the events were not willing to pay me higher fees than those I had commended previously without Chaos Bells, or than those of other artists on the shows, all of whom toured with compact set-ups such as a single laptop.

Show day logistics

To accommodate the extra time required to load in and construct Chaos Bells, plus some buffer time in case of unexpected troubleshooting, I confirmed each event under the condition that I could access the venue at least two hours prior to soundcheck. All venues agreed, but days before the Coventry show the promoter requested to shorten the load-in and soundcheck time to one hour. They also requested Chaos Bells to be set up for the day event, then moved to another room in the venue for the night event, doubling the physical labour required to install and break down the instrument. After some discussion the promoter realised that their last-minute requests were not feasible. This experience reminded me that so few artists tour with large DMIs that it is unlikely that promoters and venues may agree to making special accommodations during the booking process but may forget why they agreed to them by the show date.

Breakages

While being posted to New Orleans, one of the microcomputers was damaged resulting in only three quarters of the instrument working upon its arrival. After that experience, I began touring with a spare of every part possible. Even so, sometimes there is no time to repair the instrument if damage occurs while on tour.

The only other time that a part of Chaos Bells broke while on tour was during an event in which children could try performing the instrument themselves. The interface hardware was damaged due to a child playing the instrument too roughly, resulting in five of the pendulums stopping working. There was no time to fix Chaos Bells during that event or before the evening concert in the same venue. This experience made me wonder whether due to the instrument's size the children played rougher with it than they would a smaller instrument.

Storage

Space is a valuable commodity especially in London. Queen Mary University of London permitted me to store Chaos Bells on campus in its constructed form while conducting research studies, but due to space restrictions, refused to allow me to leave the instrument set up after the completion of the research studies even though another PhD student requested to conduct her PhD research with it. With tours and showcases planned, there was a need to install the instrument somewhere for rehearsals and maintenance. For several months, I installed Chaos Bells in my personal music studio however it occupied so much space that the studio became unusable for other purposes.

The instrument is currently packed away in its boxes stored in a loft space in my music studio. Despite the interest in Chaos Bells from the public, promoters, venues and musicians, we have been unable to find a permanent location to install Chaos Bells. The instrument has therefore joined the 47.1% of new DMIs that are not currently ready to be performed [129].

8.1.13 Hidden influence of stakeholders on large instrument culture

The influence of music industry stakeholders, such as session musicians, roadies, promoters and venue staff, on instrument design practices is often overlooked [140, 114]. My account of touring with Chaos Bells revealed frictions with stakeholders, such as promoters and venue staff, over fair payment for the increased work and expenses required when touring with large instruments, and the reluctance of venue staff to accommodate of the extra time required for setting up and breaking down Chaos Bells. These examples deter me from wanting to tour with large instruments, and in doing so illuminate ways that stakeholders in the music industry may be contributing to the cultural erasure of large instruments in favour of desktop instruments.

8.2 An account of building a desktop version of Chaos Bells

After the completion of the Chaos Bells studies, another PhD student at Queen Mary University of London exploring the potential of AI in improving latency of polyphonic gesturally controlled instruments was in search of an instrument for research purposes. The researcher identified that Chaos Bells would be an ideal instrument for conducting her research because it is a gesturally performed polyphonic instrument with 20 tones. She expressed interest in borrowing Chaos Bells for conducting her research. However due to the storage issues mentioned in the previous section, the original (two metres wide, two metres tall and one metre deep) and smaller (one metre wide, one metre tall and 50 centimetres deep) versions were too large to fit in the only location that the student was granted to store her research instrument: an office desktop. It was therefore decided that I would reconfigure the smaller (one metre wide, one metre tall and 50 centimetres deep) Chaos Bells materials into an even smaller yet desktop version of the instrument.

8.2.1 Chaos Bells Desktop

Chaos Bells Desktop (Figure 8.1) is a version of Chaos Bells that is configured to a 50cm cube. The cube design came about because it reduces the instrument to half the desk space as the original smaller Chaos Bells by relocating each set of five pendulums to the four lateral faces of the cube.

While Chaos Bells Desktop is small enough to fit on a desktop, it retains some design aspects of the large version of Chaos Bells. For instance, due to the physical design of pendulums being located on all four lateral sides of the cube, it is not possible to perform all pendulums at once. With the large version, performers must choose which pendulums to perform because of the size of the instrument, whereas with the desktop version, performers must choose which pendulums to perform because the pendulums located on the lateral face furthest away from the performer require reaching over the instrument.

Chaos Bells Desktop is constructed of smaller PVC pipes than the large version and retains the same hardware design of embedded analog accelerometers that control the same sound synthesis. Therefore just like the large version, the desktop version has incorporated the concept of the ‘micro-scale within the macro-scale’ in which very small gestures such as a millimetre change in the angle of tilt of a pendulum can result in a large change in the overall sonic output of the instrument. This sound design also allows for edge-like interactions. The desktop version sound design also features timbral variation across registers: the

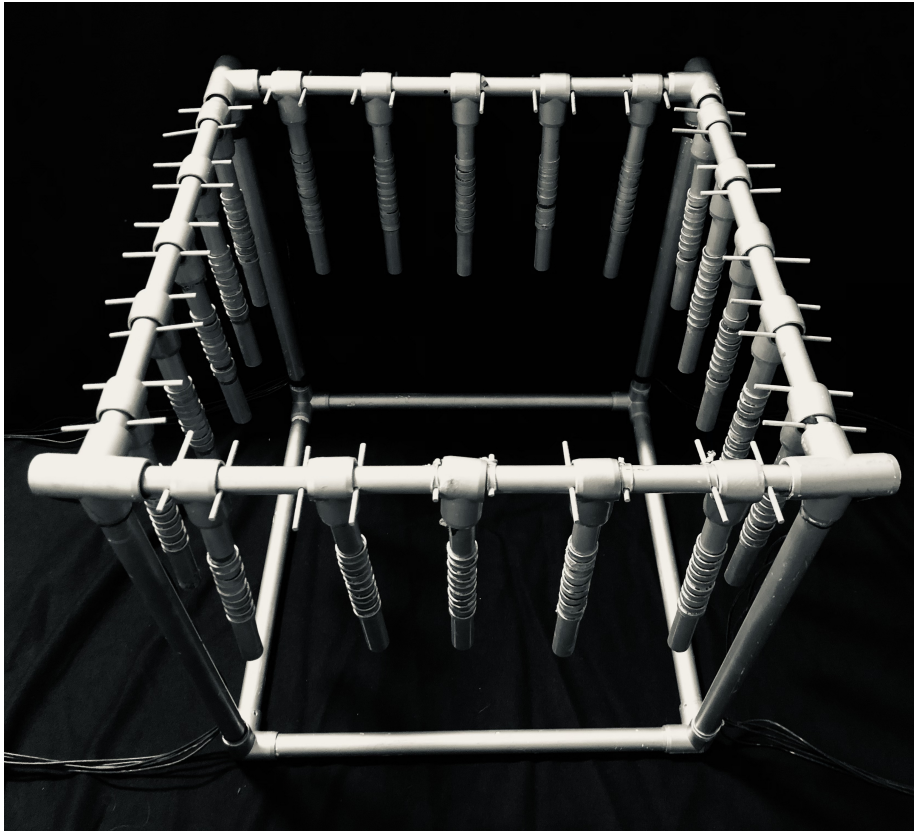


Figure 8.1: Chaos Bells Desktop is a version of Chaos Bells that is 50cm x 50cm x 50cm.

lower register tones feature a clear fundamental frequency meanwhile the higher register tones contain more inharmonic partials.

8.3 Thinking big, building small

Chaos Bells Desktop interface design of 20 silver pendulums that are performed with mallets or whole hand movements stands apart from both the commercial industry trend of fingertip controlled black box desktop instruments, and other instruments designed within the NIME community. The controlled tilting of pendulums is a unique gestural interaction not commonly seen in desktop instruments. This interaction allows for micro-gestural exploration of Chaos Bells Desktop's sound design, which, like the other versions of Chaos Bells, has the potential to create sustained 'drones' with tones that range on a spectrum from clear and stable to broadband noise. These distinctive visual and sonic design characteristics came about because the original Chaos Bells was designed before the desktop version, and the goal of designing the original Chaos Bells was to create an instrument that is larger than the performer and that requires gestural performance via full body choreographic movement, yet with sensitive sound design that can respond to microscopic gestures. We also wanted the control mechanism of each tone to only output sound while being interacted with so that we could compare the compositional choices that performers make when faced with a large interface in which they cannot physically reach all tones at any given time. Therefore enlarged sliders or potentiometers that can be left at certain settings would not fulfil this objective. By prioritizing these design goals while conceiving of the original Chaos Bells, hanging pendulums were identified as an interface that could be controlled via both large and small gestures. The angle of pendulum tilt was then mapped to the Karplus-Strong algorithm feedback coefficient, thereby allowing small changes in pendulum tilt to result in large changes in the drone decay and timbre.

Subsequently, when reducing the size of Chaos Bells to the desktop version, the goal was to capture the essence of the large Chaos Bells, therefore we retained the instrument's sound design and the choice of using pendulums as the tonal control interface.

If I had started by designing Chaos Bells Desktop first, I would not have conceived of using hanging pendulums to control the drone timbre because other mechanisms such as knobs or sliders would suffice. By designing Chaos Bells Desktop by way of the original large-scale Chaos Bells, I discovered that designing at a large scale then exploring how to pragmatically reduce the size gets the designer to a different aesthetic space than designing small to begin with. I recognise that due to the additional time, money and physical exertion

required, performing with large instruments may be unfeasible for many artists, but I argue that building a smaller instrument by way of a large instrument is an approach that can result in more unique designs, and can therefore benefit designers of instruments of all sizes.

Having now spent four years designing large instruments including Chaos Bells, I recognise that there is a different type of thinking required when designing large instruments as opposed to small ones. The results of the scoping study (Chapter 3) reveal that large instruments are not just large instruments scaled up, but instead offer different sonic and performative features to their smaller counterparts and can require precise gestural control that is certainly not scaled up. Additionally, for obvious reasons, musical gestures for performing smaller-than-the-performer interfaces do not scale up to adequately control larger-than-the-performer interfaces, as comically demonstrated in the famous oversized piano scene in the film *Big* [111] in which Tom Hanks and Robert Loggia perform *Heart and Soul* by physically jumping from note to note. Therefore designing large gesturally performed instruments calls for different design approaches and solutions than those required for designing small instruments.

In addition to developing my approach to designing desktop instruments by way of larger instruments, this longitudinal large instrument design practice has changed my perspectives within my music performance and composition practice. I now recognise that there is a homogenisation that comes with musicians using the same tools (instruments) that is not conducive to creating work that stands apart from the work of others.

8.4 Future directions in large DMI research and design

There are many more aspects of large instrument design to be explored in the future. The second Chaos Bells study revealed findings related to the responsibility of instrument designers to the bodies of performers, and performers' perceptions of their own bodies. Future large instrument design research could further explore this domain in the context of Accessible Digital Musical Instrument design and collaborative design with disabled musicians and musicians with access needs.

I plan to continue designing and performing large DMIs. Beyond this PhD research my future exploration of large DMIs will likely be practice-based research conducted from my own perspective as an instrument designer, performer and composer. Although I have no firm plans for the next large DMI that I will design, this research has opened up various potential collaborations with venues

that have expressed interest in me designing an instrument to be permanently installed onsite.

More research is required to understand the colonial heritage of the pipe organ and the experiences of its performers. While there is not enough definitive research on the topic, current data indicates that bellows performers were underpaid if paid at all [159]. This could be an interesting future research topic for a musicologist or organologist.

8.5 Concluding remarks

Starting from the critical observation around the miniaturisation of musical instruments, this research set out to envision an alternate scenario where DMIs are very large, rather than small, and unpack some of the implications of that. In doing so I hope to provide a resource for understanding the design trade-offs in other areas of experience oriented HCI.

While some individual findings of this research suggest the influence of physical design on performers' musical choices, in combination the findings reveal that instrument design cannot be totally deterministic over music creation. Approaching the findings through the lens of entanglement theories of HCI [52] shows that interaction is only a small part of the picture. Due to the recursive connection of the elements that make up musical entanglements, altering one aspect of instrument design (in this case size) impacts many other aspects of music performance including compositional choices as well as issues of identity and social relationships.

This research illustrates that musical entanglements emerge from a combination of factors including performers' bodies, personal identities, skills, experiences, cultural contexts, social relationships and aesthetics. The underlying argument of entanglement theories is that none of these factors exist independently from one another: humans, things (in this case a large DMI) and cultural systems co-constitute one another in practice [52]. Therefore agency in music performance cannot be neatly assigned on its own, it too emerges from the web of relationships between these factors. None of these factors can be individually separated from the musical entanglement. The point of this thesis is not to do that but to embrace their interconnectedness. With that in mind, I chose to focus in one particular area which relates to many things at the same time: size. This research reveals that size is not just a simple question of usability, it has recursive implications throughout the network of interrelated factors that make up musical entanglements. In this era when companies miniaturize synthesizers and drum machines to cater for the bedroom electronic music producer, there are no digital musical instruments on the market that are as large as Chaos

Bells. By elucidating the roles of size in musical entanglements this research identifies that the commercial DMI industry’s focus on small instruments and interactions has created an overlooked opportunity in DMI design and as a result we are missing out on possible music and performances.

An important factor of this research is that I myself am entangled in the complex web of relationships that makes up this research. As a multidisciplinary artist-researcher, I have approached this research as an electronic engineer, computer scientist, instrument designer, live music performer and music producer. Wearing all of these hats has allowed me to explore the extent that size impacts DMI practice inside and outside of the laboratory.

This research began from questioning ways that the commercial unavailability of large DMIs has resulted in an omission in culture of unknown musical experiences that can only be discovered through interaction with large DMIs. This work went on to reveal the unique musical capabilities of large acoustic instruments, leading to a set of design considerations for large DMIs that informed the creation of Chaos Bells. The lab-based studies conducted with Chaos Bells resulted in findings surrounding the role of instrument size in music performance and musical entanglements however due to economic factors it is unlikely that the commercial instrument design companies and the wider music industry would move towards a culture of large DMI design and performance. By taking Chaos Bells outside the laboratory for live performances and interactive demos, I gained a broader understanding of the instrument’s influence on live music performance and culture. I uncovered ways that stakeholders in the music industry, such as venue staff and promoters, may be contributing to the instrument design industry’s fascination with desktop instruments by not recognising the extra work required to perform live concerts with large instruments.

By creating a desktop version of Chaos Bells I inadvertently designed a unique instrument that does not feature the design tropes found in commercial or NIME instruments. This led me to understand that regardless of whether the final goal is a large or small instrument, starting with a goal of designing large can be of value to all instrument designers.

A surprising result of conducting this research is that I have changed the way I think of myself as an artist and composer. When interviewed by 15 Questions earlier this year [123], in response to the question ‘*Can you talk a bit about the relationship between the tools of creation and the music we make?*’ I said:

‘I used to think of myself as a composer who would use an instrument as a tool to compose music with, and regardless of which instrument I composed with I thought that I had full agency over the composition, as if the instrument is just a vehicle for realising my composition.’

But now that I build instruments I have come to realise that music making is an entangled interaction between a performer, an instrument, and the environment which includes socio-cultural contexts, and changing any element in the entanglement results in changing the music, as well as what kind of musician or composer I am. This is a school of thought known as entanglement theory. And through this lens I've come to realise that an instrument is not actually an instrument unless it is being performed. And I'm not a musician at all until I'm performing. And when I perform, the musician I am is being created in the moment.'

Before this research most of my artistic output was focused on releasing albums and touring music that I performed with desktop commercially available instruments such as drum machines and samplers. However through this PhD research I have come to understand the role that instruments play in musical entanglements, and I no longer want to play the instruments designed by the commercial instrument industry. I instead want to continue exploring the instruments they *do not* offer, including large instruments, despite their inconveniences

While this research conducted with Chaos Bells both in and outside the laboratory indicates that there are missed opportunities of musical entanglements due to the commercial industry's fascination with small instruments, as an instrument designer and performer, I choose to '*go large*', and I recommend to others working in HCI research and music performance to explore the potentials of including large DMIs in your research and practice.

Appendix A

Scoping Study interview questions

During the Scoping Study (Chapter 3), the investigator asked each participant the following questions:

- Which techniques or patterns require you to move the most?
- Which techniques or patterns require you to move the least, or require microscopic precision?
- How long can you perform the instrument before you are too tired to continue?
- What causes the fatigue?
- How do you think the instrument influences the music you make when improvising?
- Would you improvise in the same way on a different instrument?
- What is an example of well written music for your instrument?
- How would it change if you performed it an octave higher or on another instrument?

Appendix B

Scoping Study thematic analysis codebook

The thematic analysis conducted in the Scoping Study (Chapter 3) resulted in 310 coded segments clustered into the following codes:

- Impact of size, weight or fatigue of large instruments on performers (90 coded segments)
 - Which technique or passage makes the performer move the most
 - Fatigue
 - Weight
 - Strength required to perform large instrument
 - Size
- Timbral variation across registers in large instruments (40 coded segments)
 - Choosing difficult technique for the sonic gratification
 - Effects of variation across registers on repertoire and arrangements
 - Effects of playing in different registers on idiomaticity
 - Influence of timbral variation on repertoire
 - Instrument is designed to have a strong bottom register
- Micro scale within macro scale of large instruments (12 coded segments)
 - Microscopic design that has a large effect
 - Microscopic gestures that have a large effect
- Improvising or composing with large instruments (28 coded segments)

- The feel of the instrument changes how I improvise
 - What the performer does not play when improvising
- What is idiomatic, easy, natural to perform with large instruments (33 coded segments)
 - Idiomatic techniques
 - Performance of idiomatic music
 - Composition relating to idiomaticity
 - What is easy to play with the large instrument
 - What makes music idiomatic for this instrument
- Unidiomatic, difficult or unnatural to perform with large instruments (32 coded segments)
 - What is difficult to play
 - What makes a composition unidiomatic
 - Examples of unidiomatic compositions
 - Performances of unidiomatic compositions
 - What is more difficult to play than it seems
- Virtuoso or impressive compositions for large instruments (22 coded segments)
 - Video of virtuosic composition
 - Examples of virtuosic or impressive writing
 - What makes a composition virtuosic for this large instrument
- Performing a different instrument's repertoire with large instruments (22 coded segments)
 - Performing repertoire intended for a different instrument is possible
 - Performing repertoire intended for a different instrument is not possible

Appendix C

Study 1 participant pre-selection questionnaire

To recruit participants for Study 1 (Chapter 5), musicians interested in joining the study were asked the following questions via an online questionnaire form hosted by `google.com`:

- Which of the following day/s would you be available for one hour?
 - 25th of January
 - 26th of January
 - 27th of January
- Tick any of the below instruments that you can play:
 - Keyboard instruments
 - String instruments performed with the hands
 - String instruments performed with a bow
 - Percussion instruments performed with the hands
 - Percussion instruments performed with mallets or sticks
 - Woodwind instruments
 - Brass instruments
 - Voice
 - Bespoke or 1-off instruments
 - Monophonic instruments
 - Polyphonic instruments

- Other
- Tick any of the following that describe you:
 - Musician
 - Composer
 - Instrument performer
 - I perform live concerts or have in the past
 - I have composed music alone
 - I have composed music with others
 - I have released music that I have composed
 - I create musical instruments myself
 - I enjoy improvising compositions either alone or in a concert environment
- Tick any of the below musical styles that you play:
 - Jazz
 - Electronic
 - New music, neo-classical or improvisation
 - Rock, pop, metal or popular
 - Classical western
 - Classical non-western
 - Other

Appendix D

Study 1 interview questions

During Study 1 (Chapter 5) sessions the participants responded to three creative prompts, each followed by a semi-structured interview.

D.1 Creative Prompt 1 interview questions

- Can you talk me through how you imagined this improvised performance to sound like? What sounds did you imagine the instrument making?
- Can you tell me about the pitch space. Did you imagine the pitches each gesture created? Were the pitches arranged according to an order or pattern?

D.2 Creative Prompt 2 interview questions

- Can you talk me through how you imagined this improvised performance to sound like? What sounds did you imagine the instrument making?
- Can you tell me about the pitch space. Did you imagine the pitches each gesture created? Were the pitches arranged according to an order or pattern?

D.3 Creative Prompt 3 interview questions

- What is your age?
- What is your gender and what are your pronouns?
- What are your pronouns?

- What is your primary instrument?
- For how many years did you receive lessons on that instrument?
- Regardless of training, how many years have you been performing instruments?
- What other instruments do you play?
- What is your primary style or genre?
- What other styles or genres do you play?
- Do you play solo or in ensembles, and if you play in ensembles which groups do you play in?
- How does this instrument compare to other instruments that you have played?

Appendix E

Study 2 interview questions

E.1 Session 1 Interview Questions

During Study 2 (Chapter 6) Session 1, the investigator asked the participant the following questions:

- You just performed the instrument twice. Was it the same composition that you performed both times?
- Does this composition fulfil what you had been planning to fulfil when I gave you the creative prompt?
- Was this composition an idea you had prior to this session or did you come up with it during the session?
- Did you make any mistakes while performing the sketch, and if so why?
- What kind of gestures did you discover when playing with this instrument?
- What kind of gestures did you like or enjoy to perform?
- What kind of gestures did you decide to include in this sketch?
- Was there a tempo to what you were playing? And is the intention for it to be metronomically in time?
- How did you choose how fast or slow to play this sketch?
- Can you walk me through how you composed this sketch?
- Was there anything unexpected that happened with the instrument?
- Did that make it into the sketch?

- How does this sketch explore the dynamic use of registers?
- Which parts of this composition are your favourite?
- Which parts of this composition are your least favourite?
- Does this composition represent what you were intending to create during this session? If not how did it differ?
- Does this composition represent yourself musically, in that you would be happy to perform it at a public or live-streamed concert? If not, why not?
- If there was something you could change about this instrument what would it be?
- If you had to name this instrument what would you call it?

For the purpose of creating the participants statistical data (shown in Table 5.1) the participants were asked the following questions and reminded that answering them was optional:

- What is your age?
- What is your height?
- What is your gender and what are your pronouns?
- What is your primary instrument?
- For how many years did you receive lessons on that instrument?
- Regardless of training, how many years have you been performing instruments?
- What other instruments do you play?
- What is your primary style or genre?
- What other styles or genres do you play?
- Do you play solo or in ensembles, and if you play in ensembles which groups do you play in?
- How does this instrument compare to other instruments that you have played?
- Was there something you were trying to do with the instrument that you could not achieve?
- Is there anything else you want to tell me about your experience with the instrument this week?

E.2 Session 2 Interview Questions

During Study 2 Session 2, the investigator asks the participant the following questions:

- You just performed the instrument twice. Was it the same composition that you performed both times?
- Does this composition fulfil what you had been planning to fulfil when I gave you the creative prompt?
- Did you make any mistakes while performing the sketch, and if so why?
- Now that you have had more time with the instrument what kind of gestures did you discover?
- What kind of gestures did you like playing with this instrument?
- What kind of gestures did you decide to include in the sketch?
- Was there anything unexpected that happened with the instrument this week?
- Did that make it into the sketch?
- Was there something new that you tried on the instrument this week?
- Did it make it into the sketch?
- Was there something you did not want to do anymore on the instrument?
- Which parts of this sketch are your favourite?
- Which parts of this sketch are your least favourite?
- Can you walk me through how you composed this sketch?
- Does this sketch represent what you were intending to create during this session? If not how did it differ?
- Does this sketch represent yourself musically, in that you would be happy to perform it at a public or live-streamed concert? If not, why not?
- If there was something you could change about this instrument what would it be?
- Was this composition an idea you had prior to this session or did you come up with it during the session?

- Would you have come up with this compositional idea if you were playing a different instrument?
- How does this sketch explore rhythm?
- Have you composed a composition that sounds like this before?
- Does the sketch have a tempo? And is the intention for it to be metronomically in time?
- How did you choose how fast or slow to play this sketch?
- Was there something you were trying to do with the instrument that you could not achieve?
- Does the fact that all the pendulums look the same make it difficult for you to remember where the tones are located?
- Is there anything else you want to tell me about your experience with the instrument this week?

E.3 Session 3 Interview Questions

During Study 2 Session 3, the investigator asks the participant the following questions:

- Earlier you performed the instrument twice in response to the creative prompt related to texture. Was it the same composition that you performed both times?
- Did that sketch fulfil what you had been planning to do when I gave you the creative prompt?
- Was the idea for that sketch an idea you had prior to this session or did you come up with it during the session?
- Later in the session you performed the instrument twice in response to the creative prompt of composing a performance for the concert. Was it the same composition that you performed both times?
- Did that composition fulfil what you had been planning to do when I gave you the creative prompt?
- Was the idea for the concert performance an idea you had prior to this session or did you come up with it during the session?

- Which parts of each sketch (if any) did you include in your concert performance?
- Now that you have had more time with the instrument what kind of gestures did you discover?
- Was there anything unexpected that happened with the instrument this week?
- Did that make it into any of the compositions?
- What kind of gestures did you like?
- What kind of gestures did you decide to include in the texture sketch?
- What kind of gestures did you decide to include in the concert performance?
- What is your favourite part of the texture sketch?
- What is your least favourite part of the texture sketch?
- What is your favourite part of the texture concert performance?
- What is your least favourite part of the concert performance?
- Did you make any mistakes in the texture sketch, and if so why?
- Did you make any mistakes in the concert performance, and if so why?
- Was there something new that you tried on the instrument this week?
- Did it make it into either composition?
- What kinds of performance gestures do you like playing with the instrument this week?
- Was there something you did not want to do anymore with the instrument?
- Does this composition represent yourself musically, in that you would be happy to perform it at a public or live-streamed concert? If not, why not?
- Can you walk me through your process of how you composed the texture sketch?
- Can you walk me through your process of how you composed the concert performance?
- Was there something you were trying to do with the instrument that you could not achieve?

- Tell me about how you decided about the textural material of your texture sketch?
- Does the sketch have a tempo? And is the intention for it to be metronomically in time?
- Does the concert performance have a tempo? And is the intention for it to be metronomically in time?
- How did you choose how fast or slow to play the texture sketch?
- How did you choose how fast or slow to play the concert performance?
- What aspects of this instrument do you find predictable or unpredictable? How did that influence your sketches and concert performance?
- How does this instrument make you feel?
- Is there anything else you want to tell me about your experience with the instrument this week?

E.4 Session 4 interview questions after performing the smaller version of Chaos Bells

During Study 2 Session 4, the investigator asks the participant the following questions after they performed their concert composition twice with the smaller version of Chaos Bells:

- You just performed your concert composition twice with the smaller version of the instrument. Was it the same composition that you performed both times?
- When you play the concert performance with this smaller version of the instrument do you feel like it's the same composition as when you played it during Session 3?
- When I told you to play your composition with the small instrument, do you feel like you have achieved what you set out to do?
- How did you find performing your concert performance with this smaller version of the instrument?
- When you play the concert performance with the smaller instrument, does the resulting performance represent yourself musically in that you would be happy to use it for a live performance?

- Did you use any new gestures for playing the smaller version that you weren't using when playing this composition with the larger version? If so which gestures and why?
- Which version, the larger or smaller, requires the most precision to play?
- Which version, the larger or smaller, requires the most strength to play?
- Which version, the larger or smaller, requires the most mental concentration to play?
- Previously you have told me what your favorite parts of this concert performance are. Can you tell me when you playing with the smaller instrument what is your favorite part of the composition?
- Previously you have told me what your least favorite parts of this concert performance are. Can you tell me when you playing with the smaller instrument what is your least favorite part of the composition?
- Was there something that you were trying to do with this smaller version of the instrument that you could not achieve?
- Are the larger and smaller versions of the instrument the same instrument? Or are they different instruments?
- Was there something unexpected that happened while you played this smaller version of the instrument?
- What aspects of the smaller version do you find predictable or unpredictable and how did that affect your performance?
- Is there anything else you want to tell me about your experience of playing this smaller version of the instrument?

E.5 Session 4 interview questions after performing the larger version of Chaos Bells

During Study 2 Session 4, the investigator asks the participant the following questions after they returned to the larger version of Chaos Bells and performed their concert composition two final times:

- You just performed your concert performance twice with the larger version of the instrument. Was it the same composition that you performed both times?

- When I told you to perform the concert composition with the larger version of the instrument, do you feel like you have achieved what you set out to do?
- When you played the composition with the larger version of the instrument this session did feel like it is the same composition as when you played it during Session 3?
- With which version of the instrument do you prefer playing your concert performance?
- Finish this sentence '*The larger instrument makes me feel...*'
- Finish this sentence '*The smaller instrument makes me feel...*'
- How does your body feel playing the large instrument compared to the smaller instrument?
- If I invited you to perform a concert and you could choose between playing the larger or the smaller version of the instrument at the concert, what version would you choose?
- What about if it was a recording session and no-one could see which version you were playing?
- Can you compare playing the larger and smaller instrument in terms of how your body felt?
- When you returned to the larger version after playing the smaller version did you play it differently compared to how you played it in previous sessions?
- Now that you have come back to playing the larger instrument after the smaller instrument, did you try any new gestures when performing the larger version? Or did you just play it exactly how you were playing it previously?
- Did performing one of the instrument give you ideas for what you would like to do with the other?
- Do you choose for the online concert the video of you performing the smaller instrument or the larger instrument video? How did you make that choice?
- Did performing one instrument give you ideas that you wanted to try on the other instrument?

- Is there anything else you want to tell me about your experience of performing this larger version this week?

Appendix F

Study 2 thematic analysis codebook

The thematic analysis conducted in Study 2a (Chapter 6) resulted in 1338 coded segments. The codebook was subsequently updated in Study 2b (Chapter 7) to result the final version shown here that comprises 1669 coded segments.

- Gestures and techniques (126 coded segments)
 - Performance patterns
 - * Neighbouring pendulums alternating or simultaneously
 - * Pendulums above or below one another
 - Performing drones with leg
 - Muscle memory
 - Techniques that require more practice
 - Instrument size and gesture
 - Gestures that feel good
 - Ancillary gestures
- Effort (38 coded segments)
 - Choosing pendulums that can be reached in time
 - Performing with mallets to add arm span
 - Gestures that require effort
 - Developing a new gesture because it requires less effort
- Entanglement (41 coded segments)

- I work with the unpredictability of the instrument
 - The instrument makes me feel powerful
- Characteristics of the compositions (433 coded segments)
 - Elements of Western music
 - * Texture
 - * Form
 - * Rhythm
 - * Dynamics
 - * Melody
 - * Harmony
 - * Tone Colour
 - Aimed for clean tones
 - Intended to create tonal music
 - Did not have a plan for the performance at the start of the session
 - Primary instrument influenced the performance
 - The physical layout influenced the performance
 - Mistakes
 - Genre
- Reflections on the instrument (477 coded segments)
 - Enjoyed playing drones
 - Mallets should be longer
 - Comments on how sensitive the instrument is
 - The bass suits the physicality of the instrument
 - This instrument is not similar to any instruments I play
 - Enjoys hearing multiple drones at once
 - I like that the instrument can create textural tones
 - What makes the instrument fun
 - Wanting haptic vibration feedback
 - Comparing the instrument to a string instrument
 - Size and perception of the instrument
 - Timbral variation across registers
 - Easiness and difficulty

- Unpredictability
- ‘*Performing perception*’ (awareness of the audience) [40] (9 coded segments)
 - Examples of performing perception
 - Imagined instruments consider the spectator/audience
 - Considering the spectator when performing
- Bodily conceptions (53 coded segments)
 - Avoiding certain techniques because less comfortable
 - It feels nice to play a large instrument
 - The instrument feels like gym equipment
 - Tilting the upper tier pendulum/s is tiring
 - Getting into flow state was weird because I’m standing
 - Remembering the performance through body movement
- Movement (74 coded segments)
 - I like the way my body moves playing the instrument
 - The instrument is physical to play
 - The way the instrument controls movement of the body
 - Static performance
 - It feels good to move around the instrument
- Learning the instrument over time (404 coded segments)
 - Remembering the performance by the starting tone
 - Session 1
 - * New gestures
 - * Something considered but did not try this session
 - * I did not add new gestures this session
 - * What gestures I liked this session
 - * Something I did not want to do with the instrument
 - Session 2 gestures
 - * New gestures
 - * Something I considered but did not try this session
 - * I did not add new gestures this session

- * What gestures I liked this session
- * Something I did not want to do with the instrument
- * The composition was more advanced this session
- * Aiming for more tactile gestures
- Session 3 gestures
 - * New gestures
 - * Something I considered but did not try this session
 - * I did not add new gestures this session
 - * What gestures I liked this session
 - * Something I did not want to do with the instrument
- Session 4 gestures
 - * New gestures
 - * Something I considered but did not try this session
 - * I did not add new gestures this session
 - * What gestures I liked this session
 - * Something I did not want to do with the instrument
- ‘*Edge-like interactions*’ (exploratory performance interactions at the boundary between stability and instability) [131] (38 coded segments)
 - I am drawn to the ‘*edge-like interactions*’
 - Finding the ‘*sweet-spot*’ in the drone

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