The BazerBow: A Multimodal Exploration of Mimetic Design Principles

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The BazerBow:
A Multimodal Exploration of
Mimetic Design Principles

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Declaration of Authorship

I, Philip Robert Wigham, declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed:

Philip Robert Wigham

Date:

15th June 2022

‘*Praise him with the timbrel and dance: praise him with stringed instruments and organs.’*

(Psalm, 150:4)

Abstract

The BazerBow was forged from mimetic design principles to engage the audience, often overlooked in digital musical instrument design. This thesis represents a line of enquiry to develop a set of mimetic design principles through a process of music practice and research. These principles pull from five prongs of a cycle of development: mimetic theories (Cox, 2016; Maes et al., 2014; Malloch and Trevarthen, 2009; Szalavitz and Perry, 2010), digital musical instrument design, mimetic design, prototyping of BazerBows and an examination of the prototypes. Mimetic theories were amalgamated with existing digital musical instrument design research to yield initial mimetic design principles. BazerBow prototypes were produced using these principles and then explored and tested to evaluate and improve the efficacy of the mimetic design. The test phase consisted of five performance sessions that included unique real-time response sliders, questionnaires, and post-performance discussions. The data analysis, including a novel Average Distribution Method, showed that the BazerBow prototype was imbued with mimetic potential eliciting a more significant mimetic response from the audience than a commercially available keyboard. The outcome of this thesis is a collection of mimetic design principles that offer a formative toolkit in guiding instrument design towards carefully considering audience response. In addition, the novel real-time slider method and ADM analysis could be easily adapted for use in other research contexts. Significantly, there has been no previous application of mimetic theories to DMI design or creation of design principles based on mimetic theory, so this constitutes new knowledge, contributing to existing digital musical instrument design. These mimetic design principles will be continually improved and tested in the future through this iterative process, imbuing new and exciting instruments with mimetic potential.

Acknowledgements

Thank you to Dr. Jason Woolley and Carola Boehm for starting me on this journey. In particular, I would like to thank Carola for the opportunity and giving me the confidence to take on this project, and for the continued support to complete this thesis. It is very much appreciated. Thank you to my supervisors Dr. Ben Challis, for the continual encouragement, and Dr. José Dias for keeping me musical. Also thank you to Kirsty Fairclough for standing in at the last minute as a supervisor. Thank you to all the participants in this research, in particular Tim and Chris who arranged testing sessions and participants. Finally thank you to my family.

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All digital assets can be found at this website: https://research.bazerbow.uk

If necessary, the following login details can be used to access the website.

Username: **access**   Password: **H78Gbe-YgB53**

Dedicated to Jeffery Georgeson

Chapter 1

Introduction

1.1 Mimetic Design Principles

Figure 1.1: Prototype 1B - Used in the Test Phase

This PhD investigates the effectiveness of mimetic design principles by using existing theories (Cox, 2016; Maes et al., 2014; Malloch and Trevarthen, 2009; Szalavitz and Perry, 2010) to define mimetic design processes. Prototype developments exemplify these principles and provide devices for examination through multimodal testing (Figure 1.1). Although the conception of these mimetic design principles is potentially unique, the prototypes' technology and manufacture are not entirely novel. The mimetic design principles provide the primary new knowledge pulled by critical and theoretical research. However, the prototypical developments were crucial to the research providing proof-of-concept and enabling examination of the design principles through practitioner experience and participant testing. Chapter 6 discusses this prototyping in more detail.

After a positive response to prototypes, developed as part of my M.A., I formulated initial mimetic design principles from existing mimetic theories (Cox, 2016; Maes et al., 2014; Malloch and Trevarthen, 2009; Szalavitz and Perry, 2010) to provide a basis for future design. I felt that these mimetic design principles needed to be developed, examined and tested to see if they explain the mimetic potential of the instruments and the mimetic response of an audience and therefore be used effectively in future design.

To address this enquiry, I uncovered three main areas and devised questions to facilitate the comparison of the first mimetic BazerBow prototype and the MIDI keyboard. These suppositions are as follows: an instrument with more significant mimetic potential will generate:

1. greater engagement and involvement;
2. greater invitation to “have a go”;
3. provoke a greater inclusive desire to “join in”.

These attributes should be found in the performer and, more importantly to this research, in the audience. The theories look to explain mimetic response, and therefore the testing phase focussed on audience response to establish an answer to these questions.

This research shows conclusively that the audience response to the mimetic prototype showed greater involvement, invitation and inclusion, predicted by the mimetic evaluation of the devices. This research provides confidence in further developing and using mimetic design principles to produce mimetic instruments in the future.

1.2 My Practice

My music practice and research conjoined shortly after my efforts to devise electronic music performances with MIDI controller keyboard, guitar and laptop. My dissatisfaction with my existing equipment and setup started a journey to find an instrument with which I could perform electronic music whilst engaging and connecting with the audience.

This dissatisfaction led me to design a bespoke instrument. I aimed to combine the functionality of control found in the keyboard with the gestural movement and mobility of the guitar. I believed that this would allow me the playability and control over synthetic sounds yet generate a more visible and potentially more engaging performance than when I sat playing the keyboard with small control movements.

This enquiry began to pull the understanding of the design process, and although the concepts were not initially explicit, the ideas of mimetic participation were already being considered, albeit intuitively. I was intrigued by the popularity of the electric guitar amongst non-musicians, exhibited by the success of Guitar Hero (Arsenault, 2008) and the phenomenon of air guitar, evidenced by the air guitar world championships (AGWC, 2021). Other instruments do not seem to have the same effect on an audience.

As a drummer, I find the dominance of air guitar fascinating. Although imitations of other instruments such as drums sometimes manifest, they are not as ubiquitous as “air” guitar. During my M.A., researching areas that could illuminate a design process to achieve my aims, I came across a book chapter by Cox (2006) where he suggests his concept of mimetic participation may explain the air guitar phenomenon. His work, of course, piqued my interest, and I began to follow Cox’s work in developing my mimetic design principles.

1.3 The Research

This thesis’s new knowledge of mimetic design principles emerged from developing prototypes and engaging with Cox’s (2016) ‘mimetic cognition’, which underpins the theoretical and critical theories. His research describes a mechanism for how we perceive music and, although not often implemented in digital musical instrument design, is relevant in creating involving, inviting, and inclusive instruments.

Cox (ibid.) splits mimetic cognition into three consecutive mimetic processes, namely engagement, invitation and participation. These three processes are connected with action understanding (Maes et al., 2014), communicative musicality (Malloch and Trevarthen, 2009) and empathy (Szalavitz and Perry, 2010), respectively. My aim is that mimetic cognition can be further illuminated and understood by these three research areas.

This thesis proposes design principles that leverage these mimetic theories with the expectation of creating new digital instruments that are involving, inviting and inclusive. I do not present these mimetic design principles as a universal and complete set of requirements for new Digital Musical Instruments (DMIs) but to be complementary to existing design practices.

1.4 Thesis Structure

Introduction

This thesis aims to balance the input of performer and musician with that of designer and researcher and as such presents the work from two perspectives: that of the music practitioner and that of the researcher. Due to this symbiotic relationship the work moves between narrative perspectives where appropriate.

Conceptual Framework | *Design Methodology*

This chapter looks at the line of enquiry in more detail and breaks it down into sub-questions which were then tested and answered. The methodology of this research is presented including a discussion of practice-as-research as a framework and the interdisciplinary nature of this work. The cycle of development shows the working model for this project with an updated version showing how this model has changed over the course of the research, reflecting the evolving working methods and response to the research and external factors.

Critical Literature | *Mimetic Theories*

The critical literature that informs this research is presented here. The main text is Cox's (2016) theory of mimetic cognition. This is supported by three separate but complementary areas: action understanding (Maes et al., 2014), communicative musicality (Malloch and Trevarthen, 2009) and empathy (Szalavitz and Perry, 2010).

Contextual Framework | *Digital Music Instrument Design*

The research is discussed in relation to the wider areas involved in digital instrument design, including classification and evaluation with a potential classification based on mimetic theory postulated. The research areas of gesture, affordance and appropriation, relevant to my practice, are discussed. Some of the issues of DMI design are also presented in the context of these research areas and mimetic design.

Concepts Devised for this Research | *Mimetic Design*

The concept of the three I's (involvement, invitation and inclusion) is introduced and discussed. The three I's provides a link between the author's perceived issues of current DMI design and mimetic design principles. These design principles were developed as part of this research and are the central focus of the work. Three main mimetic design concepts are discussed and how these might apply in practice, namely mimetic gestures; mimetic affordances and mimetic appropriation.

Design Narrative | *Prototyping of BazerBows*

Although the first two prototypes were produced prior to the PhD, the design narrative of this prototyping has been included. The two prototypes are discussed and their mimetic potential examined in the context of mimetic design principles. A planned but uncompleted third prototype is presented to give an insight into how the evaluation of mimetic potential of the previous prototypes has effected the deign process. Although the third prototype is not yet complete there have been many prototypical elements developed towards producing this instrument. This third device represents the future direction of the work.

Test Phase | *Examination of Prototypes*

This chapter discusses the testing methodologies used to examine the BazerBow prototypes. The music performance created for the test phases is discussed, as well as a pre-test phase which provided an evaluation of potential testing processes. Finally, the improved testing methods, for the main test phase, are presented.

Data | *Data Analysis and Evidences*

This chapter presents the collected data from the test sessions. Some of this data is presented on this website: https://research.bazerbow.uk which includes Ableton Live session files, (containing real-time audience response data), the Antconc word cloud data files, video recordings from the pre-test session, and the main test 3 session. This chapter also presents an in-depth analysis of the data from the test sessions.

Conclusions

The data analysis is discussed in relation to the lines of enquiry and conclusions of the research are given, followed by a reiteration of the research questions with answers. Finally, the mimetic design principles are presented.

Appendices and Digital Assets

The appendices contain the various charts and information used in the data analysis. Appendix O presents published papers about the BazerBow, mimetic design and the real-time slider data method. There is also a range of digital assets that can be viewed at this website: https://research.bazerbow.uk/

Chapter 2

Conceptual Framework | *Design Methodology*

2.1 Line of Enquiry

The central focus of this research is the development of mimetic design principles to produce mimetic instruments. I designed a cycle of development to help improve and advance these principles through a four-pronged process (Figure 2.1). As can be seen, the research into mimetic theories informed the design considerations, which influenced the development of the prototypes, which could then be tested and evaluated, completing the cycle by feeding back into the research process.

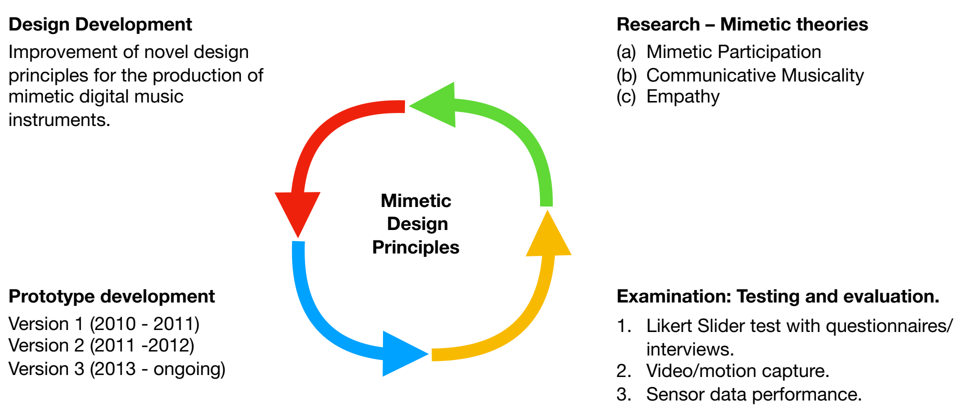

Figure 2.1: Cycle of Development — 2015

Figure 2.2: Cycle of Development — Current

However, this development cycle has evolved, becoming less cyclical and more complex, in response to additional areas of influence. Rather than a circular motion in one direction, the work is now following are more erratic movement backwards and forwards between the different prongs of influence whilst directly and indirectly inputting into the mimetic design principles. These mimetic design principles are exemplified in the prototype work, (Figure 2.2).

I used the initial development cycle during the creation of the first two prototypes, which I produced without much interruption to the prototyping process. I planned to create and duplicate the third prototype for broader use in the community. However, the more significant concerns of manufacturing processes for producing multiple quantities and better reliability caused many interruptions and diversions. This process has proven much more complex and convoluted than the previous two prototypes. Despite these issues and a third prototype not yet entirely produced, many prototypical developments have furthered the mimetic design principles.

This design narrative is discussed in more detail in chapter 6. The following chapters discuss each of the stages of this modified cycle of development in greater detail.

2.2 Practice-as-research

This research was born out of my work as a musical instrument designer. I am intrigued by the relationship between audience and performer, which has become central to my practice. I discovered music early and began performing on drum-kit as a teenager. I became aware of a dialogical relationship between the audience and performer during this time. For example, slight changes in drum rhythm would affect how the audience would move and respond to the music. This response would affect how I played, again affecting the audience's reaction. I realised that this relationship was crucial to my performance and has become a prominent contributing factor in how I devise and develop music performances.

After graduating in music, I began writing and producing electronic compositions. In 2003 I met a dancer, and we began to create electronic music together. We developed this music into a performance concept where we started to think about how those electronic compositions might be performed and compliment the dance performance. Examples of these compositions can be found here: https://research.bazerbow.uk/#music

I began devising the musical performance on a MIDI keyboard since I used it for creating and recording most of the music. In addition, I was comfortable with the keyboard, having played the piano since I was eight. I also began to look at incorporating electric guitar. I am a self-taught guitarist, playing the guitar on my recordings, so although not very accomplished, I had several years of experience when I began to develop this performance.

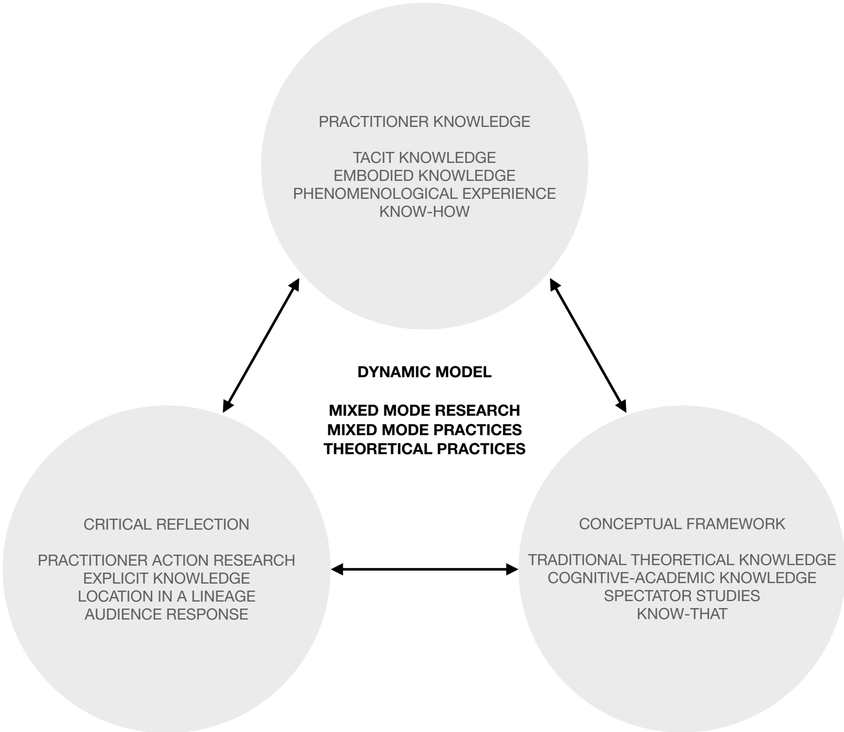

Figure 2.3: Dynamic Model of Practice-as-research (Nelson, 2006)

This process left me unsatisfied with both keyboard and guitar, and I began to think about how I might combine my favourite aspects and features of these two instruments. This work started outside of a research context, but as I began the research process during my M.A. I realised the importance of a research framework for better understanding my practice and improving and developing a framework for creating this desired instrument.

This research follows a Practice-as-research model as shown in Nelson's (2006) diagram (Figure 2.3). Practitioner inspiration sometimes requires a move or jump to the necessary area of work. It can be challenging to balance these intuitive decisions with the more traditional research methods. However, this research relies on this 'tacit' practitioner knowledge to guide and sometimes lead the line of enquiry. However, this research aimed to ensure that these intuitive concepts were thoroughly examined and integrated into the more traditional research knowledge and testing methods. The three areas of Nelson's (ibid.) dynamic model of practice-as-research can be related to the cycle of development (Figure 2.2). The critical literature, contextual framework and mimetic design considerations inform the development of mimetic design principles, and provide the "know-that" knowledge within the conceptual framework for developing and evaluating the design principles. The 'Practitioner Knowledge' is present in the making and playing of the prototypes. As a musician, performer and maker, this 'tacit' 'know-how' directs and intuitively inspires decisions. However, it is necessary to critically reflect on these intuitions providing feedback into the research and developing the process for further development. In addition to my performer insights, the test phase provides a way to explore and examine the prototypes with participants, which is especially important as audience response is central to this conceptual framework.

2.3 Interdisciplinary Nature of this Research

This research required me to wear several practitioner hats: performer, musician, designer, music technologist, maker and audience member. These multiple disciplines were necessary for the various stages of research and have added to the complexity of the practice-as-research nature of the cycle of development. This work also involves several research disciplines and testing methods. It looks at traditional areas of Digital Musical Instrument (DMI) design theory but pulls on research into music cognition, psychology, empathy, and mirror neurons. These areas are drawn together to provide meaning to the intuitive thought processes and decisions made during the development of mimetic design principles and the consequential prototypes. These practices and disciplines, when combined, have created further understanding in addition to the individual subjects. This research can therefore be considered as interdisciplinary (Boehm, 2008).

2.4 Questions Arising from the Cycle of Development

Questions were asked at each prong of the cycle of development to illuminate and probe the concept of mimetic design principles.

Mimetic Theories

The mimetic theories are based on Cox's (2016) 'mimetic cognition', the development of his 'mimetic hypothesis' (Cox, 2011).

- Could further theories be found to help understand the processes of mimetic cognition facilitating mimetic design?
  (Section 3.5).

DMI Design

Established DMI design theories and common issues encountered are explored.

- Which existing general DMI concepts are important to mimetic instrument design and what are the common issues that DMI designers attempt to address?
  (Section 4.5).

Mimetic Design

The mimetic design aims to incorporate a balanced mix of mimetic and established DMI theories into practical design considerations.

- Which design considerations are most important to mimetic design?
  (Section 5.3).

Prototyping of BazerBows

The practitioner/designer/maker initially evaluates the prototype developments based on the research and mimetic design considerations.

- Do these prototypes incorporate the intended concepts of mimetic design, and how can they be further improved?
  (Section 6.4).

Examination of Prototypes

A participant testing phase provided an evaluation of audience response by presenting the BazerBow and a MIDI keyboard for comparison.

- Does the BazerBow possess mimetic potential and therefore provoke a mimetic response from an audience?
  (Section 8.7.4).

These questions build up a body of evidence that examines the research and practice of mimetic design principles for producing mimetic instruments.

Chapter 3

Critical Literature | *Mimetic Theories*

This chapter presents critical literature, which I refer to collectively as mimetic theories. In my search for mimetic theories that could be introduced into instrument design, I endeavoured to improve audience involvement, invitation and inclusion in digital music performance. I discuss the ideas that I consider essential in mimetic design and how decisions in the design process influenced by these theories could lead to DMIs that involve, invite and include people in the world of digital performance. I must emphasise that the connections made to mimetic cognition are my own. Therefore there is some subjectivity, but this does not present a problem as the aim of “mimetic theories” was to find inspiration not hard evidence.

Designing involving inviting and inclusive digital music instruments may require implementing theories not yet fully explored for instrument design. In an interview Girard (2011:238), states that:

> All scientists know that many scientific innovations consist in importing into a neighbouring area something which has been invented elsewhere, something which has not only worked and produced things but suddenly illuminated a problem that until then was totally obscure.

The ‘importing’ of a ‘neighbouring area’ is important to this thesis. One of the neighbouring areas in my research comes from Cox’s (2016) concept of ‘mimetic cognition’. Many areas relate to mimetic cognition, such as cognitive studies, including 4E cognition, emotional contagion, the mirror neuron system (MNS) and other areas of psychology. However, action understanding, communicative musicality, and empathy are the main theories that I have gravitated towards in support of mimetic cognition. These are the main theories that I have taken inspiration from when considering mimetic cognition and mimetic design.

3.1 Mimetic Cognition

Cox's (2016) theory of 'mimetic cognition' discusses how we perceive music performances through covert and overt imitations and how a listener or audience can derive understanding and appreciation from music and therefore become more engaged in a musical performance. Mimetic cognition describes three mimetic stages—engagement, invitation, and participation (ibid.). Applying these concepts to mimetic design, I expect a mimetic instrument to instigate initial engagement, which intrigues and invites the audience to participate. To further understand how I could apply this to instrument design, I have explored the theories of action understanding, communicative musicality and empathy in more detail. I have correlated these three theories with the three stages of mimetic cognition.

Action understanding describes how we interpret movements to perceive the intentions or goal of the actions. This research has a bearing on our apprehension of how musical gestures may be perceived and understood by the observer. Maes *et al.* (2014:8) suggest that recent research indicates that '. . . the human motor system and its actions may actually modulate people's experience, perception, and understanding of sound and music'. Action understanding may help to further grasp the mechanisms of mimetic engagement and how an instrument might engage and involve an audience.

Trevarthen and Malloch's (2009) concept of communicative musicality describes an essential component of imitation learning concerning early learning and development. The musicality of early interactions between baby and mother is crucial in successful cognitive and social development. When present, communicative musicality creates an environment that encourages imitation and learning, inviting the participants to try out the things they observe. The innate response to imitate musically could potentially be used to produce DMIs designed to invoke a mimetic invitation to imitate and "have a go" of the instrument.

Theories of empathy cover a considerable body of work. The area of particular interest relates to how empathy is involved in social connection and interaction. Within a musical context, empathy induces a desire to “join in” providing inclusion (Szalavitz and Perry, 2010). The instinctive nature of imitating helps to explain empathetic responses. Decety and Jackson (2004:93) state that when ‘empathy produces… “physical mimicry” the intentional focus does not remain on the spectator’s body but is projected into the other’. To step into someone’s shoes, we instinctively covertly imitate the person’s body language, facial expressions and other mannerisms to understand how that person is responding and feeling. This process is mostly happening covertly in the subconscious mind. Szalavitz and Perry (2010:17) discuss the ‘social power of imitation’ relating to empathy and its importance in relationships and belonging. Empathy and covert imitation should be considered in DMI design to produce inclusive instruments and cultivate a desire to mimetically participate and join in.

3.2 Mimetic Engagement & Action Understanding

The concepts of action understanding and goal-oriented imitation provide a framework of mimetic engagement that could be leveraged to produce inviting and engaging instruments. To understand this area further, we need to briefly look at the related research into the mirror neuron system. Rizzolatti and Craighero (2004:169) discuss how they believe mirror neurons ‘play a fundamental role in both action understanding and imitation’. The ideomotor framework predicts that goal-oriented imitation will be prioritised over action imitation (Iacoboni, 2009). This prediction has been confirmed by imitation experiments (Bekkering et al., 2000). Having discovered mirror neurons that fire when watching or performing an action, the next question is whether the MNS is involved in understanding the intention or goal of an action. Experimental evidence suggests that the MNS system is concerned with imitating action and can be goal orientated. However, the accuracy of imitating an action may be forfeited in favour of the goal of the action (Iacoboni, 2009). Rizzolatti and Craighero (2004:173) argue that ‘if mirror neurons mediate action understanding, their activity should reflect the meaning of the observed action, not its visual features'.

The experiment of Kohler *et al.* (2002:846) postulated that if the MNS provides action understanding, then a sound related to a given action, such as a peanut being cracked when heard, should activate mirror neurons without any visual stimuli of the action. Kohler *et al.* (ibid.:846) carried out a test where they found that 'neurons in monkey premotor cortex... discharge when the animal performs a specific action and when it hears the related sound'. They infer that these 'audiovisual' mirror neurons 'might shed light on the origin of language' (ibid.:846). Rizzolatti and Craighero (2004:174) suggest that this is proof of action understanding of mirror neurons because their activity reflects 'the meaning of the observed action, not its visual features'. However, Hickok (2009:5) claims that this in and of itself is not evidence of action understanding stating that '...we don't need to endow these cells [mirror neurons] with semantic properties to explain the finding'.

Iacoboni (2009:660) discusses 'strictly congruent' and 'broadly congruent' mirror neurons. One-third of mirror neurons are strictly congruent firing for the same action both enacted and observed. The other two-thirds of broadly congruent mirror neurons fire for 'executed and observed actions that are not the same but either achieve the same goal or are logically related'. Although this may not necessarily be action understanding, it is evident that mirror neurons are involved in a more complex system than purely direct 'strictly congruent' imitation. The MNS is complex, and consequently, imitation can be consciously direct and intentional or subconsciously unintentional (Dijksterhuis, 2005; Iacoboni, 2009; LeDoux, 1996). However, action understanding and goal-oriented imitation manifest in musical imitation where someone might intentionally "air guitar" although it may also be subconscious and involuntary. Cox (2006; 2011) discusses how mimetic participation may also involve conscious (overt) and subconscious (covert) imitation.

Cox (2011:3), in discussing 'mimetic engagement', believes that although mirror neurons 'have yet to be directly observed in humans', they are likely to be 'involved in human comprehension of music'. He also feels that mirror neurons 'may eventually specify, at the level of specific neurons… mimetic behavior of humans when listening to and recalling music', but that 'they would remain only a portion of the evidence' (Cox, 2011). Another aspect of MNS linked to Cox's (ibid.) 'Mimetic Hypothesis' is that of vocalisation, sub-vocalisation and vocal mimicry. Rizzolatti and Arbib (1998) suggest that mirror neurons may explain the evolution of language in the human brain (Iacoboni, 2009). Cox (2011) discusses the importance of 'subvocalization' in the process he describes as mimetic participation and how the voice is influential in how we engage with music performance. He states that 'Mimetic subvocalization includes any motor imagery and motor activation related to the vocal musculature' (ibid.:9). Mirror neurons have been connected with facial motor control and expression, so they are likely linked with vocalisations. As imitation may occur as a covert manifestation, then it also follows that covert mimetic sub-vocalisation may also occur.

The mirror neuron system may bring further insight into the neural processes of mimetic cognition, including action understanding, mimetic participation and mimetic sub-vocalisation. Although direct evidence of this system and its relationship with mimetic comprehension is not crucial, it shows the potential importance of the surrounding research areas of action understanding, mimetic participation and mimetic sub-vocalisation to the successful creation of mimetic instruments.

Cox's (2001:195) mimetic hypothesis presents two core ideas:

> 1) we understand sounds in comparison to sounds we have made ourselves, and that
> 2) this process of comparison involves tacit imitation, or mimetic participation, which in turn draws on the prior embodied experience of sound production.

We begin to build up a knowledge and understanding of the world around us through experience, and it is this knowledge we draw upon to create perceptions of music performance. According to Cox's hypothesis, we use our current understanding of the materials around us and our experience of their acoustic properties to understand the instruments we are listening to or observing. This understanding allows us to predict the instrument's sound when hit, struck, plucked or blown. For example, for a performance on guitar, the audience will build an initial perception of the sound by understanding how the metal might sound when the strings are plucked and how the wood might resonate in response. This perception creates an expectation and imagery that lets the viewer understand and engage further in the playing gestures and sounds created.

This process is similar to action understanding, a more general theory describing how we perceive and determine actions through mental imitation, allowing preparation of the action before physically carrying out the act. Action understanding is beneficial in making new actions or gestures more likely to succeed. It is crucial in survival situations where unknown actions may be necessary to save a life, and there is no time to practise those actions. This mechanism facilitates an efficient learning process. Another benefit is to create a perception and understanding of someone's actions allowing empathy and an insight into the intention of those actions. Mimetic engagement describes this action understanding in terms of musical gestures and instrument performance. Schiavio *et al.* (2017:11) discuss action understanding specifically in relation to the '. . . embodied, goal-directed, and creative nature of musical development'. They explain their concept of 'Teleomusicality' (ibid.:9) in relation to the recent developments in 4E cognition (Newen et al., 2018). Teleomusicality refers to the ability to direct actions towards a musical goal, which is usually developed between 6 and 8 months of age. 'Original teleomusical acts (OTA)' are direct motor actions related to the creation of sound, whilst 'constituted teleomusical acts (CTA)' are a combination of embodied OTAs aimed at a more complex musical goal (Schiavio et al., 2017:7), such as musical expression. These ideas seem to correlate action understanding and mimetic engagement with the concepts of embodiment and 4E cognition (Schiavio et al., 2017:9-11; Ward and Stapleton, 2012). Teleomusicality also seems to complement Iacoboni's (2009:660) ideas of 'strictly congruent' and 'broadly congruent' mirror neurons.

Cox's (2016) hypothesis refers to two types of mimetic behaviour: mimetic motor action (MMA), which is overt observable, physical imitative actions; and mimetic motor imagery (MMI), which is covert imitative, muscle-related, imagery manifesting in the mind and therefore not visible. Music comprehension that involves MMA and MMI is referred to as 'mimetic comprehension' (ibid.:15), whilst 'mimetic participation refers to the 'joining in and taking part' and 'mimetic engagement' as the 'general aspects of merely being engaged with the music'. Cox (2016:15) suggests that 'whenever we are engaged in listening, normally we are mimetically engaged whether we are aware of it or not'.

Cox (ibid.:23) relates MMI to mirror neuron research which looks at how specific 'mirror' neurons are triggered when an action is observed. These mirror neurons can be activated without accompanying observable movements and when the same movement is actioned. Although the MNS explains direct imitations of actions, it also looks to explain goal-orientated imitation, where the ending result of the action is the focus of the imitation. Cox (ibid.:24) believes that this more complicated and layered imitation corresponds to the 'production of individual pitches and rhythms combining to make a phrase, and the combinations of phrases that make larger structures'. With the direct imitation of the actions that produce sounds combined with the goal-orientated imitation of the phrasing and expression of the music layered on top, 'we can expect to find that mimetic engagement is particularly strong' (ibid.:25).

Strong mimetic engagement and involvement in the performance rely on the direct and goal-orientated imitation in music performance, which depends on how the sound is produced and the gestural movements and actions required to generate the sounds. This layered nature occurs within musical gestures. Fully exploiting this 'nested hierarchical structure' (Visi et al., 2014:104)(Leman, 2010) can 'aid the design of expressive musical systems' (Visi et al., 2014:104). In designing a mimetically engaging instrument, the gestural language should incorporate a layered structure of straightforward gestures that can be directly imitated and complex goal-orientated gestures of expression that require more consideration.

Gestures not only provide mimetic engagement and visual clues but are a part of the inter-modal perception of an instrument. There is evidence to suggest that gestures can change the perception of sound in a listener (Schutz and Lipscomb, 2007; McGurk and MacDonald, 1976) (Section 4.4.2). This inter-modality shows how gestures are significant to music perception and the understanding of an instrument. As Visi *et al.* (2014:100) say, 'gestures become a core notion as they act as a bridge between bodily movement and meaning formation'.

Godøy (2003:318) presents a similar hypothesis of music cognition which he calls 'motor-mimetic music cognition'. He suggests that 'we mentally imitate sound-producing actions when we listen attentively to music'. Godøy (ibid.:318) explains the cross-modal perception of music in this way:

> *Motor-mimesis translates from musical sound to visual images by a simulation of sound-producing actions, both of singular sounds and more complex musical phrases and textures, forming motor programs that re-code and help store musical sound in our minds.*

Cox (2016:45) provides more detail of mimetic modalities describing three forms of MMI and MMA:

- Intramodal, or direct-matching (e.g., finger imitation of finger movements)
- Intermodal, or cross-modal (e.g., subvocal imitation of musical sounds generally)
- Amodel (abdominal exertions that underlie limb movements and vocalizations)

Concerning mimetic response, cross or inter-modality refers to a mimetic reaction that is not directly an imitation of a similar gesture. Godøy's (2003) cross-modality refers to music producing visual images or visual images producing sound. For Cox (2016) cross-modality refers to a response that is not a direct imitation, such as tapping the foot in time with the music or using the voice or "sub-vocalisations" to imitate the sounds or music. This "sub-vocalisation" is an essential aspect of Cox's hypothesis. Cox (2001:197) claims that 'we understand human-made musical sounds, whether vocal or instrumental, via covert vocal imitation or subvocalization'. Cox believes this process occurs whether we are fully conscious of singing along or subconsciously "sub-vocalising" as we comprehend music.

There is a large body of works relating to the visual, inter-modal aspect of performance and ancillary gestures (Section 4.4.2). This research suggests that any visual aspect of an instrument, from ancillary gestures to the aesthetics, could affect the audience's perception of the musical performance. Therefore, it is essential to carefully consider the inter-modal properties of the instrument and ancillary gestures in mimetic design.

Mimetic cognition explains how we understand actions relating to music and music performance. It describes how we become mimetically engaged with performance and therefore involved. Mimetic design is specifically aimed at engaging the audience with the instrument and involving them, through the mechanisms of mimetic engagement and action understanding, in the playing of the instrument. Mimetic design should incorporate the ideas of mimetic engagement and action understanding into the gestural design of its instruments so that they not only audibly engage but are visually involving. A balance of direct and multiple layers of gestural expression must be evaluated to initially instigate mimetic engagement whilst providing further audience involvement leading to a mimetic invitation.

3.3 Mimetic Invitation & Communicative Musicality

Communicative musicality (Malloch and Trevarthen, 2009) explains an innate musically imitative ability to learn, which is used throughout our lives to develop cognitively and socially. An instrument with mimetic gestures will instigate the process of mimetic engagement involving the audience in the performance. After becoming fully engaged, a mimetic invitation to imitate, through the process of communicative musicality, will occur.

Brent (2011:433 emphasis added), regarding the role of motor-mimesis in music perception and the invitation of mimesis, says this:

> ...it would go far in explaining the frustrated reactions to laptop performance... It is not as if the process of relating the minimal actions of a performer to a dense stream of musical events is an outrageously difficult task for contemporary audiences—it is that such a relationship between performer movement and sound may not clearly *invite* processes of reenactment or *mimesis*.

In discussing 'mimetic invitation', Cox (2016:47) states that different kinds of music can invite different types of mimetic engagement. In many cases, a mimetic response involves singing or sub-vocalising and dancing or movement in time with the music, either consciously or subconsciously. However, some forms of music may resist these more usual types of mimetic invitation ‘offering an attenuated mimetic response’ (Cox, 2016:48). In this case, the listener may try to find a way to engage regardless. Cox (ibid.:49) believes that through ‘repeated exposure, one finds a way to mimetically engage’. He suggests that this might explain why someone can initially dislike a piece of music but, after repeated listening, can eventually find enjoyment.

Cox (ibid.:49) suggests that ‘some music invites a relatively quiescent bodily state’, referring to types of music with no clear melody or rhythm, such as some ambient and atmospheric genres. In such cases, Cox (ibid.:49) prefers to think of this mimetic resistance as ‘offering a nonnormative mimetic experience’. Similarly, with familiar designs based on traditional instruments, the mimetic invitation would be expected to be naturally strong. However, with features or devices that are novel, such as ‘alternate controllers’ (Wanderley and Orio, 2002:62), it would be expected that the natural invitation for mimetic participation would be lessened. However, it is possible that for ‘nonnormative’ mimetic features or instruments, the mimetic invitation could be improved with increased exposure. In this situation, a ‘nonnormative invitation’ to engage is offered rather than resisting mimetic engagement. Regardless of the instrument, the audience will try to respond to the mimetic invitation, but a mimetic design needs to provide a more universal initial “normal” mimetic invitation. However, there is scope with mimetic design to encourage the player and observer to persevere with the “nonnormative” mimetic experience of new and novel aspects of an instrument and find a satisfying way to engage mimetically. The more novel aspects of the instrument could be designed to mimetically invite and encourage the audience to learn more about the device and its more unusual features.

Palmer *et al.* (1989) found that both children and adults were able to perceive something about the structure of Chinese instruments they listened to even though they had little experience with them. New instruments could be designed to generate a perception without prior knowledge. It is also likely that experience of actions might enhance mimetic response (Cox, 2016:19) and that ‘congruent experience’ (ibid.:24) and expertise in playing instruments and singing may affect mimetic response. Brent (2011:433) argues that ‘while children take part in overt mimesis, the mimetic participation of adults gradually becomes covert, yet never disappears completely'. He goes on to warn about the effect of experience on mimetic response pointing out that music-specific studies have shown that trained pianists responded differently than non-musicians (Haslinger et al., 2005; Bangert et al., 2006). Musical training and engagement must be considered in any discussions regarding mimetic response. That is not to say, however, that non-musicians do not respond but that there is a different mimetic response that needs to be fully considered—also, the question of who is a musician and non-musician needs to be addressed carefully. A mimetically designed instrument should be inviting regardless of age, experience or training. The process of communicative musicality is innate and begins from birth. Therefore, an instrument design informed by communicative musicality should produce a mimetic invitation to any spectator.

The general concepts of imitation learning (Spilka et al., 2010; Ashford et al., 2007; Iacoboni, 2009) describe how an observer is invited to imitate actions mentally, thereby experiencing and understanding the actions. Spilka *et al.* (2010:550) suggest that recent studies have shown that the MNS '. . . can also be engaged by the observation of novel actions, suggesting that this system may be important for imitation learning (Vogt et al., 2007)'. This process enables the viewer to learn how to recreate those actions and the possible effects those actions produce, provoking a desire to learn newly experienced actions through imitation. Imitation learning can facilitate DMI design to mimetically invite the audience to join in with the performance by imitating the gestures and learning how the gestures affect the sound. When someone observes an action, they mentally imitate it to understand and learn it for themselves. Then, the mind and body prepare to carry out that same action which provides a more successful learning rate. This innate imitation prepares the body's motor system to recreate the action with little to no previous physical experience of that action. This process may help explain why so many "air guitarists" are not experienced with a real guitar. The imitation learning mechanism is closely linked to communicative musicality, a theory that looks into our innate ability to imitate and how we use that imitative ability to communicate, learn and develop cognitively and emotionally.

The term 'communicative musicality' (Malloch and Trevarthen, 2009) has arisen from collaborative research between Colwyn Trevarthen (1999) and Stephen Malloch (1999) looking into child development. Trevarthen (2004; 1999) shows the importance of the communicative process between newborn baby and mother. Malloch's (1999) work shows that this communication has very definite musical elements in terms of timing and pitch intonations essential to successful communicative musicality and, therefore, child development. Malloch found that the pitch intonations between mother and baby followed musical patterns and contained turn-taking and musical rhythm. This musicality can be seen to be lacking in mothers suffering from post-natal depression or bipolar disorders, and the communication with the baby is consequently not as successful (Trevarthen, 2004). This work confirms that although instinctive and intuitive, this innate communication is complex and nuanced and necessary for bonding and relationships to develop efficaciously.

Communicative musicality involves intuitive, innate imitation and turn-taking with precisely timed elements of speech and gestures. This non-linguistic "speech" is referred to as motherese or protoconversation and although it contains no actual verbal language facilitates the essential bonding process between mother and baby. Trevarthen and Malloch's (2009) research has shown that the musical aspect of communicative musicality is so essential that when it is absent, it can harm the social and cognitive development of the baby (Trevarthen, 2004). Communicative musicality, of course, is of interest to the music therapist, where they may be able to develop a communicative process that was absent in early development.

A newborn baby is completely reliant on its primary caregiver. They are utterly incapable of surviving independently and so generating a bond with someone that can provide the baby with the necessary care is crucial to the baby's survival. Therefore the ability for communicative musicality is hard-wired at birth. Some of Trevarthen's (ibid.) experiments have taken place with babies as young as thirty minutes, and they evidence this communicative ability.

Trevarthen's (ibid.) experiment involving video screens shows clearly how advanced this ability already is in a newborn baby. Mother and baby are placed in separate rooms, and a video link is provided so they can still see each other. The mother and baby then can communicate via the video setup. Unbeknownst to the participants, the video live feed is then replaced with pre-recorded footage of the baby and mother, indistinguishable from the live feed. However, the baby becomes visibly and vocally disturbed by this change and the mother, although not knowing why feels discomfort. It is evident from this experiment that the baby and mother both discerned that they were not experiencing the same call and response from each other and that the subtle process of communicative musicality had been disrupted.

Communicative musicality is innate and vital in early development, but the process continues throughout life and is involved with our continuous social and cognitive development (Malloch and Trevarthen, 2009). Through communicative musicality, we build an understanding of the “language” of the people in our social group as we grow up. It helps us develop social connections and a shared language that allows for subtle and precise communication and knowledge of body language and emotions, facilitating the ability to empathise and sympathise (Trevarthen, 2004), helping to create a stronger community. We use the process of communicative musicality when we meet new people and groups, and cultures to begin to understand differences and how to communicate and interact effectively. This process allows continual learning and development, which is necessary for negotiating through our social environment.

Communicative musicality involves the innate ability to communicate through imitation and may help explain how we interact, perceive and appreciate musical performance and understand musical instruments through mimetic experience. Our desire to imitate actions and gestures through the processes of imitation learning is based on our desire and ability to imitate, which begins at birth through the mechanism of communicative musicality

The process of communicative musicality can be partially explained by enactive cognition (Di Paolo and Thompson, 2014; Newen et al., 2018). In discussing the ‘enactive perspective’, Schiavio *et al.* (2017:11) describe ‘Doing music, or learning music’ as ‘two examples of possible interactivities’ of ‘perception and cognition… that emerge from the constant interplay between organisms and the worlds they participate in shaping’.

However, communicative musicality does not just explain the process of imitative learning but also considers the mimetic invitation to learn that is created and perceived.

Cox (2001) refers to Malloch's (1999) and Trevarthen's (1999) work on communicative musicality as one of the pieces of evidence for his mimetic hypothesis. Cox (2001:198) states that 'Given this mutual imitation in development generally, we might expect to find it in the specific case of musical interactions between infants and parents'. Trevarthen and Malloch (2009:9) echo Cox's (2016) sentiments of the importance of movement concerning our understanding of our surroundings and, in particular, music suggesting that 'We live, think, imagine and remember in movement. To capture the essence of movement and its values, we use the metaphor of 'musicality" (Malloch and Trevarthen, 2009:9). As we hear the music and see the movement of the performance, we are invited to respond in some way. Cox (2016:46) describes this as 'mimetic invitation'. He goes on to say that 'mimetic response can occasionally feel like a mimetic imperative, which reflects the importance of imitation in human experience' (ibid.:47). Thus the crux of communicative musicality is this innate capability and the invitation to imitate, so it should not be surprising if it plays a role in music cognition and perception and, therefore, instrument design. This innate ability to engage with music performance is complex and difficult to articulate. However, Small (1999) provides the verb 'musicking' to help describe these interactions. In this context, it is easy to see that an audience's perception of an instrument is tied up in a range of more complex relationships with performer, music, and performance space, to name just a few. However, this research focuses on the specific relationship between audience and instrument. The performer inevitably impacts this relationship. And although one performer may generate a more mimetic performance on a particular instrument than another performer, an instrument may be more mimetic than other instruments. The instrument, through its design, can be a mimetic enabler, working through the agency of the performer, actively encouraging mimetic invitation.

Imitation learning and communicative musicality usually work through several modalities. Gardner and Cross (2017) found that learners of dance and guitar benefited from learning through more than one modality. Papoušek and Papoušek (2002) state that 'Parents combine auditory, visual, tactile, and proprioceptive modes in dialogues with their infants...' (Papoušek and Papoušek, 2002:194), whilst Powers (2001:16) suggests that 'Normal interactions between parents and their infants are characterised by complex dynamic interactions between different modalities'. In discussing communicative musicality and referring to the 'modulated contours of expression' of communicative musicality, Malloch and Trevarthen (2009:4) state that 'These attributes of quality will often co-occur multimodally, such that a wave of the hand will accompany a 'swoop' of the voice'. Rebelo (2006:28), in recognising this complex multimodality, discusses the relationship between performer and instrument in terms of a 'multimodal participatory space'. Rebelo (ibid.:28) suggests that in this "space", the performer's engagement with the musical instrument can be seen when thinking of the instrument as 'an entity that carries its own dynamics, expression, sociality and ecology'.

Communicative musicality relies on this complex multimodal combination of sensory perceptions. As communicative musicality and, therefore, mimetic invitation are inter-modal, the various modalities of a DMI need to be considered. The priority for most musical instrument designs is, by nature, the sound they make. However, mimetic invitation focuses on the audience's response to the multimodality of the instrument and performance. It, therefore, is affected by the combination of an instrument's aesthetics and visual aspect of the instrument and its aural output.

Palmer *et al.* (1989:34) discovered that adults and children could identify instruments from the same family from sight and sound and therefore 'detect the intermodal relation of a visual and aural presentation of a musical instrument'. Their explanation for this ability relies on the theory of affordance, stating that 'Musical instruments within families have similar affordances for playing' (ibid.:36). In referencing Gibson's (1979) "theory of affordances" Trevarthen (1999:158) states that 'We experience seeing, hearing, touching, weighing and thrusting against the objects of our acting with the exact rhythms and accelerations of the movements themselves'. Affordance is a critical process for understanding the purpose of an object or action (Bach et al., 2014) and a musical instrument requires a balance between the aural and visual aspects to provide an action causality of sound that will cause mimetic invitation driven by communicative musicality.

The mapping of DMIs is often related to an instrument's affordances (Tanaka, 2010) as the mapping is crucial to the success of casual links between action and sound. Inter-modality is also essential for mapping input gestures and sound output to produce affordances that facilitate communicative musicality and generate a mimetic invitation. The aesthetics of the instrument must be considered (in addition to the gestural input) as this will potentially affect the inter-modal perception of the instrument. The instrument has the potential through mapping to create affordances that induce the processes of communicative musicality, thereby producing a mimetic invitation to the audience before a note has been played.

Although theories of affordance and related mappings are regularly considered in DMI design, they are rarely, if ever, driven by the desire to create an instrument with the aesthetics and inter-modal potential that leverages communicative musicality to increase mimetic invitation. This research intends to create an instrument that instigates a mimetic invitation that provokes an innate desire to imitate and learn through communicative musicality and therefore produces a greater desire to participate.

3.4 Mimetic Participation & Empathy

Mimetic participation occurs as we try to comprehend and engage with the world around us. Theories of empathy help us understand why there is a natural desire to communicate and be a part of and belong to the people around us. Through covert imitation and empathy, mimetic invitation naturally leads to a desire to mimetically participate. This participation could be singing along, tapping a foot, or dancing. Most people desire to participate mimetically, but this could be subconscious covert imitation or sub-vocalisation.

Entrainment is an area of research that looks at the mechanisms of musically participatory processes that involve moving in time with music (Clayton, 2012). Killin (2016) in reviewing Tomlinson's (2015) work on the evolution of music, discusses the connections between entrainment, mimesis and gesture. In this instance, mimesis refers to the imitation of gestures that enable entrainment, or the 'matching and synchronising of two or more rhythmic oscillators' (Killin, 2016:425). This entrainment could be described as an inter-modal mimetic response and refers to moving in time with music or dancing. However, mimetic cognition provides a framework beyond entrainment by describing the processes of mimetic engagement and invitation that lead to mimetic participation.

Cox (2016) discusses mimetic participation as overt and covert. Overt mimetic participation covers any act of imitation that is physically manifested, such as tapping along with the tempo of the music, humming to the melody or physically imitating gestures such as waving an imaginary baton or playing "air guitar". Covert mimetic participation is any mimetic response that occurs in the mind, such as visualising playing an instrument or imagining sub-vocalising a sound or melody, for example. Covert and overt mimetic participation can be intentional but is often subconscious occurring entirely without the conscious knowledge of the observer.

Cox (2001) believes that our experience of materials and the experience of our voice is important to the process of mimetic participation. Most people have experienced singing and how their voice responds and works to create sound, and this is the basis we apply to mimetic participation in understanding musical performance. When someone vocally imitates an instrument, it is common to try to imitate the timbral quality of the instrument and the pitch. This attempt to vocally imitate forms empathy for the sound and how the sound has been created, facilitating an understanding of the performance gestures and how the music instrument functions.

As we begin to engage mimetically, we are invited to find ways to join in. Our initial perceptions of the instrument are refined by the imitative explorations of our vocal music experiences. As we begin to "comprehend" the instrument, we then start to mimetically participate with overt and covert manifestations of 'joining in and taking part' (Cox, 2016:15). Mimetic participation is a natural desire to join in which comes from the process of mimetic imitation and our capacity for empathy.

To empathise is to try to understand someone's position or actions and is partly explained by covert imitation. If we put ourselves in their position, we may understand something about their actions. This imitation manifests covertly and is commonly a subconscious and automatic process. Cox (2016) discusses overt and covert mimetic participation as a way of understanding music gestures. This covert imitation is vital to the mimetic process of experiencing music performance and, therefore, to mimetic DMI design. In referring to Walton (1997) Cox (2016:198) suggests that children generally exhibit overt imitation in learning about themselves and each other through social interactions. This imitation does not leave as the child grows up but becomes more covert. Brent (2011) argues that mimetic participation in adults never disappears but becomes covert, suggesting that Godøy's (2003) work on motor-mimetic music cognition implies that 'we are covertly but incessantly imitating the sounds that we hear' (Brent, 2011:433). It is possible that this covert imitation not only becomes hidden from external observation but also becomes a subconscious action. The role of this mimetic imitation is intrinsically linked with empathy. Meltzoff (2002:36) likens imitation to a 'bud' and empathy as its 'ripened fruit'.

Empathy is too large an area to consider fully for this research. However, the area of interest regarding mimesis is how empathy can be a mechanism for learning and understanding other people's actions and intentions. Although mirror neuron theories attempt to explain the biological and neural mechanisms for empathy (Szalavitz and Perry, 2010:17; Iacoboni, 2009), this is not necessary for understanding how empathy affects the mimetic process. Nevertheless, in our efforts to make sense of the world around us, empathy is an essential tool giving us an understanding in part of the thoughts, feelings, and intentions of other people.

Szalavitz and Perry (2010:12) describe empathy as the '... ability to stand in another's shoes, to feel what it's like there and to care about making it better if it hurts'. Empathy is a translation of the German *Einfuhlung*, meaning 'feeling into' (ibid.:12). Szalavitz and Perry (ibid.:12) make the critical distinction between empathy and sympathy, which is translated from Greek as "feeling with". When we empathise, our primary feelings are more related to the other person. However, when we sympathise, we might understand the other's situation, although we are not necessarily feeling it ourselves. We explicitly deal with empathy regarding mimetic response and provoke the reaction of "feeling into" what the musician is feeling, rather than just a remote understanding. Decety and Jackson (2004:93) say that when 'empathy produces... "physical mimicry", the intentional focus does not remain on the spectator's body but is projected into the other'. This "projection" may allow people to interact and feel included or invited to join in. This area of empathy needs to be leveraged within mimetic design to improve the inclusive nature of DMIs, creating a desire to participate in the instrument's performance.

In some situations, we seem to empathise subconsciously, which can occur with emotional contagion when the people around us can affect our moods and emotions. It is mainly present in babies and maybe 'one basis for the development of empathy' (Szalavitz and Perry, 2010:173). Emotional contagion is a widely accepted empathetic phenomenon but is still not fully understood. Doherty (1997) produced an emotional contagion scale to facilitate the measurement and examination of this process. Whilst a complete understanding of emotional contagion is unnecessary for instrument design, considering the implications of how we interact with each other and perceive emotional states may provide greater insight into producing a more inclusive instrument.

This covert, contagious, imitative empathy may be evidenced when a musical performance using circular breathing is observed. Suppose the spectator misunderstands the hidden technique behind circular breathing. In that case, they may subconsciously imitate a continuous uninterrupted exhalation, only becoming conscious of this mimetic response when they run out of breath (Mead, 2021). This audience response is an example of covert mimetic participation causing physical empathy and "joining in" with the performer. Therefore, mimetic participation is affected by the audience's perception and understanding and not necessarily the actual action or technique behind the sound (Cox, 2016:178-179).

Although covert, subconscious mimetic participation cannot be openly observed, the process is vital to how we experience music and musical performance. It may prove challenging to measure and evidence, but the implications of subconscious imitation and empathy should still be considered in designing DMIs that elicit mimetic participation and an inclusive desire to join in.

The theories of empathy help elucidate why we need social interaction and why we want to be included. Using empathy theories to influence mimetic design should help produce instruments that invite imitation and a desire to participate mimetically. This contagious mimesis will cultivate an inclusive desire to join in increasing the likelihood of user adoption, appropriation and improving the instrument's longevity.

3.5 Summary of Mimetic Theories

In answering this question:

> *Could further theories be found to help understand the processes of mimetic cognition facilitating mimetic design? (Section 2.4).*

Although many areas might be relevant to mimetic design, such as synchronicity, emotional contagion, flow, and 4E cognition, my research led me to focus on action understanding, communicative musicality, and empathy, to support the concept of mimetic cognition.

Cox's (2016) theory of mimetic cognition provides a well-furnished mechanism for the processes of musical involvement, invitation and inclusion. The concepts of action understanding, communicative musicality and empathy go further in helping to understand practical applications of mimetic cognition.

- When we first see a new music instrument, the process of action understanding instigates mimetic engagement (ibid.) and, therefore, initial involvement through action understanding of performance gestures.

- Once mimetically engaged, we are mimetically invited (ibid.) to respond to the affordances of the instrument through the mechanism of imitative learning and communicative musicality (Malloch and Trevarthen, 2009) finding ourselves imitating and perhaps wanting to have a go of the instrument.

- The response to mimetic invitation is to participate mimetically. Through covert imitation and empathy (Szalavitz and Perry, 2010) we find ourselves joining in with

> the performance either by direct intra-modal imitation or inter-modal manifestations of inclusive action such as tapping the foot, humming along or “air guitar”, and as such, we begin to appropriate the new instrument.

It is clear that music performance, through mechanisms found in action understanding, communicative musicality and empathy, induces a response from the listener, which triggers complex mimetic processes of engagement, invitation and participation. The purpose of this thesis is to present mimetic design principles that leverage these mimetic theories with the expectation of creating new, involving, inviting, and inclusive digital instruments.

Chapter 4

Contextual Framework | *Digital Musical Instrument Design*

In researching digital musical instrument design, it is apparent that it is a vast interdisciplinary subject. Therefore, this chapter presents the main points relevant to mimetic theories and my design process as an instrument maker and practitioner. Firstly a discussion of what a digital musical instrument is and a discussion of evaluation and classification of such instruments. As my practice involves designing alternatives for my keyboard, guitar and computer controllers, these instruments are discussed concerning their development as DMIs and computer controllers and, therefore, my work.

Secondly, in designing a DMI, I needed to look at the more practical elements of the workings of digital instruments. The practical concepts of input, mapping and output are presented.

Thirdly, I discuss the common DMI areas of gesture, affordance and appropriation. Although they were not the only areas relevant to my work, I found them the most prominent when considering mimetic design.

And finally, I then discuss some of the common problems encountered in designing and using DMIs. This discussion is not exhaustive but presents some of the issues closely related to my practice.

4.1 What is a Digital Musical Instrument?

With the proliferation of computer technology, music has taken advantage of the digital world, enabling the creation of new music sounds and sonic effects that were never possible before. Consequently, modern popular music has been recorded and produced digitally and even resides in the digital realm until streamed directly to the consumer. This convenient delivery method means that even acoustic music such as orchestral ensembles is still digitised at some point. It is now also common for digital equipment to be used for music performances, such as digital mixing desks and wireless microphone technology.

Digital Music Instruments (DMIs) are a relatively recent and varied category of music instruments. They differ from acoustic and analogue electronic instruments in one fundamental way—at least one element of the DMI utilises digital technology. That could be the input stage, mapping or output stage.

Although the creation and production of music have fully embraced this modern digital world, the most popular digital music instruments are still very much based on the traditional acoustic instruments that have been around for centuries. As a result, there is a trend to look for ways to develop instruments that can take full advantage of digital technologies. However, care needs to be taken to ensure the musicality of DMIs is not lost in a deluge of technology. DMIs need to be musical instruments, not just an extension of a computer mouse.

4.1.1 Classification and Evaluation

I regarded it necessary for the development and future potential production of instruments based on mimetic design to consider these mimetic instruments within existing musical instrument categories and evaluation methods.

To understand how DMIs, in general, fit into the world of musical instruments, we can look at how instruments have been evaluated and classified in relation to each other. This classification helps us understand how DMIs relate to other instruments and what features they share or might benefit from in future designs.

The subject of classification and evaluation are intrinsically linked. A DMI needs to be evaluated to be classified. Classification of such DMIs has been a challenge due to the multifarious nature of these instruments. However, the use of different taxonomy systems helps us understand the design process and allow DMIs to be evaluated according to type and purpose. However, the usage of the term “evaluation” is currently in flux within the NIME (New Interfaces for Musical Expression) community (Barbosa, Malloch, et al., 2015).

Evaluation of DMIs

The evaluation of DMIs is a large area of research and can lead to different results depending on the intentions of the evaluation. It poses a difficult question for the DMI community. Barbosa *et al.* (ibid.) studied various articles relating to DMI evaluation and proposed that the term be more clearly defined for further use.

There are two main areas of evaluation to consider: firstly, to evaluate the success of the instrument, and secondly, to classify and categorise DMIs. A list of properties, features, abilities or requirements needs to be specified to measure and evaluate the success of an instrument. This task is difficult due to the varied nature of DMIs, which can be highly customised and personal to the designer. Suppose an instrument maker designed and customised a device to perform a specific task. In that case, the evaluation lends itself to the interactive development of the instrument but is less relevant for application to other devices.

However, there have been several attempts to evaluate DMIs in a general way to discover DMIs with capabilities for specific contexts such as education (Pessoa et al., 2020; Förster et al., 2020) or accessible DMIs (ADMI) (Lucas, Ortiz, et al., 2019). These areas have particular needs and capabilities from the instruments, which provide a framework for evaluation. Other frameworks borrowed from existing areas such as Human-Computer Interaction (Young and Murphy, 2020; Kiefer et al., 2008; Wanderley and Orio, 2002) have also been used to help evaluate DMIs.

There are three main perspectives for DMI evaluation. The designer that evaluates their instrument against its design specifications with the aim of future improvements (El-Shimy and Cooperstock, 2016; Ghamsari et al., 2013). This type of evaluation is specific to individual instruments and is difficult to use in a generalised manner. The second type of evaluation revolves around assessing DMIs in relation to intended users who are separate from the designer. This type of evaluation looks at features, functionality and use contexts, (Brown et al., 2017). The third perspective for evaluation is the audience. This perspective is less common, possibly because the musician has often designed the instrument for performance, so the focus is on the usability and functionality from a user perspective. However, to fully communicate musical ideas successfully, the audience should be considered when designing DMIs, including the evaluation process. Barbosa *et al.* (2012:1) makes the point that the audience is an 'often ignored stakeholder'. There is room to improve the evaluation of DMIs, providing for the audience's perspective and experience to be taken into account.

Classification of DMIs

Another role for the ambiguously termed evaluation is to determine the classification of new DMIs and group them into different types. This burgeoning area of study has flourished due to the seemingly endless supply of new DMIs over the last few years. There have been many classification systems for acoustic instruments, the most widely accepted being devised in 1914 by Hornbostel and Sachs (Magnusson, 2017). This system categorises instruments by what materials produce the sound, the four main types being: idiophones, membranophones, chordophones and aerophones. In 1940 Sachs (2006) added the electrophone category to accommodate electric and electronic instruments that were being developed (Lee, 2019a). This add-on appears to be less successful in classifying instruments than the original four and, with the advent of DMIs, has become somewhat inadequate. The Musical Instrument Museums Online (MIMO) Project (MIMO, 2021; Lee, 2019a) has further developed the Hornbostel/Sachs system to include more modern electronic instrument classifications. Unfortunately, although this system accommodates electronic instruments, it seems unable to cope with the influx of new and varying DMIs fully. Bongers (2007) believes that the distinction between the electric and electronic should be stipulated, especially with the emergence of DMIs. However, this might not go far enough. It may be more appropriate to specify “digital” as separate from “electric” and “electronic”.

Reinhard (1960) proposed a classification system which differentiated monophonic and polyphonic sources and looked at how the sounds develop over time: whether the sound stops, is continuous or can be changed in some way. He also considered loudness and timbre important to classification (Magnusson, 2017; Kartomi, 1990; Brissenden, 2015).

The most straightforward way to classify DMIs might be to look at the features and capabilities of the instrument and the practicalities of playing and performing. However, this over-simplification misses some crucial connections and relationships between these instruments. Paine (2010:438) in developing a taxonomy for DMIs, concluded that most DMIs are used to improvise or play ‘music in the moment’ and control the music system. Essentially, DMIs serve as musical instruments and control an entire music system. This description is perhaps too simple in reality, and by reducing the elements of DMIs to these two separate entities, it is missing the complexities that occur in DMIs. The relationship between musical performance and control is much more complicated and not necessarily so easy to separate.

Analogies between DMIs and other non-musical systems have been used to create classifications. Malloch *et al.* (2006) uses human-machine interaction (HMI) to help define DMIs to distinguish the role of the computer in DMI creation and performance. HMI may be quite an extensive way to capture the digital features of an instrument. However, computer theory seems to underplay the musical nature of DMIs, which could easily be argued as the most important notion to consider. Looking at a more musical aspect in discussing the design of modern DMIs, McPherson (2015:42) argues that ‘The Value of Imperfection’ is important and that the limits for control are a part of the design. Of course, there is an element of imperfection in acoustic instruments which in some DMIs could be eliminated by the “perfection” of computer code. However, as McPherson (ibid.:42) alludes to, the ‘imperfection’ of instruments can be necessary for the successful design of DMIs. Therefore, it is not necessarily appropriate to use areas of computer research exclusively when discussing DMIs.

Any successful classification of a DMI needs to consider new characteristics and digital capabilities without losing the overall musical intention of the instrument. Comparing DMI classification to the established models Magnusson (2017) argues that as the materials that DMIs are made from do not produce the sound, other properties such as mapping, algorithms, gestures and modalities for sensors need to be considered in the classification of digital music instruments. The gestural and modal qualities can be seen in acoustic instruments, whereas the mapping, algorithms and sensor modalities are unique to digital instruments, possibly providing areas for successful classifications.

Wanderley and Orio (2002) present four generalised DMI categories: “instrument-like”; “instrument-inspired”; “extended-instruments” and “alternate instruments”. They argue that designers tend to create instruments that either utilise an existing gestural vocabulary or the complete opposite avoiding any connection with existing instruments. These categories of DMIs are a sound basis for looking at new DMIs, with their four categories conceivably covering all types of new digital instruments.

Palmer *et al.* (1989) look to affordances in DMIs to categorise the instruments. They believe that people without specific knowledge can identify and categorise instruments based on what they see and hear. Therefore, similar instruments will have similar affordances perceived by the observer. This approach allows similarities to be found between DMIs that might be missed if only looking at the feature set. This method also utilises categories that people without the experience or knowledge of new DMIs would naturally understand and therefore be able to use. This method seems to be a more encompassing way to describe DMIs allowing the musical nature of the instruments to be considered within the context of the controlling aspect that DMIs afford.

Spiegel (1992:5) makes the point that initial terms to describe computer-based music, such as ‘intelligent instrument’, came about due to the ‘simple need to communicate to others what unprecedented things we were trying to do, in the absence of any established terminology'. As the boundaries of music technology are stretched, the instruments seem to lie beyond the classification of the more traditional attempts. To accommodate this Spiegel (1992:5) suggests:

> ...exploring a representation modeling musical creative processes as a multi-dimensional space, in which methods and systems can be localized as positions and movements along various continua encompassing all characteristics of importance.

To this end, many 'non-quantifiable variables' would be involved and consequently produce a matrix that would be 'relative rather than absolute' (ibid.:5). This model provides an all-encompassing taxonomy but is more complex to use and decipher than other models.

As can be seen, there are many different ways to categorise DMIs, each with its benefits and advantages. The DMI designer does not have to be capable of categorising their creation. However, these discussions can help better understand the design process and what constitutes a DMI and potentially what will constitute a DMI in the future.

When considering DMIs, it is essential that although the digital aspect and functionality are discussed, this is not to the detriment of the instrument's musicality. On the contrary, part of that musicality is how the instrument can perform and communicate musical ideas. So it is also crucial to acknowledge the importance of the audience's perspective and people with no or little knowledge of digital instruments.

It is an impossible task to create a complete taxonomy for DMIs due to the varied nature of the instruments. It will probably be necessary to utilise several classifications to fully describe, evaluate and categorise DMIs depending on the context. However, there may be methods of evaluation and classification that by prioritising certain aspects of instrument design will prove more useful in general.

In developing mimetic design principles, it may be helpful in the future to evaluate an instrument's mimetic potential by providing another tool for classification. Mimetic evaluation would need to be used in combination with other systems to be helpful as a more general classification taxonomy. As an instrument maker, I found Reinhard's (1960) concepts of note polyphony and duration, Wanderley and Orio's (2002) four types of DMI, and Spiegel's (1992) alternate taxonomy the most useful when considering my design.

Although not developed as part of this research, I believe a classification that includes an instrument's mimetic potential would be useful in the future.

4.1.2 Digital Music Controllers

Whilst researching the commercial aspects, designs, and DMIs available, another area of classification arose—the nature of MIDI controllers. Many digital keyboards have built-in synthesis that enable the sounds to be produced from the one device. In some cases, the amplification and speaker system are also built into the device. However, the ability to split the input and output stages of DMIs and the increasing popularity of computer software for performing sounds has led to separate input devices that do not generate any sounds on their own. These input interfaces measure gestural movement and control input from sensors and knobs and send this data to a sound output device. The majority of these controllers utilise the MIDI protocol for connecting and sending performance and control data. Hence, these devices are collectively referred to as "MIDI controllers".

Technically using the simple criteria of a device that produces MIDI but not a sound would classify the instruments I designed as MIDI controllers. Yet conceptually, I have always thought of them as instruments. Although my devices could have been designed to produce sound, it was outside my technical capability both as a designer and maker. The relative simplicity of MIDI has allowed me to explore the concept of digital musical instruments despite my lack of technological know-how. Although the commercial manufacturers of MIDI controllers may use this more practical classification, I tend to think of MIDI controllers as the devices used to control the computer system rather than to produce musical notes. Although this could be the same instrument, many devices are dedicated to controlling audio software, particularly Ableton Live.

MIDI Pad Controllers

With the popularity of Ableton Live software (Ableton, 2020) there has been a rise in controllers specifically targeted at Ableton users, including Ableton's own "Push" (Ableton, 2021). These devices consist of a grid of pressure-sensitive pads, usually with multi-coloured LEDs giving the pads illumination to indicate various modes and settings. In addition, Ableton software also utilises a grid of music clips which these controller buttons can trigger in multiple ways.

These controllers move the performer away from the laptop to a more responsive and potentially musical interface. The small performance gestures required to press the buttons and controls make it difficult for an audience to see and respond to the performance. These devices seem to be aimed at the user, boasting greater and simpler control of complex music systems with little consideration of how an audience might respond.

There are currently many other similar pad controllers available most notably Novation's Launchpad series (Novation, 2021). These controllers are not entirely new however as they have descended from Akai's MPC series (MIDI Production Center) designed by Roger Linn (Roger Linn, 2021) in 1988. Modern versions are still in production today (AKAI, 2021). These electronic sample machines loaded short audio samples, which could be triggered by "playing" a 4 x 4 grid of pads. Due to the short sample memory, these devices became very popular for creating and performing drum patterns. This "finger drumming" has become a sophisticated performance of virtuosity showing off musical and technical skills.

These DJ style controllers provide control over complex systems. However, it seems that the control of the system resembles more of an extension of the computer mouse rather than a musical instrument. The finger playing may be more musically engaging to spectators but would need to be observed at close quarters or displayed on a large video screen as playing gestures are small. In addition, the demand for system control is increasing with the universal use of laptops and computers for music production and performance. System control is a positive feature for DMI devices, but if this becomes the sole purpose behind the design, then the musicality of the device might be impaired.

The Laptop as a DMI

Computers have become an essential part of many performances, both in commercial music and experimental genres. Laptop orchestras have been producing music performances for many years, investigating the “performativity” and “liveness” of the laptop as an instrument. These performances have instigated the idea that an audience might not know whether the laptop performer is performing music or just checking emails. Kraftwerk has explored the use of laptops through humorous performances where they leave the stage. At the same time, their robot counterparts continue to “perform”, provoking an article by Pareles (2005) in the New York Times to declare that ‘Its robots were far more demonstrative than the band itself’.

Cavdir *et al.* (2019:53) have created laptop instruments that leverage ‘musical gestures’. These instruments seem to be halfway between the standard laptop orchestra, where the focus is entirely on the laptops and MIDI controllers, which move the focus to performance gestures. Care needs to be taken to avoid DMIs that are perceived as an extension of the computer keyboard or mouse, as Billinghurst (2011:1-2) states, ‘using a mouse… for gestural interaction restricts the user to the gestural vocabulary of a fruit fly’. Even if the input device provides complex control over the laptop, the input gestures must communicate musical expression for the device to be perceived as an instrument rather than computer input hardware.

Many modern performances include elements of sounds that are pre-recorded, played back and mixed with live performance. Frengel (2010:96) suggests that ‘a perceptual dissonance often arises between visual and aural stimuli’ with performances that have mixed live and non-live sound sources. This dissonance is a factor in laptop performances, with the gestures of performance being dislocated from the produced sounds. Lee’s (2019b) possible solution lies in mirroring the computer monitor on a large screen visible to the audience. This mirroring allows spectators to see what is happening on the screen but will not necessarily enable the audience to understand how the sounds are produced.

It is undeniable that the computer can be a powerful musical tool, which has given rise to a vast range of controllers and instruments. Many of these controllers seem to have a design and features that are more conducive to music system control than audience perception and engagement.

In designing new DMIs, the input device is crucial to how the instrument communicates musically with the audience. The common lack of visible gestures with laptop performance, and to some extent, controllers that involve small buttons, is detrimental to any mimetic response. Mimetic design requires visible performance gestures to generate mimetic engagement, invitation and participation.

4.1.3 Digital Keyboards and Guitars

The keyboard offers an easy to use interface for initiating notes, selecting pitch and varying dynamics of play. It is very recognisable, and the skills learnt from pianos and other keyboard instruments are instantly transferable. However, as synthesis has developed and the requirements for input control have become more demanding, the standard keyboard has fallen short in the advanced expression and controllability of modern synthesisers and sound generators. Therefore, the functionality of control needs to be considered carefully in new DMIs by providing an approachable interface in its simplicity of playing and offering more advanced combinations of control and manipulation of sound without interrupting the playing of notes.

In modern pop and rock music situations, the keyboard is stationary compared to guitars. The guitar can be carried over a large stage, especially due to wireless technologies. It can also be moved around in relation to the player as far as the strap will allow. Various MIDI, digital and augmented guitars have been produced, so it is now possible to use a guitar as a MIDI controller and connect it to the same sound devices like a keyboard and play and control the same sounds. However, despite its greater mobility and visual presence, the guitar is not commonly used as a MIDI controller or digital instrument. Understanding the popularity and pervasiveness of keyboards and guitars may illuminate areas of significance that can improve DMI design.

The Keyboard — A Standard MIDI Controller

The commercial keyboard design is based on the shape and layout of the keys of a piano. This design has been the most prolific input interface for DMIs since the introduction of synthesis and electronic instruments. Over the years, additional sensors and controls have been added and somewhat standardised for many digital keyboards and controllers. Pressure sensors under the keyboard provide velocity sensing (how hard the key was played) and aftertouch, allowing detection of changes in pressure after playing the note to modulate the sound further. Pitch bend and modulation wheels are also very common.

Extra knobs, sliders, joysticks and other controllers are often included. Although not standardised, customised mapping can connect these additional controls to the sound synthesis output. Pedals and footswitches are commonly used with the keyboard, usually providing control over sustain and expression (additional volume control).

Korg has continued building on the success of the original M1 workstation with their flagship product, the Nautilus (Korg, 2021). This workstation can now record audio as well as MIDI and has a massive range of accurately sampled acoustic sounds and futuristic synthesis engines, providing a comprehensive studio system. The input section is traditional and limited with keyboard, modulation and pitch joystick and pedal inputs. There are some extra control knobs for changing synthesiser parameters, but most control is accomplished with a touchscreen. This control system seems to be provided as an alternative to using a computer. The gestural input for performance has not been developed beyond the standard keyboard interface.

Other commercial products provide similar feature sets without really developing the gestural input for the instrument. There are many MIDI controllers also available with limited or no built-in synthesis. They often have many more controls, knobs and sliders, but these controls seem to be designed for computer control rather than music performance. This computer control has been taken a step further by Native Instrument's Native Kontrol System (NKS) (Native Instruments, 2021) which provides a computer music software system that has been integrated into the hardware. Much of the customised mapping needed for other controllers is unnecessary, providing tight integration with software control and hardware. However, the emphasis again is on system control, not musical performance gestures and expressive control.

More Freedom of Movement

The keyboard is usually stationary and not particularly mobile. There have been several attempts to mobilise the keyboard with a strap, initially unpopular due to the weight, but with more modern light-weight plastic devices became known as the “keytar”. Currently, still in production by several manufacturers, the modern keytar is designed so that the right hand can play the keyboard. In contrast, the left hand modulates the notes via additional sensors and controls.

The Alesis Vortex (Alesis, 2021) uses a tilt sensor to detect the movement of the keytar. This sensor can be mapped to MIDI control parameters. Tilt sensors usually rely on accelerometer technology which senses the acceleration of the device. Although they can quite accurately detect the direction and angle of motion, they are not as accurate for motion as other technologies, such as gyroscopes or IMUs (inertial measurement unit), for measuring the position, movement and rotation of objects. There is limited functionality when mapping tilt sensors directly to CCs, as the data they produce is not as precise and smooth as turning a knob or moving a slider.

Accelerometers used in isolation produce more of an on/off functionality than accurately tracing from 0 to 128. They are also difficult to precisely control and accurately reproduce the effect of playing gestures regardless of proficiency with the device. The imprecision of some sensors can produce a novelty feature rather than one that has any practical use in musical performance.

More Expressive Control

The keytar was developed to address the mobility of the static keyboard, especially to compete with the mobility of the guitar in pop and rock bands. Most modern keyboards and MIDI controllers now have extended features to modulate the sounds further and command any connected systems, providing extensive control over complex setups for music production and performance. However, most of these extra controls require using a hand that would otherwise be playing the notes on the keyboard. The additional gestures for modulation on guitars tend to be combined with the playing gestures so the guitarist can play the notes whilst controlling and modulating the sound simultaneously.

Devices have been designed to embed controls into the keys to allow simultaneous continuous control and note playing. The Haken Continuum (Haken et al., 2021) tracks the fingers in X, Y and Z axes independently for up to ten simultaneous notes. Each key has individual sensors allowing for separate control of modulation on a per-key basis, commonly referred to as polyphonic expression, so, for example, a pitch bend effect can be applied to a single note in a chord. Traditionally the pitch bend and modulation wheel effects are applied to all the notes currently being played. Combining the sensors into each key allows for modulation of continuous controls without interrupting playing the notes, unlike traditional keyboard controllers and Keytars.

McPherson's (2012) Touchkeys and Lamb's (2014) Seaboard are similar devices that look to address the issue of multiple simultaneous and independent control using a keyboard. However, the Touchkeys system is not a complete DMI but overlays onto an existing keyboard or piano, extending the instrument's capabilities. The Continuum, Seaboard and Touchkeys have all been designed to expand the expressive capabilities and control of the standard keyboard controller.

Whilst it is a common endeavour to endow the keyboard interface with greater control and expression, especially with modulations and control of the sound during sustained notes, the design of this functionality tends to focus entirely on the user experience. How an audience might interpret the instrument's performance or understand how it is being played is not necessarily considered when choosing the design of extended gestural controls. However, this is important in mimetically engaging an audience in the instrument.

Guitars

The acoustic guitar was a well-established instrument before luthiers took advantage of the discovery of electricity. Unlike an acoustic guitar, where the acoustic resonance of the body amplifies the strings' vibration, the metal strings of an electric guitar induce an electric current in magnetic pickups. This induced signal is then sent to an amplifier and speaker for the sound to be produced and heard. Initially, electric guitars were designed with a hollow body similar to an acoustic guitar. However, it was not long before Les Paul (Waksman, 2001) took complete advantage of amplification by creating a guitar with a solid body that had no natural acoustic volume.

The electric guitar uses an electric circuit to produce a signal that, when amplified, generates sound. The playing interface of the electric guitar is similar to an acoustic guitar and, because the playing mechanism is instantly recognisable, it is easily imagined and understood. The electric guitar extends the capabilities of the acoustic version. The amplification allows much louder playing and provides the player with techniques unique to the capabilities of the electric guitar, such as pinched harmonics, extended sustain and the whammy bar (which produces pitch changes). The loud amplification has enabled the electric guitar to be used as a solo instrument against a loud background, such as in a typical rock band of drums, bass, and keyboards. The electric guitar can also be used as a part of an ensemble. Due to the many effects that can be applied to the guitar sound, it can be comfortably used in many different musical genres and situations.

An interesting aspect of the electric guitar is how miming the playing gestures, namely "air guitar", has become a worldwide phenomenon, with annual national and world championships that attract many entrants from around the world (AGWC, 2021). Other instruments are mimicked in this way but not to the extent of the electric guitar. It seems specific to the extended gestures that the electric guitar adds to the acoustic guitar and the exaggerated large inter-modal gestures used in expressive performances.

The "air" phenomenon has inspired a range of research into how we understand and perceive musical performance, including gesture, neurology, psychology and of course, instrument design amongst others (Dahl, 2015; Jensenius, Wanderley, et al., 2010; Godøy et al., 2006; van Mourik Broekman et al., 2018; Vets et al., 2017; Kanebako et al., 2007). There is a common understanding of the electric guitar and its gestures, demonstrated by "air" performances of "non-guitarists". Therefore, "air guitar" is an important aspect to consider in designing mimetic DMIs that can genuinely connect with and inspire an audience. In addition, given the widespread popularity of the electric guitar and the well-established design of its acoustic cousin, its gestural repertoire is vital to consider for generating mimetic instruments that are involving, inviting and inclusive.

Augmented and Digital Guitars

Some DMIs utilise guitar design, ranging from accessories that extend standard guitars to fully customised digital guitars. Godin (Godin Guitars, 2021) produce a guitar with custom pickup electronics that can produce MIDI in conjunction with a standard guitar signal. The guitar is traditional in design and provides MIDI control for existing guitar players without needing to learn new playing gestures or techniques. The Roland GK-3 MIDI pickup provides similar MIDI capabilities but can be added to any existing electric guitar. These MIDI guitar devices utilise six individual pickups, one for each string, which send the signals to a box which converts them into MIDI data.

MIDI pickups were initially unreliable and suffered from latency issues. Although the current versions have significantly improved, they remain a niche product, possibly due to the available guitar sound effects and pedals. Therefore, it is perhaps a superfluous complexity for the average guitarist.

Also, playing keyboard sounds, such as a piano, from a guitar might feel somewhat unexpected and therefore unnatural, creating a disconnect between the playing gestures and the sounds produced. This disconnect may also be an issue for audiences as they will expect the type of sounds that should be emanating from a guitar. When presented with an unexpected sound that is out of context, the gestural causality of the sound could be weakened.

Boss has developed a guitar effects pedal (BOSS Corporation, 2021) that separates pitch from a standard guitar signal and produces synthesiser sounds from this data. This pedal is a more comfortable approach for guitarists, not needing modifications to the guitar or a hex pickup. This guitar synthesiser can easily be added as an “extra” to the range of effects commonly found in a guitarist’s selection of pedals. Boss has limited the range of sounds to synthetic tones similar to guitar sounds in this instance. There is no MIDI output, so although the guitar has additional digital sounds, it is limited to the range provided by Boss. This limitation ensures that there is no “disconnect” issue with the sounds that can easily occur with a MIDI pickup guitar.

Several guitar-like digital controllers have been produced, most noticeably the Ztar by Starrlabs (Starr Labs, 2021). The traditional strings and fretboard are replaced with an arrangement of small buttons, one for each string and fret position. The Ztar can be played using similar techniques and hand positions to the electric guitar using this arrangement. The button arrangement produces much more reliable pitch data than MIDI pickups. The plucking side of the Ztar is available in two variations: a button trigger method; and short strings plucked like a guitar. The second of these allows for traditional plucking techniques to trigger the sounds.

Several companies have also produced a range of augmented guitars. These do not create MIDI but use digital technologies to enhance the sounds and add features unavailable to standard electric guitars. The Variax by Line 6 (Line 6, 2021) is probably the most commonly used of these devices. A standard electric guitar has a digital circuit added that takes the guitar signal directly from the pickups and alters it in a way the user selects before sending it to the standard guitar jack. The sound options that can be chosen often use modelling technologies to create emulations of existing guitar types, from acoustic sounds to various electric guitars, including selecting different kinds of pickup to be emulated. In addition, each string can be digitally pitch-shifted, allowing the user to play different tunings on the guitar without needing to retune the guitar physically. These options are embedded in the guitar electronics. More extensive editing is available by connecting a computer and using software to reconfigure and upload the new settings to the guitar. Although there is much more potential to manipulate the sound and generate new and synthesised sounds, the Variax feature has been specifically targeted to guitar players allowing their existing techniques and knowledge to apply to the guitar and the sounds being produced.

The Artiphon (Artiphon, 2021) is a string-like controller, initially developed to replicate the aesthetics of an acoustic instrument, with a handcrafted wooden body. The mechanism consisted of a pressure-sensitive fretboard which sensed the position and pressure of the "fret" hand. A specific smartphone needed to be connected to the Artiphon, which was used to detect the strumming, bowing or plucking gestures and produce the sounds via an application installed on the phone. The Artiphon has undergone a dramatic design change to avoid the reliance on a phone to function. A set of pressure sensors have replaced the necessity of the phone setup. It also has built-in sound synthesis, an amplifier and a speaker. It can be used independently or connected wirelessly to a phone, allowing the device settings and sounds to be configured.

The new version has a plastic construction, which may make the device feel more like a toy than a musical instrument compared with the previous handmade wooden version. Although the original reliance on rapidly evolving third party technology was incredibly detrimental to the device, moving from an aesthetically pleasing wooden construction to cheap plastic may also have a negative impact on mimetic response. Acoustic instruments have traditionally been made from wood and other natural materials, while computers and computer peripherals use plastics. Spectators and users may be less likely to perceive the plastic Artiphon as a musical instrument than a wooden version.

The currently available digital keyboards, controllers and guitars provide many new features and capabilities compared to their traditional counterparts. The extended keyboards from Haken, Lamb and McPherson address some of the issues of greater expressive control for keyboards. Godin, Roland and Starr Labs have created devices that can take advantage of MIDI technologies and mobility while retaining the guitar's familiarity and playability.

However, most keyboard and guitar-based DMI designs focus predominately on the user experience. To produce a DMI that can genuinely engage both the player and the audience, the balance of greater gestural control and musical expression for the player, and action causality of the sounds for the audience, needs to be considered. The choice of materials used to produce such an instrument is essential to the overall perception of the device. When considering a new mimetically designed DMI based on an existing instrument, the design should ensure that the perception of the new capabilities is not constricted by being so closely aligned with the instrument it is based on.

4.2 Design Practicalities and Technologies

Modern digital technologies and the accessibility of affordable and easy to use components has led to a proliferation of home made and custom devices, and is also true in the area of music instrument design. This digital technology presents some common practical issues that need to be considered before delving into some of the underlying DMI theories.

The advent of digital technologies has meant that in most cases the gestural control input of a DMI is distinct and separate from the output of the sounds being produced. The input "controller" generates performance data from sensor input technologies which is mapped to the output sound generator.

The input controller usually consists of a variety of sensors that can sense and track the players performance gestures, whilst a range of buttons, knobs and sliders add further control. This input data is digitised and mapped to the output. The input is not always a physical controller. In the case of A.I. systems the computer can automatically generate performance data without any control from a performer (Kirke and Miranda, 2009; de Mantaras and Arcos, 2002). Also V.R. systems utilise controls within a virtual environment (Atherton and Wang, 2020; Serafin et al., 2016). That being said the majority of DMIs have a user control input interface.

A DMI requires the input stage to be mapped to an output stage and for most devices the gestural performance input is "connected" to an audible sound output. Mapping can be very simple or complex. Quite often the mapping is left configurable so that the user can create custom controls, which is useful due to the immense range of sound generation available and the vast amount of controls presented to the user. Mapping can be applied within the input controller using firmware programmed on an embedded microcontroller unit (MCU) or using software on a computer system.

Once the input has been converted into a digital signal any number of processes can be applied to connect it to an almost unlimited array of output devices, synthesisers and sound generators which in turn could be digital, analogue or even acoustic via mechanical devices.

4.2.1 The Input — Sensors and Controls

The input stage of a DMI usually consists of a gestural interface which senses various modes of motion, pressure and other parameters which are converted into a digital signal. With modern sensor technology there are many different types of input sources. The most common are position, pressure and motion. Less common sensors might include biological sensors such as heart rate monitors or environmental sensors like temperature and barometric pressure. Digital input can be generated without a physical interface. A.I. computer systems can automatically generate input data. V.R. systems although requiring gestural input do not have a physical interface as this occurs rather in the virtual space. However, it is more common for DMIs to use some form of interface that requires user input to allow for musical control and expression and playing of the instrument.

DMIs that are to be “played” by a person often use position and pressure sensors to track the position of hands and fingers and the pressure which they exert. Sensing technologies can be combined and processed together (Medeiros and Wanderley, 2014) to generate more responsive instruments, for example motion sensors can be combined with motion capture techniques to detect the small gestures and also the large movements of the player and the instrument (Visi et al., 2014). These advanced sensor techniques should be considered in the design of DMIs to achieve a greater level and range of sensing to produce more expressive and responsive instruments.

Knobs, buttons and sliders can be added to allow further control. In some cases these controls are exclusively used with minimal or no gestural sensing. This setup is common in software controllers and devices used in conjunction with audio software. With this type of controller it is debatable what constitutes a musical controller and a computer controller. A mixing console is not usually referred to as an instrument but digital consoles utilise knobs and faders to control music software using the same principles as music controllers, the only difference being the use context.

McPherson (2015:28) seems to agree with Verplank's (2009) assessment that 'Handles can be analogic' and 'Buttons are more likely symbolic". The handles refer to continuous controls such as sliders and knobs whereas the buttons are typical on/off switches. Verplank (ibid.:6) goes on to say that he uses '…buttons for precision' and 'handles for expression'. In many cases this could be true with the use of controls where data can be dialled in very precisely. The more "analogic" sensors where control is not as precise may approximate more accurately to the experience of musical gesture on an acoustic instrument. However, it could be argued that, as with an acoustic instrument, the more difficult gestures can be mastered over time and potentially become as accurate as the seemingly more accurate on/off button. This is how an instrument may be more 'inevitable' (Machover, 2002) whilst being 'efficient' (Puig, 2005) providing an intuitive and inviting instrument that rewards practise with precise control over the playing of the sounds.

The input interface and its range of controls and sensors is a very important element to DMIs that are to be "played". The design of this interface and the way the instrument is played and its pursuant gestures, motions and controls will affect the spectator's perception of the performance, music and the instrument. However, the success of the input interface also depends on how the data is digitised and mapped to the sound output which determines the musical and sonic capabilities of the instrument.

4.2.2 Mapping — Connecting Input to Output

Most sensors are connected to a microcontroller unit (MCU) which takes the output of the sensors and translates the message into digital data that can be sent to the output of the device. MCUs convert continuous analogue voltages into digital data as well as capturing the output from digital sensors and inputs.

Once the input data has been digitised by the MCU it is transformed into usable data depending on the output device. In many cases this is MIDI data allowing the device to be directly connected to other MIDI devices. Any processing occurring on the MCU can be difficult for user customisation as this requires the firmware of the MCU to be reprogrammed for any changes to be made. Sending the sensor data to a computer allows for software to modify the input data, making a more accessible way for customisation. The raw sensor data can be sent directly to a computer which maps this data to the output sound source, often synthesis software on the same computer.

Programming an MCU has become much easier in recent times with the advent of user friendly integrated development environments (IDE)[1] in particular the Arduino platform. This platform was particularly developed to simplify the process of coding and programming MCU firmware. Roger Linn's Linnstrument uses an Arduino MCU and has been released with the original programming firmware available for editing and reprogramming of the instrument. This allows complete customisability over the device and mapping of input to output. This is unusual for commercial products which normally have locked firmware with curated options for customisation built-in which are either changed on the device or via a computer or tablet application.

The Eigenharp requires a connection to a computer running its companion software to function, which allows the device to be customised. In some ways this is more limiting as the device always needs to be connected to a computer. The products from larger companies tend to be self contained providing basic customisation through the hardware interface with more extensive customisation available when connected to an application

[1] Software applications used to program MCUs.

on computer or tablet. This design provides advantages from both methods by allowing the device to be used stand-alone without a computer but with extensive customisation.

Customisation varies from being able to initialise and adjust how sensors respond to the mapping of the sensor data. This customisation is more important for devices that are stand-alone, as an attached computer can handle all the mapping from raw sensor data. When the mapping is done within computer software the data can be further manipulated in an unlimited number of ways and so there are many varied ideas of how a DMI should be mapped. This of course depends on the desired outcome and capabilities of the instrument.

Mapping Strategies

Mapping is the process of connecting the input stage and an output stage of a DMI. The input stage digitises the performance gestures which are then mapped to the output for the production of sounds. This digitisation provides an almost limitless capability to manipulate and map the input and output signals. With a DMI there is now no need for the input gesture to be directly connected to the output sound generation. With just one touch of a button a complex and sustained layer of sounds can be initiated.

The mapping process can be built into the functionality of the hardware through its internal programming (firmware), outputting MIDI data or similar music control data. Alternatively this could be part of a software programme that receives “raw” sensor data from the controller then interprets, converts and sends an output to a software synthesiser or MIDI output. In both instances there could be a mechanism in place to allow user customisation for different hardware and software configurations. Although this provides a framework for greater combinations of hardware and software it also opens up a debate about what should be connected to what?

Much of the discussions surrounding DMI design revolve around mapping and this is not surprising as it is one of the elements that differentiates a digital instrument from an acoustic instrument. Mapping can be a simple cause and effect button triggering a single synthesised note or a bewildering matrix of connections between multiple gestures and numerous sound parameters producing complex and evolving sounds. Hunt and Kirk (2000) argue that complex multi-parameter mappings can be more engaging to the user than simpler one-to-one mappings. However, Fels *et al.* (2002) suggests that in some cases the one-to-one mappings are more suitable when aiming to provide 'mapping transparency' for the audience. A possible problem with more complex mappings can be a dislocation of causal gesture from the sound initiation or modulation. A spectator may find it difficult to understand how the instrument is played by only observing, which limits the ability to imagine playing the instrument and connecting with the performance. It is possible that this will lead to decreased engagement, (Emerson and Egermann, 2018) and a lesser desire to imitate the instrument.

It is possible for a computer to "play" a digital instrument by playing back a pre-programmed sequence or even generating its own musical ideas. A complex digital performance could be instigated by a simple gesture of pressing a start button or controlling the performance from a computer. In this case is the computer a musical instrument or just a computer device and how would the audience perceive the difference? This question of gesture shows how mapping and gestures are intrinsically linked. Visi *et al.* (2014) have looked to use traditional instrument gestures to inform mapping strategies. This allows an already established gestural vocabulary to inform the mapping in a way that may be more musical than a more artificial mechanism. Jack *et al.* (2017) have taken a similar approach by using the body motions and movements that are desirable for performing to inform the design and mapping of DMIs.

Mappings can be fixed within firmware or left to be customisable, and will depend on what the sound output device is likely to be. Many software synthesisers are configurable to accommodate compatibility with a large range of controllers. However, if the output device is a MIDI hardware device these options are likely to be more limited and so may require some customisability of the mapping within the input device.

Complete control over the device such as the Linnstrument may seem desirable and will definitely appeal to a certain element of performers. However, with such customisability comes a much more complex system to use, programme and understand fully. It is also possible that without the expert knowledge of the instrument designer a novice user may be unable to create satisfying or usable settings, producing a situation where the user is unable to fully enjoy and appreciate the instrument. In many cases, especially in commercial instruments, there is a balance between customisable mapping and fixed mapping. It seems that the instrument should be usable out of the box in a "plug and play" fashion and that the customisability provides additional layers of complexity and control as the user begins to understand and learn the instrument.

It is undeniable that, as West *et al.* (2020) suggests, mapping effects the behaviour and feel of a DMI. Mapping is therefore crucial to DMI design for engaging the user (Hunt, Wanderley, et al., 2003), providing expressive control for musical performance (Rovan et al., 1997) and particularly the perception and understanding of the instrument by spectators (Emerson and Egermann, 2018), a point which is often overlooked (Wu et al., 2016; Barbosa, Calegario, et al., 2012; Lai and Bovermann, 2013).

Contemporary designs of controller and instrument often focus on providing the performer with more knobs, sliders, buttons and so forth allowing the user more control over the digital sounds being performed. However, there may become a point at which the complexity and design of these controllers produce devices more akin to the computer than a musical instrument. The audience could then perceive the device as they would any other computer device and their imaginings and perceptions would be diverted from music instrument performance. As a consequence the overall involvement with the music performance will be reduced compared with DMI design that considers audience response and understanding of performance and gestures. Utilising a completely new gestural language may be engaging for the user but less inviting to the spectator. It is important to consider the combination of a well known gestural language that can be inviting to the observer whilst including new gestural expression that allows for user engagement.

An inclusive DMI should incorporate some customisability but not at the cost of producing an instrument that is overly complex and intimidating to understand and use by a new player. Customisability should be unnecessary at first but allow the user to begin to discover and explore new mappings as they begin to learn and appropriate the instrument.

The original Theremin, an electronic instrument played with hand gestures, had very little in terms of customised mapping as it was not a digital instrument. However, the relative success of the instrument could be due to how the gestures are connected with the sound as Billinghurst (2011:6) states 'there is a direct mapping of hand motion to continuous feedback, enabling the user to quickly build a mental model of how to use the device'. The recent resurgence of the Theremin has brought about a digital version which now does have customisable features and a range of sounds to play. However, the original Theremin is testament to a new gestural instrument that although limited in its customisability can still be inclusive and inviting to play, due to its design and the "mapping" of gesture to sound production. Unlike many DMIs it may not be necessary to provide complete customisability over the mapping and features of the instrument for the DMI to be involving and inviting to both novice and expert players.

There needs to be a balance between simple and complex mappings, the recognisably 'transparent' (Fels et al., 2002) and new gestural language that is mapped and levels of customisability balanced with the fixed mappings. There is no one simple route to the perfect controller. However, with the intention of creating an instrument that is involving, inviting and inclusive, a pathway through the complex issues of mapping may be navigated.

4.2.3 The Output — Sound Generator

The output sound generator is a device or computer software that receives and uses data from the mapping stage of a DMI to initiate and manipulate sounds. The sound generator converts the digital audio output to an analogue signal that is made audible using an amplifier and speaker.

MIDI is the most common connection for DMIs. A MIDI compatible input controller can be directly connected to a MIDI sound output device. In fact, a single controller can be connected to multiple output devices or conversely multiple input devices can be connected to a single output device. In the first instance this may be useful to expand the sound options by combining the sounds from several output devices. In the second instance it might be desirable to combine the control capabilities of two input interfaces, one controlled with the hands and a device that is controlled with the feet.

Although originally MIDI was sent through DIN cables which many devices still use, MIDI data can now be sent directly to a computer via USB. This connection allows a MIDI device to take advantage of a computer as sound generator. A myriad of audio software is now available to create any kind of sound from accurate sampling of acoustic instruments to other worldly synthesised sonic sounds. They usually have a large range of parameters to modulate the sound, many of which can be mapped to the controller. This diversity of sound requires different types of control interface, to take full advantage of the range and capabilities of these sounds. The keyboard has become the ubiquitous controller of choice providing a wide range of playing and control possibilities.

An issue that can affect audience understanding of music performances is the sound dislocation that can occur. As the input and output of a DMI can be two different devices or even the same device but requiring separate amplification and speakers to be heard, the sound can emanate from a different location to the actual device. This phenomenon is uncommon for acoustic instruments, although the pipe organ also can have a separated input and output. This separation can be easily remedied by placing the speaker close to the performer so that the sound seems to be emitting from the locality of the instrument. In larger performance contexts this is not the same issue as all instruments are amplified through a P.A. However, in these situations the understanding and perception of the instrument performance may be impaired by the greater distance between audience and performers. This issue can be partially remedied by the large video screens that often show the performers. However, the smaller and more subtle gestures of keyboards will be more affected in this situation than the potentially larger and exaggerated gestures and freedom of movement of the electric guitar.

New DMI design that aims to create involving and engaging instruments needs to consider the output sound engines that the input interface is likely be used with and how the sound will be produced. This task is difficult due to the numerous output devices and software that can be played and controlled by a DMI. However, the coupling of gestural input and the consequential sound output or sonic modulation is crucial to an audience's perception and successful understanding of the instrument.

4.3 DMI Theories

There are many theories which DMI designers draw from, but the most common and relevant to audience perception and mimetic design will be presented, namely gestures, affordances and appropriation. Each area covers a wide range of topics, so only the specific areas pertinent to instrument design concerning the aims of this research will be discussed.

4.3.1 Gestures

The subject of gesture is, not surprisingly, one of the main areas of discussion for many DMI designers. The topic is far-reaching, from sensing gestures to how gestures are perceived. Some DMI designers may not consider gestural input until the interface has already been devised, and the gestures are then discovered as the instrument is used. In other cases, the concept of gestures is considered to inform the instrument's design at the start of the process. The gestures of virtual, gesture-only DMIs consist of the "instrument" itself, as there are no devices to hold and play physically. This type of instrument disembodies the gestures from the necessity of a device, allowing complete freedom of movement. At the other end of the gestural spectrum, gestures may not be as important as the device's functionality in the case of laptop performances or computer-generated music systems.

Gesture is generally accepted as a crucial aspect of DMI design in communicating the connection between the sound causing action and the sound produced. Therefore, gesture is essential from an audience perspective as the success of expression and understanding of a musical performance relies on the effectiveness of the gestures to fully convey the musical intentions and connection to the sounds produced by the performer.

How gestures are designed and used varies greatly depending on the designer's intentions. When control of the performance and systems is of utmost importance, the gestural aspect of the instrument may not be very relevant. For example, many DJs control their music performance from controllers with minimal gestures relying on large video screens, elaborate lighting, and pyrotechnics to connect visually and entertain the audience. However, the connection and involvement of the audience and player with the instrument and performance is central to this research and will be the focus in the context of gesture.

Producing DMIs capable of musical expression that can mimetically engage an audience begins with the design of gestural input. The large body of work relating to the perception of music-related gesture (Jensenius, Wanderley, et al., 2010; Gritten and King, 2006; Wanderley and Depalle, 2004; Delalande, 1988; Cadoz, 1988; Gibet, 1987) is an excellent starting point. However, to create mimetic gestures, the design decisions need to be influenced by the concept of mimetic cognition. Accordingly, to instigate mimetic engagement, musical gestures need to be visible and contain significant musical information that conveys the performer's intentions so that the audience can understand their actions.

Consideration of the gestural nature of the DMI during the design process should allow for the audience's perspective to be taken into account. Van Nort (2009:177) suggests an alternative approach to gestural design 'from the point of view of the perception of human intentionality in sound'. A DMI does not need to rely on an existing gestural repertoire but can utilise a range of entirely new musical movements. Rather than producing an interface and then deducing the gestures required to play that instrument, the musical gestures can be considered initially and used to inform the design process. Unrestrained by traditional movements, this design method allows the freedom to fully anticipate how a DMI might communicate musical expression to others. When looking at the overall design of the DMI, however, there will be some limitations to the available gestural content, in particular the influence of the instrument's size and layout (Mice and McPherson, 2020). Regardless of any limitations, the possibilities for the gestural capabilities of DMIs are extensive.

Virtuosity

It may be argued that music performance of the western classical tradition has moved away from the corporate inclusion and participation of traditional folk styles to a performer and spectator relationship where skilled performance is appreciated from a position of very little involvement on behalf of the audience. In some cases and for some performers, virtuosity is crucial to the performance requiring an audience appreciation of the musician's skill. How is this appreciation of virtuosity perceived? Brent (2011:429) borrows from critical theory and neuroscience research to explain why our desire for connections between the sound and sound-producing gesture is more than just 'fascination with virtuosity'. He discusses Godøy's (2003) ideas of motor-mimetic music cognition and Cox's (2001) mimetic hypothesis as well as mirror neuron research to provide a biological and neural explanation of how we engage and perceive musical performance and gestural information. This neural process provides a basis for the audience's understanding of musical instruments and performance and goes beyond an appreciation of virtuosity. In addition, it provides a biological framework of how an audience becomes involved and engaged in music and music performance. The intimation here is that virtuosity may seem pivotal to audience appreciation. However, the neural processes for audience perception and understanding that allow such appreciation occur with most musical performances regardless of virtuosity enabling audiences to become involved with the music.

In a panel discussion about virtuosity in live electronic music Michel Waisvisz (2006:415) asks, 'Do we operate our electronic systems or do we play them?'. This question provides an important distinction in DMI design as "operating systems" suggest an extension of a utilitarian use of a computer where musical instruments are "played" not "operated". There are examples of virtuoso use of MIDI controllers but is this just a case of well-performed control, like a typist touch-typing very quickly, or is it performing musically? It may be that virtuosity in and of itself is a signpost of well-developed control but that a virtuoso musical performance also requires the audience to become musically involved through the biological mechanisms suggested by Brent (2011)(Cox, 2001; Godøy, 2003).

Talking about virtuosity Wessel and Wright (2001:11) suggest that DMIs should have a ‘Low entry fee with no ceiling on virtuosity’. Furthermore, DMIs should be accessible enough to engage the novice and have the responsive and expressive musical control that would involve an expert user, providing for the possibility of virtuoso playing. However, it is necessary to design an instrument that connects and involves the audience musically for this virtuosity to be perceived as musical expression and not just an impressive feat of control.

Machover (2002) referring to the ‘inevitability’ of DMIs, asks how we might ‘teach audiences to understand and appreciate the virtuosity and musicality’ of new instruments. The inevitability of a DMI interface may be necessary to how audiences perceive the instrument and make new instruments approachable to new users. However, it is important to realise, as Brent (2011) believes, that our appreciation of music performance goes beyond just appreciation of virtuosity and that these neural mechanisms are part of a complex system of musical perception. Machover (2002) seems to acknowledge this by asking how an instrument might lead to the ‘consideration of rich, expressive, meaningful experiences’.

Gesture-Only Instruments

Gesture-only instruments provide an interesting resource for gestural research as, by nature, there is no discernible interface, and so the performance is entirely gesture-based. This category of DMIs could include glove controllers (Mitchell and Heap, 2011) and potentially body controllers (Tragtenberg et al., 2019) as they are designed to allow the body to act as the controller using various sensors in the gloves and suits. Other gesture-only instruments use separate external sensors such as motion capture technology. For example, the Leap Motion Controller (LMC) (Ultraleap, 2021) has been popular in this area as it is affordable and relatively easy to set up and use. Brown *et al.* (2018) created the ‘Leimu’, which is a gloveless interface that uses a wrist-mounted Leap sensor, for example. Pra *et al.* (2014) compared the infra-red nature of the Leap with an alternative ultrasonic device for finger detection for piano keyboard, concluding that IR sensors could be more sensitive but at shorter distances. Bachmann *et al.* (2018) reviewed the LMC within the confines of HCI (Human-Computer Interaction), concluding that the LMC shows promise in augmenting primary input but suffers in low light conditions. These systems use gestures to control the sound without specifically manipulating an instrument. As a result, it may be challenging to communicate to an audience that the gestures are sound-generating rather than purely synchronised movements to the music.

Billinghurst (2011) describes the Theremin as a natural gesture-only device. However, this instrument has a subtle difference. Although the control is performed with gestures that do not touch any physical object, the performer interacts with a visible physical device. This difference could be crucial for an audience's interpretation of the performance and whether they perceive it as musical.

Perception of Errors

The question arising from these instruments for DMI design is whether the performance is perceived as live or mimed. It is possible, of course, that a digital performance could be entirely played back by a computer whilst the visual performance is carefully choreographed to ensure that the musical movements suggest sound causality. Very small imprecision or performance variations are found in the control and performance of acoustic instruments. Perceived "errors" might elucidate the issue for the spectator and that minor, negligible errors in the performance might even be desirable to assist the audience in understanding that the performance is live.

Part of spectator understanding of music performance is the recognition of "performance errors". Fyans *et al.* (2010) studied the error recognition by spectators of DMI performances. They suggest that a DMI should reveal errors without directing attention toward them. There are several areas of error that can occur within a DMI system. The performance errors are one part that may also communicate the tacit knowledge that the instrument is being performed live by the player. However, potential system errors can occur within a DMI environment. These errors may be computer errors affecting the mapping or sound output or at the input stage where gestures have not been processed correctly or as intended. Acoustic instruments suffer mainly from performance errors, although they can also break, such as a guitar string breaking. The system error of a DMI is unnatural and can detract from the performance. Brown *et al.* (2020:168) found that an increase in system errors also increased performer errors leading to a reduced sense of control and, therefore, the 'instrument being perceived as less accurate and less responsive'. A DMI designer needs to ensure that system errors are kept to a minimum if not eradicated to produce consistently reliable instruments for both the user and spectator.

The gestural language of a musical performance is undeniably a crucial part of responsive and expressive musical instruments that can effectively communicate musical performance to an audience. A DMI that can genuinely involve the user needs to be purposely designed to evince a gestural palette that is initially accessible and approachable but with sophistication for the potential for learning and mastery. It should also be capable of being played with errors when not mastered whilst free from system errors.

As well as being engaging for the user the instrument also needs to involve the spectator in successfully communicating the instrument's playability, the musical expression, and any performance errors that might occur.

The introduction of digital technology provides the possibility to eliminate potential performance variations. For example, in music engineering, a recording can be quantised to adjust the rhythm of the performance to be completely and precisely in metronomic time. However, depending on the style of music, using quantisation to this extreme is usually avoided because it makes the performance sound unnatural and robotic. A DMI that can evidence that a performance is live needs to be capable of generating micro-variations in performance that cannot be controlled and allow performance discrepancies and errors to occur.

Human-Computer Interaction

Human-Computer Interaction (HCI) is a subject that looks at how humans interact with computer technology and devices, which could entail anything from an automated teller machine (ATM) to a TV with speech recognition. In the case of an ATM, it is essential that the interface is intuitive and easy to use and that a new user can understand how to operate the machine immediately with very little guidance. This intuitive nature of the device is crucial for its success; otherwise, many ATM cash machines would have potentially long queues.

HCI has been connected with the design, development and evaluation of DMIs (Young and Murphy, 2020; Knees et al., 2015; Kiefer et al., 2008; Wanderley and Orio, 2002). The overlapping areas of human-machine interaction (HMI) (Cavalieri et al., 2016; Fels et al., 2002; Bachmann et al., 2018) and even brain-computer interfaces (BCI) (Nijholt et al., 2018) have been used to help create and develop new music interfaces. Computer technology heavily influences these areas, which tend to treat a DMI as an input interface. The gestural research based in HCI relates to these types of interfaces.

Billinghurst (2011) discusses gestures concerning HCI design. His work focuses on computing, but his ideas translate to discussing and defining gestures on DMIs. He refers to two types of gesture-only interfaces, namely ‘natural gesture only interfaces’ and ‘symbolic gesture recognition’. Billinghurst gives the Theremin as an excellent example of a ‘natural gesture only’ device as the instrument produces sound in response to the user’s natural hand movements. Of course, DMIs will benefit from natural gestures, and it may be that this type of gestural input may be more desirable than precise tracking in some instances. Symbolic gesture recognition (ibid.) unlike natural gestures, is created to interact with pre-trained gesture shapes. These gestures are regularly a part of VR systems, for example, making a fist to pick something up. VR based DMIs use these types of gestures, but physical controllers may incorporate these types of gestures, such as many of the glove based DMIs (Kestell, 2019; Mitchell and Heap, 2011; Waisvisz, 1985).

Billinghurst (2011:1) uses Kurtenbach and Hulteen's (1990) definition of gesture in relation to computers:

> A gesture is a motion of the body that contains information. Waving goodbye is a gesture. Pressing a key on a keyboard is not a gesture because the motion of a finger on its way to hitting a key is neither observed nor significant. All that matters is which key was pressed (ibid.).

This definition suggests that not only does a gesture need to be visible, but it must contain significant information. Hatten (2004) and Delalande (1988) agree that a gesture must be significant to constitute a musical gesture (Jensenius, Glette, et al., 2010). Both natural and symbolic gestures may be significant depending on the gesture and context. This significance must be considered with DMI design to ensure that the gestural language of the instrument can fully communicate its purpose to the audience whilst remaining intuitive and naturally musical for the player.

Although these areas of computer and machine research can provide interesting illumination in the design of DMIs, there can be a tendency to focus on the functionality and responsiveness of an input interface rather than the capability for communicating expressively on a musical instrument. Many of these DMIs are produced by the designer for their use. The novice user is not necessarily considered at the design stage. These instruments may not be particularly intuitive for the uninitiated and perhaps be intimidating or overly complicated to approach and understand.

Summary of Gestures

Acoustic instruments are designed with the sound production, the resonance of the sound and tone, timbre and quality of the sound as a priority. The performance gestures are taken for granted in most cases as the majority of these instruments are designed in well established gestural languages. An acoustic instrument's initial and modulating gestures are restricted by the mechanical requirement to produce and affect the sound. Although this is true to some degree for most DMIs (Mice and McPherson, 2020), there is much more freedom in the design and use of gestures.

A DMI designed to be involving and engaging for both novice and expert users must consider the inevitability (Machover, 2002) and efficiency (Puig, 2005) of the design, creating an instrument that has intuitive initial playing gestures whilst affording complex gestural control of nuanced modulation of the sound, with the freedom of expressive gestural control, but with the possibility for performance errors to occur.

Novice users will likely experience new DMIs as a spectator. Their desire to try out the new device would have originated from being initially engaged in a performance of the instrument from an audience perspective. It is therefore vital that a DMI involves the audience and the user. Gesture plays an essential role in spectator perception and understanding of instruments. The gestural language of an engaging DMI needs to provide observable movement and an unrestricted vocabulary of significance that can be communicated fully to an audience. The perceptions and significance of gestures require exploring other research areas to help understand how to design effective music gestures for mimetic musical instrument design.

4.3.2 Affordances

Affordance is a theory that looks at how a design may embody a particular way of being used that is obvious or intuitive to the agent or user (Gibson, 1977; Norman, 1998). For example, in the case of a chair a user will instinctively know the chair's purpose and how to use it. However, the context and the knowledge of the agent (user) can inform the affordances. For example, a person will sit on a chair, and woodworm will eat it. However, a person who is under attack might use the chair in self-defence (Cano, 2006; Clarke, 2005). Affordances can therefore change depending on the agent and the circumstances.

Society and culture can also influence the affordances of an object (Einarsson and Ziemke, 2017). Knowledge of our surroundings and objects built up through education and experience also creates certain expectations of an object's use and purpose. Discussing cultural constraints, Magnusson (2006:443) suggests that ‘The trained musician often has problems of breaking the boundaries of the expressive scope of the instrument’. These musicians may experience constraints when introduced to a new and unfamiliar musical interface.

In the case of DMI design, the theory of affordance helps explain and explore how digital input interfaces can be designed to be used and played as musical instruments. Cannon and Favilla (2012:459) suggest that ‘Expression is proportional to the sum of invested play and the processional affordances latent within the DMI system’. This interaction with the musical instrument is an artistic process governed by the DMI system’s affordances’. The process of “play” allows the player to develop a relationship with the instrument. The affordances give an initial pathway to “play”, which is moulded into more nuanced performance and control over the instrument given time and practise. The development of a DMI is often an iterative process which can benefit from user input to develop and increase the effectiveness of the instrument’s affordances. This process can help produce expressive DMIs that are initially accessible and inviting to the new player yet allow for developing technique and nuanced control for the experienced player.

Bell (2018:168b) presents the 5 Ps of affordance for DMIs and devices. ‘Presumptions’ are the basic functionality necessary for the instrument to work. ‘Privileges’ are functions that are designed to be easier to guide the user to them. ‘Provisions’ are controls of the device that provide a multi-functional purpose where the user has a choice of control. ‘Protections’ are hidden controls or functions that require user knowledge to access them. Lastly, ‘Preventions’ are functions that are deliberately removed and are inaccessible from the device. The 5 P’s provide a framework to develop multiple levels of affordance. For example, Cannon and Favilla (2012:464) confirm that ‘increasing the number of mapping layers and signal routings, will afford an increase in expression’. Affordances must therefore be considered multi-layered. However, care must be taken not to overcomplicate such designs taking into account the “prevention” of some functionality for the good of the device as a whole. There may be a limit to the number of control layers a user can fully utilise. Cannon and Favilla (ibid.) found that number was between six and ten with the two

DMIs they were studying. More complex mappings can also disrupt the aural causality of the sound and, therefore, audience perception.

Acoustic instruments have affordances that enable a new player to pick up the instrument and instinctively know how to hold the instrument and produce an initial sound. When dealing with a new DMI design, this affordance may be lost, so a new player may not be able to ascertain how to hold, play or control the instrument and may not even know that the device is a musical instrument in the first place.

Tanaka *et al.* (2012) found that consistent mapping of controllers to sound and sonic effects allowed users to experience musical affordances. Paine (2009:142) argues that 'interfaces need to communicate something of their task' and that the device's affordances are crucial for action causality of the sounds to be clearly perceived as performance gestures. DMI design needs to consider consistent mappings to generate effective musical affordances and communicate their musical task.

The affordances of a musical instrument should invite the user to want to play and use the instrument (Cano, 2006; Volli, 2003; Cox, 2001). An instrument that invites the onlooker to "have a go" should afford a basic understanding of what the instrument is and how it functions and is played; otherwise, it would be difficult for the observer to imagine playing the instrument and, as a consequence, diminish the desire to play the instrument. These 'Presumptive' affordances should be obvious. However, the 'Privileged', 'Provisioned', and 'Protected' affordances can be layered to allow the user further discovery and development of their playing skills and musical expression. It may also be necessary to 'Prevent' some affordances when considering the music interface and system as a whole (Bell, 2018).

4.3.3 Appropriation

Dix (2007:1) states that 'users appropriate and adapt technology in ways never envisaged by the designers'. However, this does not necessarily mean that the device has built-in configurability but that the user has adopted the instrument and uses the instrument in ways that the designer might not have intended. In discussing design constraints

Magnusson (2006:443) looks at how tools have their 'designed usage' and 'transformed usage'. Transformed usage is when the device is used in ways not intended by the designer. Transformed usages may often come about through design constraints rather than excessive features.

Zappi and McPherson (2018:1) have considered Dix's principles of appropriation in relation to music instrument design and were led to the conclusion that tighter design constraints can 'paradoxically lead to a richer performer experience'. Wright (Wright, 2020) agrees with this belief suggesting that 'the high degree of constraints led to a diverse range of playing styles, allowing each player to appropriate and explore the instruments' (Zappi and McPherson, 2018:1). Zappi and McPherson (ibid.:15) suggest that the concept of appropriation should be considered in DMI design 'because the most artistically successful uses of a new instrument may be those that the designer has not foreseen'. The question for the designer then is not necessarily to focus on customisation but to consider how appropriation may be enabled. 'You may not be able to design for the unexpected, but you can design to allow the unexpected' (Dix, 2007:1).

Many newer DMIs can control a self-contained music system allowing the performer to be a modern digital "one-man-band". DJ performances have commonly been solo performances, but there has been a trend to use digital music equipment to control the recording, looping, and playback of live performances. These performances consist of a single performer playing various instruments or creating different musical parts and layering these loops to create a complete musical performance on their own. An inclusive DMI should encourage the use of technology in collaboration rather than in isolation. The instrument should provide the features and control of the sound production that allows the performer to integrate with other instruments and performers. This aim can be difficult if the instrument controls the entire music system and is being used with other DMIs that also control music systems. A DMI should be designed for musical collaboration despite the difficulties.

Moldover's Octasmasher (Blanes, 2018) was designed specifically for this purpose, where each of the eight sections of the instrument requires a separate performer to control the different sounds. Although most instruments will be designed for a single user, the concepts of inclusion and collaboration that were the inspiration for the Octasmasher will surely benefit any new DMI. Calegario *et al.* (2020) have created the Probatio toolkit for developing DMI prototypes. This project gives access to hardware and software methodologies for producing DMIs. It provides more structure for generating DMI ideas helping reduce the time and effort in building prototypes. This project may produce a community of DMI designers that are more collaborative due to the shared starting point for design instead of the very bespoke nature of many devices. Devices that leverage Internet of Things (IoT) technologies allow many small devices to connect and talk to each other. In the case of Smart Musical Instruments (SMI) they can communicate with each other, opening a new way for DMIs to collaborate. Turchet and Barthet (2019:364) have investigated the emerging area of collaborative SMI. They noticed that some of their participants wanted to explore ‘crosscontrol between performers’. SMIs could provide mechanisms whereby multiple performers can control different aspects of the same sound generator or output. There is a great potential for collaborative projects in DMI creation. With these new digital technologies, new ways of collaboration are to be explored beyond the traditional musical concepts of joint participation. These technologies may help direct DMI design towards a more collaborative ethos with the hope that the appropriation of these instruments will also cause an appropriation of the inclusive ideals by the user base.

Kano’s *et al.* (1984) theory is focused on consumer satisfaction and is an established theory in quality control. The success of a product is affected by user understanding and perception of the design and their satisfaction. Although these design theories are typical for companies that produce musical instruments for commerce, they are not usually considered for DMIs that have been created within the research community. However, this type of design theory is still worthy of consideration within the research context. Kano describes three categories of consumer expectation: basic needs, performance needs and attractive (delighter) needs. Basic needs are the minimum requirements for the device; for example, a watch must tell the time. Performance needs are expected features that can be defined, discussed, and separated from competitive products, such as a more accurate watch. These needs could include price, feature set, level of performance and quality. The “delighters” or attractive needs are those that are unexpected but excite the user (Južnik Rotar and Kozar, 2017). A watch may measure heart rate, for example. One of the concepts from Kano’s theory helpful to this discussion is the idea that features that were once exclusive “delighters” eventually become expected “basic” features. This idea is commonly experienced with the development of cars, providing endless examples. For example, at one time, power-steering was only found as an added extra or on high-end vehicles. However, it is now an expected feature and appears in all cars regardless of size or cost. This transition of features occurs with commercial DMIs as well. The first controller keyboards introduced features such as pitch bend as additional “exciters” for their product. However, as the consumers appropriated those features, they eventually became part of a consumer expectation and, therefore, a basic feature. These “delighter” features must also be considered in DMI design in addition to the “basic” and “performance” features to encourage adoption and appropriation of the instrument.

The nature of DMIs allows for customisations that can create bespoke instruments for particular user needs. This potential for customisation has made these instruments attractive for adaptive technologies, which benefit people with some restrictions or difficulties in playing existing instruments. The popular button type controllers dominate the current market for controlling performance software such as Ableton Live. Roger Linn’s “Linnstrument” is a highly configurable type of button controller. It includes a grid of LED-lit pressure-sensitive multi-function pads. Compared to other commercial counterparts, the main difference with this device is its open-source platform on which the firmware is based. The MCU hardware and firmware are based on the Arduino Due (popular with makers and hobbyists), and the custom Arduino Linnstrument firmware has been made openly available to the public. This open firmware means that the hardware is entirely customisable, allowing owners to reconfigure all settings and functionality, including sensor interpretation, mapping and MIDI output. This level of configurability can also let the user “break” the device and requires a specific level of expertise to manage these customisations. Novation’s Launchpad, like most commercial devices, has a closed firmware and so the user can only access the functions and customisations chosen by the designers.

Graham Pullin (2009:86) suggests that 'Sometimes it is better to deny the user a feature that could have been useful, in favor of a better overall experience' (Bell, 2018:169a). The Linnstrument's complete customisability may conflict with the overall experience limiting the user base to a niche expert consumer. Goudard (2019) comments that the customisation of user bespoke instruments found in many DMI designs may prove to be difficult for others to adopt. Like the Linnstrument, these devices will have a very limited user base. Cannon and Favilla (2012:459) discuss this issue where they suggest that 'appropriating the latest forms of technology' is for 'novel and often short-term musical ends'.

Customised DMIs can make music more inclusive. However, the ability for user customisation may not always produce an inclusive instrument. Extreme customisability may be prohibitive and intimidating to users due to an overwhelming and unwanted capability for modification. Customisation can encourage appropriation of the instrument, but there needs to be a balance between inclusive customisation and prohibitive complexity.

When considering expanding the user base beyond the usually small group consisting of the designers themselves, the relevance of business design models for DMIs becomes more apparent. Considering the commercial aspects of design will help produce instruments that are more likely to be appropriated and, therefore, more fully explored, exploited and further understood as the users take the instrument beyond the original design intentions. There needs to be a balance of simplicity and complexity provided by additional features and customisability to avoid the 'reverse' undesirables of customer satisfaction whilst providing the 'exciting' features that will lead to appropriation (KANO et al., 1984).

The precepts of collaboration need to be embedded from the initial design process to encourage musical collaboration and inclusion of the instrument within more diverse musical contexts. Some customisation needs to be provided to produce a more inclusive device but not at the detriment of the overall user experience. This balance is crucial for the user experience and how the instrument will be perceived by and include an audience. A more inclusive DMI is likely to create a more extensive user base and user community, which will generate more appropriation that should produce more long-term use.

4.4 Challenges for DMI Design

The low cost and availability of modern sensor technologies, electronics kits, micro-controller units, and integrated development environments (IDEs) for programming the MCUs have spearheaded a burgeoning ‘’maker” age. With the proliferation of access to relevant information and equipment, any interested party can learn, understand, design and develop electronics for many applications. It is not surprising then to discover that there has been a surge in interest in developing new and custom DMIs. The information and technologies available provide the basis for creating instruments of almost any configuration and design, seemingly only limited by the imagination. And so, the attention of some DMI builders has turned to the question of why not how. Designers draw on many areas for inspiration and direction. Many problems challenge the perception of what constitutes a DMI and how the instrument’s success is measured and categorised in a cornucopia of design ideas, concepts and instruments. There are several common challenges in DMI design that are worth looking at more closely.

4.4.1 Audience Engagement

Although not central to many DMI designs audience perception is an important consideration to some DMI designers. Pivotal for these discussions is the link between the gesture or musical movement and the sound or sonic effect that it produces (Jensenius, Wanderley, et al., 2010). Frengel (2010:96) suggests that ‘disparity often arises between the physical gestures made by the performer and those implied by the music’. Emerson and Egermann (2018:23) discovered that a ‘higher degree of perceptible causality’ in the design and performance of the instrument ‘provides the spectators with more information and more reference points for evaluating the performance'. They, therefore, believe that designing DMIs with greater 'perceptible causality' will produce new DMIs that 'are to play' and 'perceive'. Which, in turn, should produce instruments that are more involving and engaging to an audience.

Audience engagement is an essential aspect of new DMIs, but in the design, the spectator is often overlooked (Wu et al., 2016; Barbosa, Calegario, et al., 2012; Lai and Bovermann, 2013). Solving the sound decoupling problem is part of the larger issue of audience involvement and engagement, but this is more complicated than action and sound synchronicity and causality. Audience understanding and interpretation of gestural intention are crucial to how the DMI is perceived and accepted as a musical instrument. The performance gestures, going beyond the pressing of a key on the keyboard, must contain 'information' that is 'observed' and 'significant' (Kurtenbach and Hulteen, 1990).

Spectator perception of digital instruments and performance cannot entirely be understood through analogies of acoustic performances (Barbosa, Calegario, et al., 2012; Gurevich and Fyans, 2011). HCI theory has been used to understand DMI design further. However, there are some disadvantages with HCI concerning the audience perspective. In HCI, the focus is on user interaction which has often led DMI designs to consider the spectator perspective (Barbosa, Calegario, et al., 2012) insufficiently.

The audience should not need any proficiency or experience in playing an instrument to engage in the instrument thoroughly, which is evidenced by the popularity of the World Air Guitar Championships, where competitors are quite often non-guitarists. The spectator, however, needs to have a basic understanding of the workings of the instrument to appreciate the performance (Fels et al., 2002). This understanding comes from cultural knowledge, which might include previous knowledge of the instrument but also more general 'percepts of physical causality relationships' (ibid.:111). However, Bin *et al.* (2016) discovered that increased audience knowledge does not seem to have an impact on interest or enjoyment.

Capra *et al.* (2020) have designed a system to provide the audience with more information and cues during performances with DMIs. Their non-invasive system can be used without altering the design of DMIs. This system is helpful for existing instruments providing a possible mechanism for greater audience engagement. However, for new DMIs, the audience perspective should be considered in the design at the beginning, not retrospectively. O'Modhrain (2011:33) recommends that the spectator should be involved in the early stages of the design process to ensure that 'intended causal links are evaluated'.

Many factors influence audience involvement. There is always 'some form of communication and interaction between performer and audience' (Lai and Bovermann, 2013:173). This communication can come from gestures which are causal to the sound. However, there are performance gestures that, although do not directly play or affect the sounds they, are important in audience perception. These 'ancillary movements' (Cadoz and Wanderley, 2000; Jensenius, 2007) are commonly accepted as integral in the communication of musical performance and expression. Inter-modal gestures must be carefully balanced with sound causing gestures to ensure minimal sound decoupling.

Sound Causality and Dislocation

The nature of DMIs having a separate input section connected to the output sound source can often lead to sound decoupling or dislocation. This characteristic is not unique to DMIs, however. With the advent of amplification, a sound source can be heard from speakers that are at a distance from the instrument, typical for the electric guitar, which needs an amplifier and speaker. Even further back in history, however, the pipe organ could also be described as having sound dislocation, especially when the keyboard section was located at a distance from the pipes that produce the sound. Emmerson (2007; 1994) presents three 'acousmatic dislocations':

- *Time* (recording);
- *Space* (telecommunications (telephone, radio), recording);
- *Mechanical causality* (electronic synthesis, telecommunications, recording).

Emmerson (2007) suggests that these dislocations may be re-established through a more 'ambiguous relationship': by 'mixing some directly perceivable cause-effect chains'

(Emmerson, 2007:91) with gestures the performer understands, but not the audience, and experimental, gestures that are unpredictable. These dislocations and modern complexities of live performances and digital technologies have blurred the lines between live performance and 'mediatization' (Sanden, 2009:8). Rather than distinguishing between "live and "not live" Sanden (ibid.:8) suggests that we should consider a '*trace* of that which could be live, in the face of the threat of *further* or *complete* mediatization'. This "trace liveness" may, in some cases, be difficult to determine but could be key to finding ways to re-establish the perceived causal links of sound production.

Although decoupling of sound and gesture may be due to the physical separation of the gestural device and sound source, it can also be caused by a lack of understanding and knowledge of the performance gestures and linked sounds. However, even if the audience misunderstands a particular sound production, the audience may still be led to perceive the sound as having been played live. Sanden (ibid.:8) agrees with Emmerson's (2007:93) suggestion that this 'trace of liveness' could be imagined, and therefore the importance is that the sound is perceived to be live whether a corporeal physical action produces it or not. A sound emanating directly from an instrument that is not understood may still be perceived as having a decoupled sound. For example, when a keyboard with built-in speakers plays a guitar or drum sound. These sounds are not expected or understood as being produced from the action of a keyboard. However, the same keyboard could play a piano, organ or harpsichord sound with much less decoupling. In contrast, an electric guitar is so familiar that there is a basic understanding of the workings of the guitar. So an amplifier separate from the guitar, even at a considerable distance, may not cause decoupling as this separation of guitar and produced sound is now universally accepted and understood.

Maes *et al.* (2014:1) state that 'perception spurs action tendencies' and that 'close coupling of action and perception' are central to music cognition. Barbosa *et al.* (2012:2) believe that this coupling of action and sound is key for 'making a performance convincing for the audience'. O'Modhrain (2011:33) agrees with this supposition, suggesting that causal relationships need to be reintroduced that 'allow for the modeling of performer intent'. The concept of 'performer intent' is critical to understand in the context of DMIs. DDMIs designed for body control of music, such as motion gloves (Mitchell and Heap, 2011) lack an obvious musical interface. Although the movements may seem in time with the music, they could lead the observer to assume the movement is purely synchronised to the music and not actuating or causing the sounds. These movements may be perceived as moving to the music and dancing rather than intended musical performance and control, therefore decoupling the causal movements from the sounds.

At the extreme of this issue of decoupling is laptop performance, where it has commonly been discussed that the performer might be writing emails rather than performing music. Brent (2012) states that 'early criticism of laptop performance focused on the unclear nature of connections between physical action and sonic result', and according to Brent, this is due to 'jarring' caused when the basics of understanding of the physical relationship between the performer and instrument are missing. Lee (2019b) argues that the audience should see the laptop screen to communicate something about the laptop performance. The visible laptop screen may allow stronger links and associations with the workings of the laptop and the sounds produced. However, understanding the mechanism of the laptop may not entirely convince the audience that the tapping of keys on a computer keyboard has any musical intention. Van Nort (Van Nort, 2009:177) suggests that the 'perception of human intentionality in sound' should be considered as a design principle. This intentionality of sound should communicate to an audience the necessary significant information regardless of audience experience or knowledge.

Spectators must perceive musical intention to successfully connect the playing gestures on the device and the resulting sound output. Therefore, this musical intention is crucial for audience understanding, engagement, and involvement in the performance. The complex area of gesture and audience perception involves many different areas of research and consideration. However, this complexity does not mean that the spectator viewpoint and audience engagement should be ignored in DMI design.

4.4.2 Inter-modality, Aesthetics and Expression

It may seem obvious that the aesthetics of an instrument and the visual display of gestures of a musical performance are important to its perception. However, the link between the visual and the aural goes much deeper. Inter-modality is a term used to describe how our perception consists of the sum of all our senses, not relying entirely on just one sense. Our perception can lead to one sense overriding another, leading to the other being perceived "incorrectly".

Shams *et al.* (2002) double flash experiment shows that what we hear can affect the perception of what we see. In the experiment, a single flash on a screen is accompanied by a double beep sound. The viewer is convinced that they see two flashes even though their eyes only ever see a single flash. McGurk and McDonald (1976) discovered that this inter-modality could occur between hearing and sight, which their experiment shows clearly. When we see a person's lips moving to speak a "fah" sound and then hear the sound of someone speaking a "bah" sound, the information from the eyes overrides that of the ears, and we perceive a "fah" sound regardless of what our ears are actually hearing. This effect still occurs even when the viewer knows of the effect and that they should hear "bah". Regardless the "fah" sound is still successfully perceived. There seems to be no way of consciously turning this inter-modal perception "off".[2]

This McGurk effect has far-reaching implications for music instrument design once we accept that the perception of what we hear can be significantly different to what our ears actually hear. In discussing Motor-Mimetic Music Cognition, Godøy (2003:317) states that '...the cooperation or interaction of the senses is "spontaneously" at work in any act of human perception and cognition'. The instrument's appearance and how it looks might affect the perception of the sound being played. What is seen during a musical performance may not only change the way the performance is perceived but might change the sounds that are perceptibly heard. Great consideration needs to be taken to ensure the aesthetics of a mimetic instrument take full advantage of inter-modality, ensuring that

[2] An example of the McGurk Effect can be observed here: https://research.bazerbow.uk/McGurk-Effect/

the device is perceived as a musical instrument, not just another computer device or toy.

Ancillary Gestures

Dance and music have always gone together (Duerden, 2007). The expression of movement found in dance communicates much of what the music does. Krumhansl and Schenck (1997) found that the dance from a ballet conveyed similar emotional and structural information as the accompanying music. Most musical performances include playing gestures that are not physically necessary for the production and modulation of the sound. However, these ancillary gestures, as with dance, play an important role in communicating musical expression and emotion.

The role of gesture in music performance with acoustic instruments is linked directly to sound production. However, many performers use ancillary gestures in addition to those necessary for sound production. It is debatable whether these additional gestures directly affect the sound or only have a visual presence.

The Moeller technique (Famularo and Bergamini, 2001) is a gestural technique applied to drum playing. It is often implemented in military snare drum technique. The complex gestural system can be very visual but also has a practical musical use. The different gestures and positions of the hands and arms precisely control the volume and tone of the sound produced. By incorporating the elaborate gestures, drummers can achieve a high level of speed, control and consistency. In this instance, although seemingly inter-modal, these gestures have a physical effect on the production of the sound.

True inter-modal or ancillary gestures do not physically impact the production or modulation of the sound. However, these gestures are still crucial to musical expression. Wanderley and Vines (2006) have explored the ancillary gestures of clarinettists, discovering the importance of these gestures for communicating expression. Weiss *et al.* (2018) have studied how these gestures affect the perception of musical performance. Their tests showed that these motions do influence perception and that performances with larger ancillary gestures scored higher in their test, showing greater communication of expressiveness, fluency and professionalism. Their tests also showed that experienced musicians were more influenced by the sounds they heard and were more capable of perceiving and understanding performances with little movement by the musicians. Other studies also confirm the importance of inter-modal gestures in musical expression across different styles of music and instruments (Davidson, 2006; Elsdon, 2006). Inter-modal gestures also benefit audience engagement (Paine, 2007) and communication (Thompson et al., 2005) between performer and audience (Mitchell and Heap, 2011).

Palmer *et al.* (1989) showed that children and adults could both perceive the inter-modal relationship of the sight and sound of a musical instrument. Therefore, no particular experience or training is necessary to detect inter-modal relationships. However, it may be that the instrument's design can affect this perception.

Light and Sound

There has always been a strong interest in light and sound, both scientifically and musically. The Pyrophone was invented by Frederick Kastner around 1876 (Peacock et al., 1988) which connected a keyboard to the ignition of the gas. The Pyrophone is one of many instruments which aimed to include some kind of light capability. The Laser harp (Szajner, 1982) a more modern light instrument, was introduced in the 1980s, arguably invented by Geoffrey Rose or Bernard Szajner. It was made famous by Jean-Michel Jarre (Jarre, 2021) who has used this instrument at many of his performances. The Laser harp is an array of laser beams which, when interrupted by an object, usually the hand, a signal is sent to a synthesiser and sound is produced. The different laser beams correspond to different pitches. There have been various incarnations, but they embody the same principle.

The importance of visuals in modern performance cannot be underestimated. Combining the visual with the audible pervades much of modern musical performances, especially contemporary popular styles of music with light shows and video an integral part of the concert and often accompanied by fireworks and other pyrotechnics harking back to the Pyrophone. Robert Henke has produced and performed "Lumiere" (Henke, 2013) since

2013. As one of the developers of Ableton Live, Henke utilises this software to perform all the sounds and laser show from the same computer system, therefore, complementing each other to allow the music to combine and respond to the light show. This system creates a light show perfectly synchronised and performed with the audio. Despite the popularity of live visuals in modern music performances, their effectiveness in audience understanding of electronic music performance has not yet been fully explored (Correia et al., 2017). Thompson *et al.* (2005) suggest that the facial expressions and gestures of the performers are being replaced by other types of visuals such as the light shows.

Aesthetics and Materials

If inter-modality plays a part in informing the perceived sound, then the aesthetics and materials of the instrument are more critical than purely cosmetic. Acoustic instruments tend to be made from materials that resonate, such as wood and metal. We understand and have an expectation of the sound that these materials might make. Computer control devices tend to be made of processed materials such as plastics and PCBs. DMIs often look more similar to these computer devices as they share the technologies and are often made with the same materials. However, DMIs that are designed and use materials that pertain to an acoustic instrument may be able to leverage inter-modal perception creating a DMI that an audience will perceive as capable of producing sound. The audience's expectation of this sound will affect their overall perception of performance before any sound is heard.

New DMIs are often presented in a development stage, and as Goudard (2019:351) has observed, they are 'often fragile, prototypical assemblies, full of cables…'. For example, Jordà (2005:276) presents the Qwertycaster, which uses parts of computer input devices cobbled together. It represents this prototypical group of DMIs. These instruments are an inevitable stage of development, but the inter-modal response could be negatively affected by the unfinished state of these DMIs. There are examples of fully developed DMIs, such as the Eigenharp, made from wood and metals, making it look and feel like an acoustic instrument.

Modern production methods and technologies such as 3D printing and CNC machining have opened up more possibilities for manufacturing devices. Virtually any shape of an instrument with any playing gestures can be designed, produced and mapped to synthesisers, so maybe the question should not be what but why? Brown et al. (2017) suggest that usability and aesthetics are often the primary focus for DMI evaluation whilst ‘enchantment’, ‘motivation’ and ‘frustration’ are overlooked. In this case, however, aesthetics mainly refers to how the instrument looks without considering inter-modal perception. A DMI design that is genuinely inviting to the audience must consider the implications of inter-modality beyond purely aesthetics or ergonomics of the instrument.

Expressive Control

Rovan *et al.* (1997:68) suggest that ‘A common complaint about electronic music is that it lacks ‘expressivity’. They postulate that to model this expressivity, the ‘physical gesture’ must be modelled ‘in all its complexity’. This modelling is intricate in practice, however. Jack *et al.* (2017) discuss the issues involved in sensing complex gestures and describe a ‘bottleneck’ of ‘reduced control’ that occurs within the process of capturing gestures. Their solution is to reposition this ‘bottleneck’ through design choices and, therefore, must be considered at the start of the design process. Medeiros and Wanderley (2014:13583) suggest there needs to be an improvement in sensing design by using ‘state-of-the-art engineering techniques’, which they believe will ‘bring improvements concerning explorability and feature controllability’. Using advanced sensing and processing techniques may also help to alleviate Jack’s *et al.* (2017) ‘bottleneck’.

Expressivity in new DMIs is quite often approached by designing instruments that provide more gestural control. These gestures may have been informed by acoustic instruments where the traditional gestures are imitated to some extent. Various technologies have been implemented to capture the complex motions of music gesture (Hemery et al., 2015; Overholt et al., 2009). New MPE technology extends conventional keyboard’s capabilities by adding very nuanced gestural control to the more traditional gestures of keyboard playing. MPE allows a new level of expressive capabilities for the performer, but these features alone do not address how the audience will perceive these small nuanced gestures. The capability of these instruments facilitates far more control over the expansive synthesised sounds available to the modern performer. However, the nature of this control may not be evident to the spectator and, therefore, not fully communicate the musical intentions of the performance.

Mapping is of great importance in generating expressivity in DMIs (Wanderley and Depalle, 2004; Fels et al., 2002; Rovan et al., 1997). Wu *et al.* (2016) found that synchronous mapping was found to be more expressive and engaging, whilst Rovan *et al.* (1997) found the more complex 'divergent' mapping to have potential for greater expressiveness. It is likely, however, that a combination of direct and simple 'transparent' (Fels et al., 2002) mappings and those of a more complex 'multiparametric' (Hunt and Kirk, 2000) nature will produce an overall greater capacity for expression. Expressive capabilities are often discussed with only the performer in mind (Wanderley and Depalle, 2004; Arfib et al., 2005). However, the audience plays a significant role in how this expression is perceived and interpreted (Weiss et al., 2018; Fels et al., 2002). Larger gestures can be perceived as more expressive even if those gestures are ancillary and inter-modal (Weiss et al., 2018; Nusseck and Wanderley, 2009). Therefore, it is crucial to consider audience perception during the design process to ensure that larger gestures are incorporated and mapped to communicate musical expression to spectators fully.

Emerson and Egerman (2018:5) discovered that the visual aspect of musical performance is significant to the perception of the performance, concluding that 'conflicting or confusing audiovisual information might be less effective at communicating musical intentions to an audience'. The visual aspect of a DMI is crucial to the success of expressive musical communication with an audience.

Medeiros and Wanderley (2014) suggest that a balance between the areas of arts, design and engineering is necessary to produce aesthetically appealing instruments that are also robust and responsive. Although DMIs are usually heavily laden with technology, the artistic side of the design should not be neglected over the technical and digital design and engineering of the device. There seems to be an artistic process in building acoustic instruments, especially hand-built instruments, that pervades the instrument throughout the process, eventually leading to musical performance. Unfortunately, this art is mostly lost when DMI design focuses on technology and “digitalness”.

Artistic and aesthetic intentions should be fully integrated into DMI design by considering how inter-modal perception might affect an audience’s perception of an instrument and how sounds performed by the instrument might be perceivably heard. Also, a balance of simple and complex mapping needs to be considered to provide effective music expression and encourage gestural performance that gives the performer nuanced control and successfully communicates expressive performance to an audience. Jordà’s (2005) theory of instrument efficiency looks to formulate the complex balance of simplicity versus complexity in instrument design, aiming to understand how this affects playability, longevity and a player’s perception of an instrument.

4.4.3 Longevity and Popularity of Design

As longevity requires consistency over time, a DMI needs to develop slowly and iteratively to allow the full exploration and appropriation of the device by a user community. Some may see the common ephemerality of DMIs as a desired and innate characteristic of such devices due to their usually bespoke nature (Goudard, 2019). This attitude is perpetuated by the current trend of the ‘economy of obsolescence’ (ibid.:350) of modern commercial, technological devices and the rapid transformation of the technology sector as a whole. This rapid transformation produces compatibility issues and requires immense forward thinking to develop technologies that will guarantee compatibility far into the future. MIDI has provided a solid framework for the connections of music devices that have lasted several decades whilst creating a new standard that remains compatible with the original protocol developed in the 1980s.

Cannon and Favilla (2012:459) believe that the ‘culture of *disposable* instruments’ is detrimental to the longevity of DMIs as little time is invested in playing and learning these instruments. The design of DMIs needs to be inclusive in nature to encourage longevity, inviting players of all abilities to want to invest their time in playing and learning the instrument. To appeal to a broader user base, encouraging playing and learning, DMIs also need the capability to be used in the many and varied use contexts that music provides with the ability to join in with improvised performance, be a part of an ensemble or a soloist in a group. Arfib *et al.* (2005:127) suggest that this adaptability of an instrument affects its expressiveness: the more adaptable, the more expressive. The larger the range of music situations the instrument can be used in, the greater the number of potential users. This diversity perhaps explains, to some degree, the popularity of the keyboard. Despite lacking in visual presence, it has become a versatile digital instrument capable of playing in traditional and contemporary settings as a solo instrument and well suited to group playing.

Goudard (Goudard, 2019) argues that the modular nature of DMIs adds to the perception that DMIs do not reach maturity. However, this modular nature is not unique to DMIs. For example, the modern drum kit has always had a modular structure (Bell, 2018) allowing the drummer to select different types of percussion and add it to the kit for different genres and musical scenarios. The drum kit is generally perceived as a single instrument rather than as the many different and varied parts that makeup drum kits. The drum kit has become a well-established instrument, particularly in popular music. It has now also been recognised by many of the more traditional music establishments by providing drum kit syllabuses and exams (ABRSM, 2014).

DMIs should be designed with a balance of commonality and individuality. It should serve the purpose of more than the customised intentions of an individual. It should be adaptable to a wide range of use contexts, compatible with past and future technologies and make potential users want to invest in learning and playing. How do designers go about this difficult and complex task? The answer lies partly in the careful consideration and integration of audience inclusion and appropriation from the beginning of the design process. Most stakeholders for any particular instrument will have been initially attracted to the device as a spectator.

Lucas *et al.* (2020:248) suggests that users of DMIs would benefit from a 'community of practice' rather than '*service-based* support'. Marquez-Borbon and Avila (2018:190) support this supposition but add that in addition to a target community, 'a non-traditional pedagogical system that sustains artistic practice' may also be required. This community of stakeholders is crucial for the long term support of new DMIs, but how can these people be brought together? Vine (2010:167) believes that a shared knowledge base could help new DMIs to be appreciated by a wider range of '...players, composers and researchers/developers'. This statement misses out on an important group of people—the audience.

Morreale and McPherson (2017) have looked into designing for longevity by researching various instruments presented at five successive NIME conferences between 2010 and 2014. Their research consisted of interviews with the designers providing an interesting illumination of the designer's process and development of a DMI but completely ignores how the instruments are perceived and received by an audience. The audience seems to be overlooked in the case of the potential longevity of new DMIs. Each new design needs to recruit a critical mass of interested parties for the instrument to continue into future works and performances. Once the instrument has been designed and built, it needs composers and performers outside of the designer's world to take on the instrument and begin to use the instrument for musical purposes. These composers and performers will usually have experienced the new DMI as a spectator, and something about the instrument in relation to the audience's perspective sparked an initial interest. New mimetic DMIs need to be inclusive to a wide range of people focussing on an audience perspective to ensure they can engage and invite new users of all abilities and musical experiences to encourage a diverse user base for the continuation of the instrument in the future.

4.5 Summary of DMI Design

In addressing this enquiry:

> Which existing general DMI concepts are important to mimetic instrument design and what are the common issues that DMI designers attempt to address? (Section 4.5).

I identified three main theories that were relevant to my design process:

- Gesture
- Affordance
- Appropriation

and several common challenges that I found to be important to my work:

- Audience Engagement
- Inter-modality, Aesthetics and Expression
- Longevity and Popularity

The next chapter aims to incorporate these ideas with the concepts from the mimetic theories (chapter 3) to present mimetic design principles that I formed, developed and used in the design and making of my prototypes and the subsequent testing phase.

Chapter 5

Concepts Devised for this Research | *Mimetic Design*

This chapter will discuss my concepts of mimetic design, including the three I's of audience involvement, invitation and inclusion and how mimetic design addresses these three I's. Mimetic design principles are presented to conclude this chapter.

I constructed these mimetic design ideas in response to my earlier experiences of electronic performance with guitar, keyboard and controllers. Dissatisfaction with my setup at that time led me to consider not only the practicalities of designing and using a DMI but questions surrounding why I was dissatisfied. Researching mimetic theories and general DMI design led me to a much deeper consideration of several important apspects to mimetic design that aim to solve my discontentment.

During this research I realised that my main focus in design was to create instruments that involve, invite and include the audience. These "three I's" seemed to me to be inextricable correlates of the mimetic processes of engagement, invitation and participation, respectively. The three I's provided a common thread which helped me link the relative mimetic and DMI theories with the mimetic design. This allowed me to construct mimetic design principles which have informed the prototyping, test phases, and the evaluation of mimetic potential of the prototypes.

There is an obvious link between the gestures required to play an instrument and the mapping of those gestures to the sound output, which creates musical affordances, resulting in the use and eventual appropriation of the instrument. Mimetic design needs to consider these elements and how they impinge and interact. The question then is how these elements can be brought together in balance to create a mimetic DMI that is involving, inviting and inclusive? I chose to consider mimetic design in conjunction with other design criteria to provide a better understanding and pathway to achieving my desired outcomes, with a particular emphasis on creating involving, inviting, and inclusive instruments. Modern manufacturing capabilities allow instruments to be created with any shape and map any input gestures to any type of sound generator whilst providing a plethora of features and customisation. The question pertaining to this research is how to design DMIs which possess enhanced mimetic potential and are naturally inclusive, involving and inviting.

5.1 The Three I's — Involvement, Invitation and Inclusion

With the various DMI designs and theories, there is a lack of attention towards the audience's involvement, invitation, and inclusion. In many cases, digital instruments and their technology are the focal points of the design, pointing to computer devices rather than musical instruments. This focus is perhaps because the synergy between technology and art necessary for DMI creation is tipping towards technology and away from artistic endeavours. Within the NIME (New Interfaces for Musical Expression) and ICMC (International Computer Music Conference) communities 'usability' is one of the most common metrics for evaluating DMIs from a user perspective and 'aesthetics' from an audience perspective, whilst other sentiments such as 'enchantment', 'motivation' and 'frustration' are often ignored (Brown et al., 2017). The heavy influence of HCI and other technology-based research has tipped the scales of DMI design towards "technician" and away from "musician". Of course, this is not always the case but is common for many digital music interfaces. There needs to be a balance of 'arts, design and engineering' (Medeiros and Wanderley, 2014) to produce instruments that are both visually appealing and musically expressive yet technologically robust.

5.1.1 Involvement

The gestural language of a DMI visually connects the instrument to the audience. The gestures are therefore essential for audience engagement. Machover's (2002) idea of inevitability should inspire instruments that can be understood and have an "inevitability" or intuitive nature. Combined with Jordà's (2005) 'efficiency', the instrument should also be simple to access initially whilst having features that allow the player to explore, learn and gradually master. The initial sound production should be inevitable and easy to achieve. At the same time, the additional playing gestures, although reproducible, should allow nuanced control that requires practise to acquire playing accuracy. This control is essential if the instrument is to avoid being perceived as a novelty "toy" or "game". These nuanced gestures can be inspired by the likes of the Continuum (Haken et al., 2021), Seaboard (Lamb, 2014) and Touchkeys (McPherson, 2012), where advanced tracking of playing gestures allows a higher level of definition and resolution of control. Design principles that aim for inevitability and efficiency but with a high level of control and expression through multiple nuanced gestures should generate an instrument that is both intuitive and involving for the player, but how can these instruments be designed also to be as involving for the audience?

5.1.2 Invitation

The aesthetics and mapping of a DMI should be carefully considered to provide affordances that invite the spectator to want to understand and play the instrument. Although the aesthetic of an instrument is commonly evaluated from both user and audience perspectives (Brown et al., 2017), it needs to be considered in the larger context of inter-modal perception. With this in mind, the aesthetic of instrument design is critical in the success of the spectator's perception and understanding, but how can this lead to the audience feeling invited to have a go of the instrument?

5.1.3 Inclusion

Appropriation of a new instrument is crucial for its longevity. Using commercial design theories may improve popularity and should encourage a broader user base, improving the instrument's chances for long-term success and its continued use in the future. Appropriation may require some customisability of the DMI but not at the expense of simplicity. It should be possible to maintain the simplicity of design with some customisation. How can this be achieved whilst at the same time providing a musical instrument which inclusively invites people to join in?

The theories of gesture, affordance and appropriation should be considered with the audience perspective as central if the challenges of audience engagement, aesthetics and longevity are to be fully addressed. How a spectator understands, perceives and interprets an instrument is crucial to a DMI's success as a good communicator of musical expression and, in turn, as an instrument that involves, invites and includes the audience.

So what does this all mean for new mimetic design? Historical context is important for learning lessons from the past. However, as Luening (1968:145) states:

> Only if we develop a sense of responsibility and a deep desire to bring human satisfaction to large numbers of individuals can our vision become penetrating enough to draw on the greatness of the past, add to it our new findings, and move forward into a future that even now promises beautiful new experiences as yet undreamed of.

To address the challenges of mimetic design, fully understanding what constitutes a DMI and the practical application of technologies is essential, as is the consideration of established design theories. However, to produce involving, inviting, and inclusive instruments that provide 'beautiful new experiences as yet undreamed of' require drawing from other wells of knowledge, bringing seemingly disparate research together to inform, influence, and inspire new instrument design. This research endeavours to address the challenges of audience engagement, aesthetics, expression and longevity by applying mimetic theories to the areas of gesture, affordance and appropriation, thereby increasing an instrument's potential for audience involvement, invitation and inclusion.

5.2 How Mimetic Design Addresses the Three I's

When the theories of action understanding, communicative musicality and empathy are applied to the theories of gesture, affordances and appropriation, consequently influencing DMI design, the ensuing instruments will be imbued with the capacity to induce mimetic cognition. Therefore, mimetic design should engage and invite the spectator to participate mimetically. Consequently, these instruments will be more involving, inviting and inclusive to both player and audience. How does mimetic design help to create instruments that do precisely that?

5.2.1 Mimetic Gestures and Involvement

Mimetic gestures should instigate mimetic engagement using a combination of small to large gestures, which allow a full range of control and communication of musical expression. Mimetic gestural design should consider a balance of simple, direct gestures and more complex goal-oriented gestures to produce strong mimetic engagement (Cox, 2016:24-25). Smaller gestures will allow precise user control, but larger gestures should also be essential to the playing of the instrument as they can be perceived as more expressive to an audience (Weiss et al., 2018; Nusseck and Wanderley, 2009). Many larger gestures could be inter-modal, but this needs to be considered at the design stage, creating an instrument that positively encourages ancillary movements.

Mimetic gestures need to be observable and have musically significant information (Billinghurst, 2011; Kurtenbach and Hulteen, 1990; Hatten, 2004; Delalande, 1988; Jensenius, Glette, et al., 2010) that can be understood and perceived as causal to the sounds they produce. Mimetic gestures should consequently mimetically engage the audience and limit sound dislocation. Small gestures could benefit from digital technology to increase visibility, such as LED illumination or video projection.

The gestural language of a mimetic instrument should include intuitive gestures that afford new players to begin to play the instrument. New and novel gestures should also be devised to control the modulations and parameters found in synthetic sounds, inspiring new players to spend time exploring the instrument. Although the gestures should be easy to understand as an observer, they should also require practise to fully acquire precision and repeatability, encouraging learning and development of expertise. The gestures should mimetically engage the spectator and maintain audience involvement after the initial interest has quelled, leading to a mimetic invitation to learn and understand the instrument through imitation.

Mimetic Gestures

Mimetic design needs a balance of simple direct gestures that are easily understood and the introduction of new types of musical gestures related to new digital sounds that will intrigue the audience after the more obvious gestures initially engage them. There also needs to be a balance between large, visible gestures capable of involving the spectator and smaller gestures that provide nuanced and precise control over musical expression for the user.

To this end I created the Mimetic Gestural Matrix (MGM) (Figure 5.1), based on Wanderley and Vines (2006:165) translation of Delalande's (1988) classification of gestural types:

> (1) Effective gestures; those that actually produce the sound;
>
> (2) Accompanist gestures, expressive body movements; and
>
> (3) Figurative gestures, gestures perceived by a listener, but without a direct correspondence to a movement of the performer.

The mimetic gestural types follow the same premise. Therefore, they can be divided into similar mimetic gesture categories:

> (1) initial gestures that trigger the sounds;
>
> (2) modulating gestures that manipulate and modulate the sounds; and
>
> (3) inter-modal gestures that do not directly affect the sound.

Adding three size categories of “small”, “medium” and “large”, to these gestural types, provides a framework to ensure a balanced design of gestural type and size (Figure 5.1).

Mimetic Gestural Matrix		Gestural Size		
		Small	**Medium**	**Large**
Gestural Type	**Initial**			
	Modulating			
	Inter-modal			

Figure 5.1: Mimetic Gestural Matrix

Initial Gestures are the movements necessary to initiate the sound, usually striking, plucking, bowing or blowing. Mimetic design may incorporate novel initial gestures. However, they may not be as easily recognised and therefore reduce mimetic potential. The initial gestures play an important role in determining the type of instrument perceived by a listener. In addition, this gesture produces the transient of the sound for acoustic instruments, which is often vital for a spectator to identify and classify an instrument (Malloch, 2000). The initial gesture is an essential element of mimetic design as it will provide the connection and causality with the sounds being played. However, designing this gesture can be difficult for controllers connected to external sound generators. The designer cannot anticipate what sounds will be used and cannot plan gestures with any particular timbre in mind. It may be advantageous for mimetic DMIs to have the sound generator built-in as a part of the instrument from the beginning of the design process. However, sound synthesis is an expert field and adds more difficulty in producing a prototype instrument. My lack of expertise in this area led me to focussing on creating instruments that could connect to MIDI sound generators. Also, an advantage to a MIDI capable instrument is that many users require a controller that can connect to and perform with their various synthesisers, software and sounds. With a controller, the design of initial gestures cannot be directly defined by the sounds it will produce. However, mimetic design should consider how an audience may perceive such gestures with a wide range of sound outputs.

Using initial gestures inspired by existing instruments can help produce gestures that can be instantly recognised and connected with sound production. Due to its percussive nature, the piano has limited gestures, with easy control over which notes are played and how loud they sound. The electric guitar also has relatively easy control over the pitch but limited control over note volume. However, the guitar has a variety of ways for the sound to be initiated. For example, the strings can be plucked with plectrums, fingers, or both, hit or strummed, producing differences in sound. The left hand can also initiate the sound through techniques such as hammer-on/off. Also an "EBow" (EBow, 2021) can be used to create an electronic "bowing" effect allowing the strings to sound indefinitely.[1]

The initial gestures of a mimetic DMI need to have accurate control over which notes are played and how loud they are played. The initial gestures should be relatively simple controls over the selection of pitch and playing of melodies to ensure access to a wide range of users. A variety of other inputs could also be used. However, a greater variety of initial gestures may reduce the clarity of sound causality, which would reduce mimetic potential. Smaller initial gestures could also provide greater control and expression over the initiation of the sounds.

Modulating Gestures provide control over sustained sounds. These gestures occur after the transient and can affect the decay, release, pitch and volume amongst other sonic characteristics creating sound modulations such as vibrato and tremolo. These gestures allow for control and playability of nuanced modulations and musical expression, providing potential for discovery and mastery over the instrument.

The modulating gestures for an acoustic instrument usually provide a change in volume or pitch, creating tremolo or vibrato type effects. Electric guitars utilise these modulating gestures with the addition of a whammy bar for pitch modulation and effects such as a wah-wah pedal which uses a filter to create modulations in timbre. The modulation of the sound is generally not connected to the recognition of the timbre. However, it is often

[1]This device was designed specifically for use with electric guitars because the strings need relatively little movement to produce sound due to being amplified. Using an EBow on acoustic guitar produces a very quiet sound on the thinner strings and is unable to vibrate the heavier strings.

used to ornament the sound, especially for longer notes, to provide interest and variation. Any modulation effects that have acoustic analogies, may already have an expected causal gesture, such as bending a guitar string to create pitch bend. In this case mimetic engagement will benefit from creating a DMI gestural analogue that fulfils this expectation. Due to their lack of acoustic analogies, some modulations of new synthetic sounds and their parameters, such as filter and LFO modulations, have no established causal gestural concept. A novel gesture could be used in this instance without diminishing the mimetic potential, as there are no entrenched expectations. Mimetic gestures should include a balance of expected movements that have acoustic analogies and novel gestures with no acoustic derivative that produce non-analogous synthetic modulations and effects.

Inter-Modal Gestures can occur at any time, before or after the initial gesture. They include any gesture or movement that does not alter or modulate the sound in any way but, according to the McGurk effect, (McGurk and MacDonald, 1976) may affect not only how the performance is interpreted but how the sound is perceivably heard.[2] Inter-modal, ancillary gestures often vary between performers (Nusseck and Wanderley, 2009; Vines, Krumhansl, Wanderley, Dalca, et al., 2011). However, mimetic gestural design should take into account the instrument's visual aspect and consider how the instrument may provide a propensity for certain inter-modal gestures.

Gestures that do not directly affect the sound still provide an important way for performers to communicate individual expression. These ancillary or inter-modal gestures have been found to imbue important characteristics and convey emotions and expression which affect the perception of the sound (McGurk and MacDonald, 1976) and performance (Section 4.4.2). Designing for inter-modal gestures is difficult due to the individual nature of the performance of such gestures. However, the instrument's design can encourage or diminish inter-modal gestures. Therefore, mimetic design should encourage inter-modal gestures by ensuring freedom between the instrument and player for additional movements.

[2]An example of the McGurk effect may be seen here: https://research.bazerbow.uk/McGurk-Effect/

However, there is another element to inter-modal design generally specific to DMIs. The use of digital technologies such as the typical implementation of LEDs, video and other sensor technologies connected to non-music related systems such as live animations, if coupled with the gestural input, could be considered inter-modal. These inter-modal gestures could exaggerate and embellish certain gestures to provide more clarity of sound causality for the audience. Inter-modal gestures could prove an essential bridge between audience engagement and the new digital instruments providing greater insight into the more complex processes of DMI performance.

Small Gestures may include changing the pressure of the fingers, such as aftertouch on a keyboard. A small gesture can be an initial or modulating gesture, but these would not naturally be inter-modal due to the lack of visibility. However, the performer may add inter-modal gestures before or after applying a “small” gesture, to acknowledge and amplify the gestural connection with sound production or modulating effect. For example, a guitarist might swing their strumming arm which creates a larger more visible gestural movement that is unnecessary for the small movement of the hand to pluck or strum the strings. In this instance the larger ancillary gesture is signposting the smaller sound causal gesture.

It is important for the mimetic potential that gestures of this nature are somehow visible to the audience to be perceived and understood through mimetic cognition. Without seeing small gestures, the audience is left to make assumptions about what has happened to produce the sound. This situation could easily lead to a dislocation of the sound from the performance or a misinterpreted gesture leading to a wrong understanding of the instrument. An audience needs to be aware of an instrument’s playing gestures and movements to imagine playing it and therefore engage mimetically. Mimetic DMIs are able to incorporate features in the design that highlight small gestures that are not ordinarily available on traditional acoustic instruments, such as the integration of LED lights. However, care needs to be taken that this visual emphasis of gestures does not detract from the gestural performance.

Medium Gestures could include a gesture of the hand moving a small distance above the instrument. These gestures can be initial, modulating or inter-modal due to the visibility but become less effective for an audience further away. With modern DMI performances, it is common for close up cameras to project performers on a large screen allowing audiences further away to appreciate the performance of these “medium” gestures. Unlike small gestures, the visibility of medium gestures means that there is no need to highlight them using technology such as LEDs. However, performers may also exaggerate these gestures, either consciously or subconsciously. For example, a piano player may use a more elaborate movement approaching the keys and moving away after playing the keys. These larger additional inter-modal movements would exaggerate the “medium initial” gesture.

Large Gestures can be seen the farthest away and often can be inter-modal. A large gesture can be counter-intuitive to learning and playing an instrument as they are much less efficient than small gestures. Playing an instrument with speed and control usually requires implementing small and medium gestures, which leaves the larger gestures to be added when the performance allows. However, large gestures can also be initial or modulating, such as the large gestures required to play loud on a drum kit. Large inter-modal gestures may also be used to exaggerate the small and medium gestures such as a guitar player swinging his or her plucking arm in a “windmill” fashion where a very large gesture is unnecessary for the initial gesture of plucking the strings. This movement highlights the usually much smaller plucking gestures.

The three types of gestures can be used in simple isolation or in a more complex combination to provide the audience access to the small, medium and large gestures. The design of a mimetic instrument needs to balance all these gestural types and sizes to fully communicate musical expression and enable the audience to perceive and understand the gestures and the causality of the sounds produced. This combination of gestures provides the audience with the observable and significant musical information necessary to engage and become involved in the performance mimetically. The gestures of a mimetically designed instrument should enable mimetic cognition, which will increase the audience's involvement in the instrument and begin the process of mimetic engagement, priming the audience to respond to the instrument's mimetic invitation.

5.2.2 Mimetic Affordances and Invitation

The affordances of a mimetic instrument should invite the spectator to want to understand, learn and inevitably want to imitate the instrument. Mapping is essential to inviting, mimetic affordances. These mappings should include synchronous (Wu et al., 2016), one-to-one controls that provide transparent (Fels et al., 2002) connections between gesture and sound. This will initially invite the spectator to understand the instrument. However, to initiate imitative learning through the processes of communicative musicality (Malloch and Trevarthen, 2009) some mappings need to provide more complex (Rovan et al., 1997) and multi-parametric (Hunt and Kirk, 2000) connections generating curiosity and intrigue.

The initial gestures should be directly mapped to the produced sound, but the modulating gestures, depending on their commonality, could be obvious or more obscure (Figure 5.2). The pitch bend effect is commonly understood on acoustic instruments, so certain accompanying gestures are already expected. Modulation of a synthesiser parameter that is not analogous to any acoustic counterpart is free from expectation. In this case the mapping can be much more experimental and less obvious using divergent (Rovan et al., 1997) and multi-parametric (Hunt and Kirk, 2000) mapping which encourages exploration and provides nuanced, expressive control (Tanaka, 2010; Wanderley and Depalle, 2004; Fels et al., 2002; Rovan et al., 1997).

Mimetic design should carefully consider inter-modality and aesthetics in producing DMIs with affordances that invite the observer to perceive and understand the device as a musical instrument. Materials commonly used for making acoustic instruments should be preferred with this aim in mind. Hiding necessary technology, such as cables and PCBs, within the device will also benefit the mimetic affordances and perception of the DMI.

A balance of the 5 P's of affordance (Bell, 2018:168b) should also be considered in mimetic design, paying particular attention to functions which should be "hidden" or even "prevented" ensuring a simplicity to the instrument, without compromising expressive functionality.

Mimetic Affordances

An object's affordances (Gibson, 1979; Norman, 1998) invite the agent to use the object in a particular way. Therefore to produce mimetic invitation in DMIs, communicative musicality should influence the decisions surrounding the instrument's affordances. These affordances are naturally affected by the instrument's aesthetics, but for DMIs, they are also affected by the mappings that connect the gestures to the musical output (Tanaka, Altavilla, et al., 2012). Communicative musicality provokes an invitation to imitate and learn, and to want to "have a go". Mimetic instruments must do the same. Their aesthetics and mappings must provide musical affordances that invite the spectator to perceive the device as a musical instrument, thereby providing a clear causal link between gesture and sound output (Paine, 2009).

The mapping should provide a balance of simple one-to-one (Fels et al., 2002) and more complex multi-layered (Hunt and Kirk, 2000) connections that instantly invite but maintain interest and provide scope for expression (Tanaka, 2010).

The chosen affordances should provide essential functionality, intuitive control (ibid.), and hidden layers of capability. Some affordances should also be prevented (Bell, 2018) within the design phase for the greater good of the design.

The aesthetics of a DMI should balance the engineering needs of the device with the artistic intentions (Medeiros and Wanderley, 2014). The device should be technologically sound without system error (Brown et al., 2020) but it should also be a complete and aesthetically appealing instrument. The aesthetics partly comes down to the choice of materials and combining more traditional instrument production methods with the technological production needs. The artisan luthier creates a piece of artwork in and of itself, which could still be the case for DMIs. However, the technology in many DMIs is very prevalent and can lead to perceiving a DMI as a computer device rather than a musical instrument.

Addressing the aesthetics of the instrument impacts the inter-modal perception of the instrument. Inter-modality is important in successfully communicating musical gestures and mapping to sounds. The visual aspect of a musical instrument can provide significant information (Vines, Krumhansl, Wanderley, and Levitin, 2006:107; Davidson, 1993:103) that is combined with the aural signal to produce an overall perception. Therefore, mimetic design and mimetic invitation must ensure that the device is perceived from the first moment as a musical instrument.

It is important in creating a mimetic invitation for the audience to have an initial concept of how the sounds are produced and modulated to enable the desire to imitate. Some of the mappings, in particular for initial gestures, need to be simple and transparent (Fels et al., 2002) to allow an initial perception of how the gestures produce the sound. In addition, these mappings, by necessity, should be more intuitive (Wu et al., 2016). However, the instrument should also have more complicated mappings. There needs to be something to learn for communicative musicality and imitative learning to be initiated. If all the mappings were obvious, this might lead to an instrument that, although initially fun, could lose the interest of most spectators. Modulations and effects unique to digital sounds and synthesisers have no acoustic analogue. Therefore they can have more creative mappings to various digital sensors (Hunt and Kirk, 2000) which intrigue the audience provoking a desire to learn and therefore imitate. In this case, the audience will have no preconceptions about how the gestures may control these effects, so they will be more willing to learn the new mappings instigating imitative communicative musicality.

Figure 5.2 shows a simplified concept of how mapping could be applied to the mimetic gestures to produce mimetic affordances. In essence, the initial gestures should use simple, transparent (Fels et al., 2002) mappings to an expected causality of sound initiation or modulation. The modulating gestures can benefit from more experimental mappings but are dependent on the modulation type and known expectations. For example, any

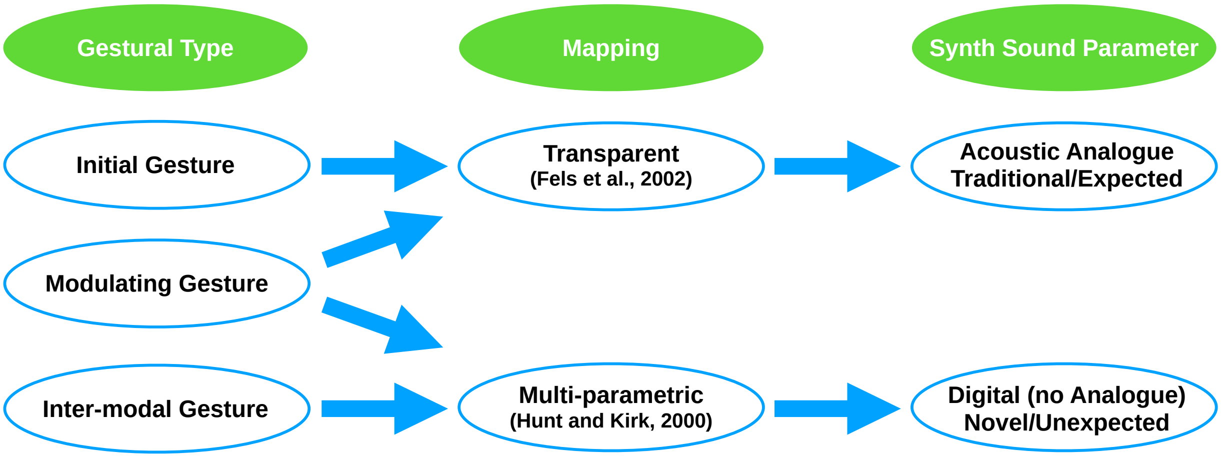

Figure 5.2: Mimetic Affordance Mapping

modulation that has an acoustic analogue or is well established, such as pitch bend, should still be simply mapped. On the other hand, any new modulation or control should benefit from creative and complex, multi-parametric (Hunt and Kirk, 2000) mappings that expand the instrument's capabilities. This balance should produce an instrument that, although new and interesting, is not alienating or misunderstood. As inter-modal performance gestures do not affect the sound, they do not need mapping in the same way. Any digital inter-modal features, such as LEDs, have no direct acoustic comparison and so can be utilised in creative, novel and unexpected ways without detriment to mimetic potential.

The aesthetics and inter-modality of a mimetic instrument should create affordances that invite the audience to perceive the device as a musical instrument. An instrument that instigates mimetic invitation through communicative musicality and imitation learning needs to have a mixture of intuitive and complex mappings providing initial invitation and further interest and intrigue, producing a desire to want to imitate and learn. However, for complete mimetic cognition, the desire to imitate must lead to the desire to participate.

5.2.3 Mimetic Appropriation and Inclusion

Mimetic invitation should effectuate a desire to join in through empathy (Szalavitz and Perry, 2010), leading to mimetic participation and eventual appropriation. Mimetic appropriation requires the DMI to be inclusive of a wide range of people with varying musical capabilities and experiences. Therefore, the instrument should be approachable and creating sounds with it should be simple. To this end, it may resemble, and borrow from, existing instruments. However, it should be far enough removed from any known instrument to avoid generating any intimidating expectations of needing to be musically “good enough” (Ruddock, 2010; Finnegan, 2007).

The instrument should also be inclusive in that it can be used to play different styles of music within different musical situations and adept at prepared playing and improvisation. This flexibility should encourage mimetic DMIs to be used in inclusive contexts with other musicians and instruments.

Mimetic DMIs should also be capable of exhibiting performance errors (Fyans et al., 2010), but without suffering from system errors (Brown et al., 2020). The set of features should be balanced between simplicity and customisability. Some customisation will make the instrument more inclusive, but this cannot be at the expense of creating an instrument that, due to its complexity, is inhibitive to use and configure (Bell, 2018).

In addition to Kano’s (1984) “basic” and “performance” features, a mimetic instrument should also provide “delighter” features that are not just a passing novelty but that will be “used” (Dix et al., 2003:5). With modern technologies, it is tempting to make a new DMI with endless features and customisation. However, the success and popularity of a design, and therefore its longevity, can be in its simplicity (Paine, 2015).

If the audience is mimetically engaged and involved through and mimetic engagement and action understanding, then mimetic invitation will occur through the mechanism of communicative musicality and imitation learning, and finally, mimetic participation will transpire due to empathy and covert imitation.

Mimetic Appropriation

Empathy and covert imitation provide a glimpse into how we interact, socialise and understand each other. We respond to a mimetic invitation because, by nature, we empathetically desire to be included. Mimetic participation (Cox, 2016) is the natural response to ‘feel into’ (Szalavitz and Perry, 2010:12) a music performance by projecting ‘physical mimicry’ (Decety and Jackson, 2004:93) onto the musician and instrument.

The concepts of appropriation (Zappi and McPherson, 2018; Dix, 2007), product satisfaction (KANO et al., 1984) and social empathy (Szalavitz and Perry, 2010; Rabinowitch et al., 2012) can be utilised in mimetic design to enhance the appeal and user satisfaction of new DMIs to encourage mimetic participation, increasing the user base and therefore longevity of the instrument.

An inclusive instrument needs some ability to be customised for individual use and different musical contexts. However, an instrument that is entirely bespoke and designed specifically for one user may be complex for other users to adopt (Goudard, 2019). Users that begin to explore and invest time in playing and learning a new instrument will begin to appropriate the instrument for their musical purposes. An instrument that encourages appropriation needs to have a balance of customisable features that facilitate appropriation and those features that are better denied for the greater good of the mimetic potential and inclusion of the instrument as a whole (Pullin, 2009:86; Bell, 2018).

Dix *et al.* (2003:5) state that:

> There are three ‘use’ words that must all be true for a product to be successful; it must be:
>
> **useful** – accomplish what is required: play music, cook dinner, format a document;
>
> **usable** – do it easily and naturally, without danger of error, etc.;
>
> **used** – make people want to use it, be attractive, engaging, fun, etc.

This statement provides an excellent general guide for design success. However, it is more illuminating to mimetic design if it is combined with Kano’s (1984) theory (Section 4.3.3). A “Useful” product relies on “basic” features, and a “useable” product on the “performer” features. A “used” product should incorporate “delighter” features into the “basic” and “performer” design elements.

Figure 5.3 shows how these two theories relate and the corresponding examples of design features for mimetic appropriation. The pyramid represents the consideration of these theories in mimetic design. Firstly a strong foundation of basic elements that make

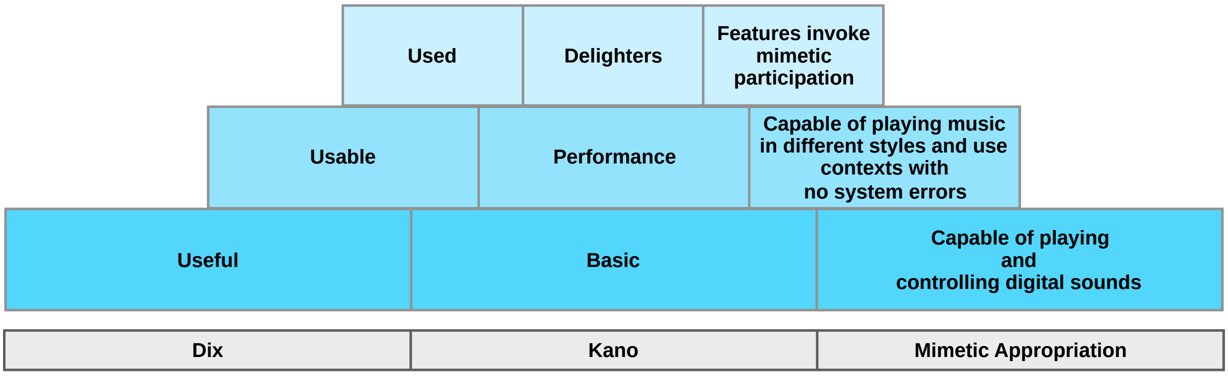

Figure 5.3: Mimetic Appropriation Pyramid

up the DMI and provide useful features, such as the capability of playing and controlling digital sounds, should be established. Secondly, usable performance features, such as the capability of playing music in different styles and use contexts with no system errors, should be developed. And finally, to be used, the delighter features should be incorporated into the design to invoke mimetic participation.

The pyramid also represents the proportion of each type of feature-set. The basic useful components make up the largest part of the DMI, whilst the smaller number of usable elements are focussed on performance. Lastly, the smallest proportion of features, namely the used delighter features, are concentrated on invoking mimetic participation. Too many delighter features can detract from the instrument's basic and performance qualities, creating potential confusion about the device's purpose and impairing the mimetic potential. Successful appropriation of new DMIs must provide this balance of features and customisation without being overly complicated. The device needs to be approachable and intuitive ("useful" and "basic") yet have an underlying functionality and complexity that allows the development of expression and control over time ("usable" and "performance"), and be interesting and exciting to watch and play ("used" and "delighters"). This balance of features should appeal to a broad range of people.

In her research into music activity in the community, Finnegan (2007) discovered that the perception of non-musician and musician is very misleading. Many people engage in musical activities and have a valid musical experience that is often ignored when questioned about musicianship. Ruddock (2010) found a similar discrepancy in actual musical experience and activity and perceived musical ability. This perception affected the way people approached playing an instrument or singing. The expectation of natural musical talent inhibits many people from joining in musical activities as they do not see themselves as musically “good enough”.

Non-players understand most acoustic instruments through the natural mechanisms of sound production. The piano keys are hit, the string is plucked, and the drum is hit. Mimetic design should aim to strengthen a DMI’s sometimes tenuous link between causal action and sound to avoid diminishing this natural intuition. However, a DMI that is very closely identified with an acoustic instrument may have similar expectations of how it should be played and therefore be intimidating for people who consider themselves “non-musicians” (Ruddock, 2010). This aspect is important if the instrument aims to evoke mimetic participation and include a broader demographic of players. Mimetic design should aim to balance acoustic inspired and novel features.

Music is important in the community and for social interaction, and as Finnegan’s (2007) research shows, people enjoy engaging with many different types of musical activity and music contexts. Oxytocin is a human biological chemical necessary for people to make connections with each other and is important to empathy (Szalavitz and Perry, 2010:66). For example, levels of oxytocin have been found to increase when people listen to or play music together (Levitin, 2015; Nilsson, 2009; Grape et al., 2003). The strong link between oxytocin, empathy and social interaction and the social benefits of music activity and involvement indicate that music may positively impact our social well-being within the community. Many of our musical experiences are shared within a social context which may affect the perception of music (Maes et al., 2014; Liljeström et al., 2013; Egermann et al., 2011). When experienced in a group, music may promote and improve empathy (Rabinowitch et al., 2012). These social experiences inform our empathy and musical perception and affect our inclusion and mimetic participation in music performance.

An instrument that can be genuinely inclusive must be usable in various social musical occasions and stylistic situations. Arfib *et al.* (2005) state that:

> Musicians are not supposed to be restricted to a single musical style and are expected to be able to switch from one to another, crossing the frontiers between them.

They see this adaptability as an aspect of an instrument's expressiveness, suggesting that this might not only include utilising different tone scales, but also being capable of 'composing the whole phrase in terms of time, energy and spectrum' (ibid.:127). Another aspect of an instrument's adaptability is its capability to be used as a soloing instrument on its own or as part of an ensemble. Arfib *et al.* (ibid.:127) describe an instrument's ability to be heard and identified as a soloist above the background of an ensemble, as 'emergence', and suggest that this can be achieved by changing a sounds characteristics such as "brilliance" or "attack". An adaptable and inclusive instrument should also be capable of being used to follow a set piece of music or to improvise within different social and musical contexts or "musical field", by 'changing the range of parameters or the sound palette' (ibid.:127). As Arfib *et al.* (ibid.) suggest, 'An "expressive musical instrument"... allows a performer to follow other musicians in various musical directions'. This musical expression should enable a broad demographic of people to play and join in with the instrument.

Instruments designed to be "used" with features that "delight" should provoke a strong desire for mimetic participation from a wide range of people, facilitating appropriation whilst ensuring greater inclusion and promoting longevity. The mechanisms that produce empathy are involved in our everyday experience of music. Empathy with the performer causes covert and, in some cases, overt mimetic participation. This mimetic participation is essentially a desire to join in with the performance, which may be a desire to play the instrument or a more inter-modal manifestation such as humming, tapping along or dancing to the music. The influence of empathy and mimetic participation on instrument design will facilitate the production of DMIs that are inclusive in nature evoking a desire to join in across a diverse group of people.

5.3 Mimetic Design Principles

To summarise mimetic design and to answer the following question, mimetic design principles are set out in Figure 5.4.

Which design considerations are most important to mimetic design? (Section 2.4).

Mimetic Design Principles	**Mimetic Gestures**	**1**	Balance of size and type of gestures.
		2	Balance of simple direct and layered, goal-oriented (non-normative mimetic) gestures.
		3	Gestures should be observable and musically significant, limiting sound dislocation.
	Mimetic Affordance	**4**	Balance of transparent and multi-parametric mapping.
		5	Consideration of aesthetics and inter-modality in the design, materials, and finishing.
		6	Balance of functions: essential functions, intuitive control, customisable controls, hidden functions and prevented functions.
	Mimetic Appropriation	**7**	Capable of a range of styles and playing scenarios. Simple to approach, complex in mastery.
		8	Capability of allowing performance errors but no system errors.
		9	Inclusion of mimetic “delighter” features to Mencourage the instrument to be “used”.

Figure 5.4: Mimetic Design Principles

Prototypes have been developed, based on these design principles, with the aim to test the consequential manifestations of the mimetic process:

- Involvement—audience engagement.
- Invitation—the desire to “have a go”.
- Inclusion—the desire to “join in”.

These prototypes are discussed in Chapter 6 and the prototype testing in Chapter 7.

Chapter 6

Design Narrative | *Prototyping of BazerBows*

This chapter introduces my prototyping stage, discusses the reasons for creating these BazerBows, and how I relate to these instruments. This discussion is followed by an overview of the guitar and keyboard connected with my work, the three prototypes and the upgrading of prototype one, ending with a brief comparison of the prototypes in relation to the mimetic design principles (MDP), presented in Section 5.3.

The guitar and keyboard and each prototype are presented with photographs and a summary evaluation of mimetic design principles. Various elements important to each device are discussed, followed by the instrument's MDP evaluation table. Mimetic gestural matrix (Figure 5.1) evaluations, informing the gestural elements of the main MDP evaluations, particulary mimetic gestural principle 1, can be found in Appendix B.

The evaluation of the devices presented below assessed the concepts, set out in Section 5.3, in relation to the ongoing development of the prototypes.[1] Each of the nine principles was assessed. The summary evaluations were created based on whether I considered the design principle non-functional, functional but needing further optimisation or functional and fully optimised.

[1] The representation of my prototype evaluation was inspired by Phil Brissenden's (2015) PhD thesis.

6.1 The Inspiration for the BazerBow

During my time at University in 1999, I began experimenting with digital technology and performance using electronic drum equipment. At a gig where I used only electronic drums, the overwhelming audience comments suggested that it seemed like I was miming, although the drums sounded realistic. I soon realised that digital instruments brought about unique issues. One problem was the need for sufficient amplification to balance the volume of the digital devices with the acoustic instruments. Another issue I came across was the need to be able to control the digital music system/environment. However, the main issue was how to communicate to an audience that I was performing live with this technology.

The technology for developing my prototypes was initially inspired whilst working with a dancer. We began developing a music and dance performance, and I started exploring ways for the dancer to digitally interact with the music.[2] This exploration led to various sensors and a central control system that could communicate with the music system. While developing these performances, I used an M-Audio Ozonic MIDI keyboard, a Yamaha ERG121 electric guitar, and a laptop. The laptop provided all the synthesised sounds and effects for the guitar. In developing the music compositions, there was no guitar part.

It was only in developing a way of performing the music that I chose to play certain synth parts with the guitar. This process was the beginning of my thinking about a new musical instrument that was more like a guitar but could control synthesisers like the keyboard. Unfortunately, no commercial devices attracted me, so I wondered if I could use the sensor technologies I had been researching to create a new instrument for these performances. I began early prototyping as part of an MA, building the original prototype 1 and prototype 2. As I continued to develop my skills as a builder, I realised I needed a framework to address the issues I had experienced as a drummer and performer. This research has enabled me to explore research areas that provided the necessary framework to inspire and develop mimetic design principles and, consequently, prototypes. This research is iterative and ongoing by nature as the cycle of development describes (Section 2.1), and therefore this

[2] Examples of this music can be found here: https://research.bazerbow.uk/#music.

chapter represents a snapshot of the development of BazerBows.

During this research, the question has arisen: is the BazerBow an instrument or a MIDI controller? Although the BazerBow does not produce sounds and could be described technically as a MIDI controller, it was designed as an instrument, and I personally treat it as such. There is some confusion when comparing with commercial instruments as there seems to be a specific use of the term MIDI controller, which applies to devices that do not produce their own sound. However, there is little distinction between the MIDI controllers that consist of a set of buttons and faders, such as those that might be used for mixing or DJing and MIDI controllers that are much more instrument based. After consideration, I believe the BazerBow can be categorised as ‘instrument-inspired’ (Wanderley and Orio, 2002). The electric guitar inspired the BazerBow and, although it has digital strings, is different from the guitar in many ways. Reinhard’s (1960) concepts of note polyphony and note length are helpful in classifying multiple parameter polyphony and therefore, effective in describing the BazerBows. Although, the first BazerBow is monophonic, the others are polyphonic. Reinhard’s (ibid.) classification system is also useful in considering the additional controls that focus on modulation of fading or continuous tones, to provide multidimensional MIDI polyphonic expression, similar to the guitar or violin. Using these terms, I am confident in classifying the BazerBow as an instrument.

6.2 Yamaha ERG121 and M-Audio Ozonic

Figure 6.1: Yamaha ERG121

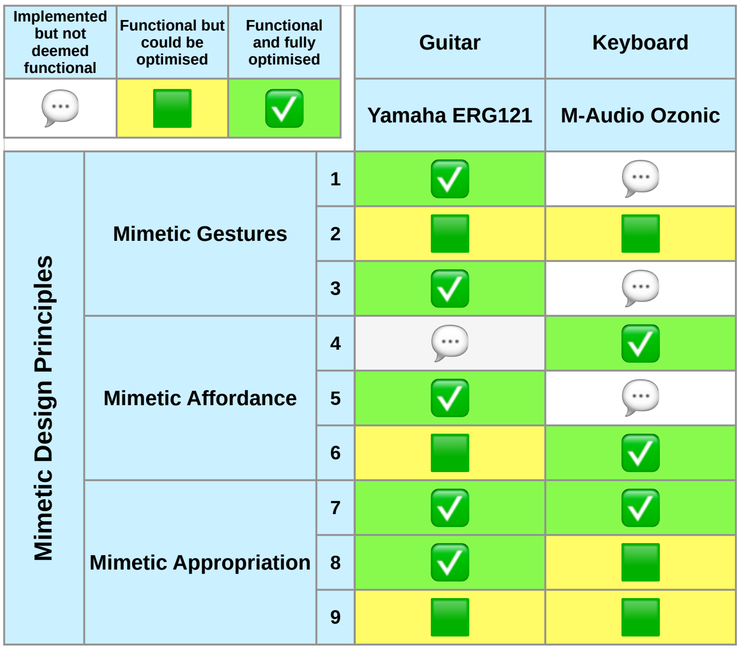

Figure 6.2: Guitar and Keyboard Evaluation

The mimetic evaluation methods have been applied to my guitar and keyboard. Figure 6.2 shows the summary evaluation. As can be seen, the guitar benefits from a good mimetic potential in its gestural capability and aesthetics, whilst the keyboard has excellent digital functionality and capabilities. The full MDP assessment of the guitar and keyboard can be found in Appendix C. Suffice it to say that the prototypes aimed to combine the successful mimetic features of the guitar and keyboard.

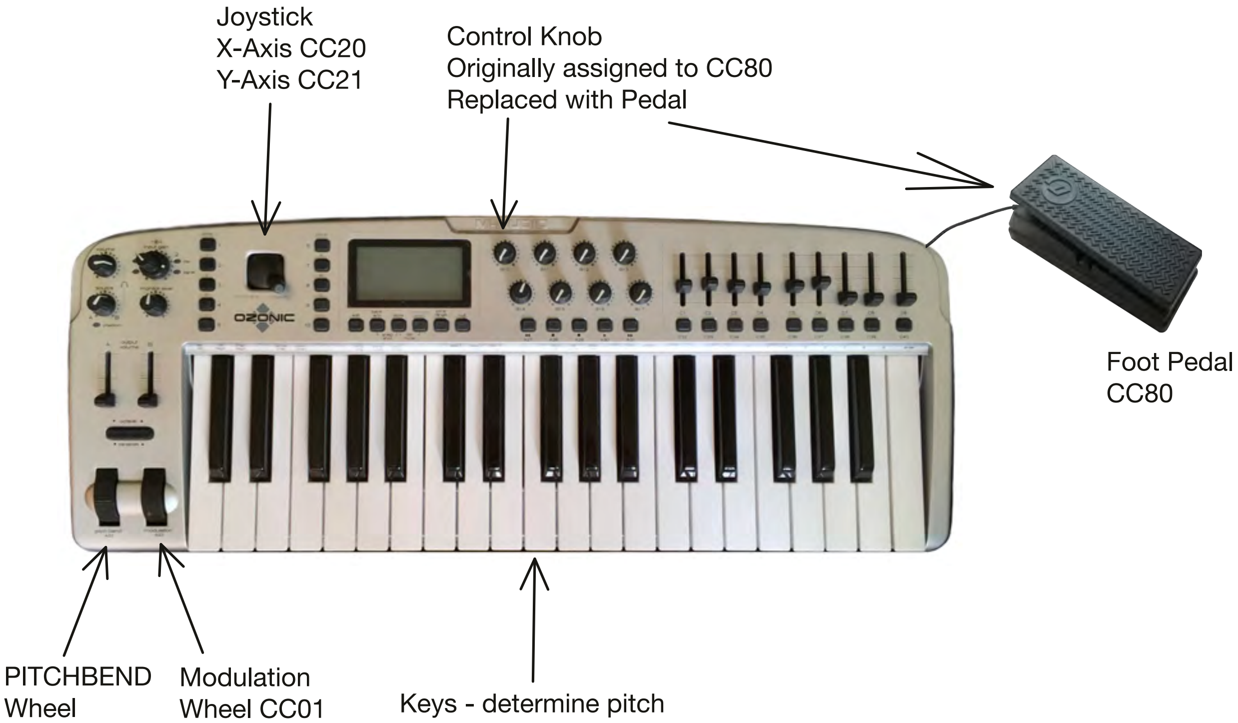

Figure 6.3: M-Audio Ozonic

Figure 6.3 shows the typical features of the Ozonic keyboard that I aspired to combine with the gestural possibilities and aesthetics of the guitar and incorporate into the BazerBow.

6.3 The BazerBows

In developing prototypes that exemplify mimetic design, I found some constraints in the practical necessities of manufacturing and my limited knowledge of various production techniques. Therefore, there has been a constant tension between the mimetic design and the necessary elements of production, which was much more apparent with the development of the third prototype, where certain constraints strongly impinged on the practical inclusion of mimetic principles. The first prototype was handcrafted, whilst a more complex but accurate templating method was used for the second. As a result, the third prototype required a more comprehensive range and in-depth knowledge of production techniques and a more precise and reproducible template system. Unfortunately, this additional knowledge and experience have meant that the third prototype is still incomplete. However, in comparing the build process and intentions of the third prototype with the first two, and the subsequent upgrade of prototype 1, several areas of mimetic design and my thought process in applying these theories were illuminated.

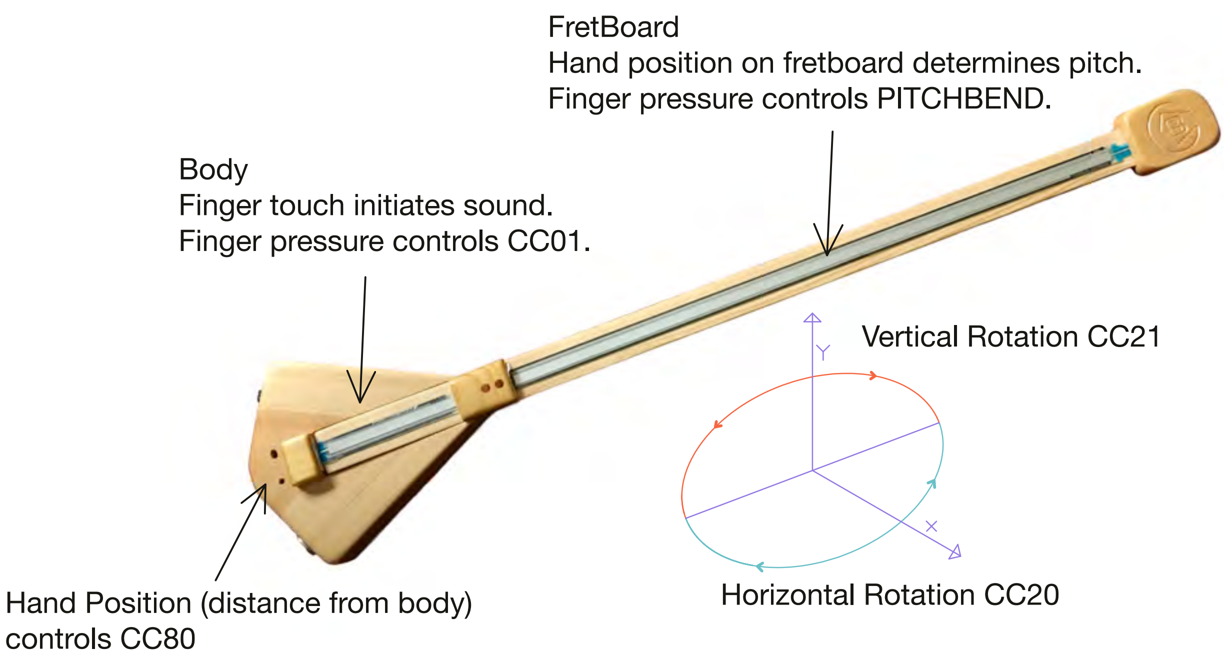

Figure 6.4: Prototype 1 — Features

Figure 6.4 shows the features that I chose to incorporate into the first prototype, which correlate with the keyboard controls (Figure 6.3.) All three prototypes essentially have these same features. The right-hand triggers the notes on pressure and position sensors allowing control over volume (position of the finger) and modulation (pressure of the finger) of the sound. Under the right hand is a proximity sensor measuring the hand's distance from the instrument. The left hand has a similar position/pressure sensor. The position selects the pitch, and the pressure creates a pitch bend effect. In addition, the instrument has a 2-axis motion sensor detecting the tilt and rotation of the device, allowing further modulation control.

The BazerBow is connected to a sound generator via MIDI. Although there have been issues with MIDI due to its lack of development since the 1980's it has recently been updated and addresses these issues, providing a digital system for future multi-gestural instruments with polyphonic expression. MIDI now provides a future-proof and ubiquitous connection. Therefore, I felt confident using MIDI as the primary connection to external devices. [3]

[3] A discussion of these developments in MIDI can be found in Appendix A

6.3.1 Prototype 1 — Baby BazerBow

Figure 6.5:
Playing Prototype 1

Implemented but not deemed functional	Functional but could be optimised	Functional and fully optimised	BazerBow Prototype
💬	■	✓	Prototype 1

Mimetic Design Principles	Mimetic Gestures	1	■
		2	✓
		3	✓
	Mimetic Affordance	1	✓
		2	💬
		3	✓
	Mimetic Appropriation	1	■
		2	💬
		3	💬

Figure 6.6:
Prototype 1 Evaluation

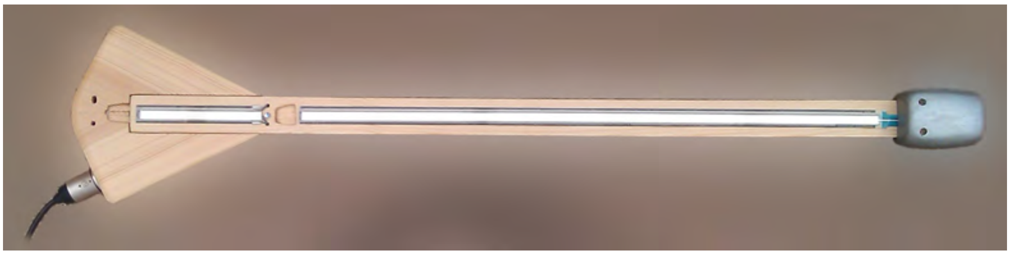

Figure 6.7: Prototype 1

Although my first attempts at prototyping were limited by my novice carpentry and lack of tools, I aimed to produce a more aesthetically pleasing device than a typical prototype plastic box stuck together with gaffer tape. Prototype 1 (Figure 6.7) was built after a few simple proofs of concept tests and, as can be seen in Figure 6.5 it can be held in the hand comfortably. The diamond shape of the body came about in the way I prepared a plank of scrap wood. The grain direction was quite accidental but aesthetically compelling. It seemed appropriate to finish the instrument with varnish as it had turned out reasonably well. However, this first version had a silver “headstock” which I was never quite satisfied with, either shape, colour or size. I made every effort to hide the screws and other fixings and as much of the technology as possible. The cables connecting the right-hand sensors can be seen in this version. Although the functionality of this BazerBow was adequate, I always intended to build a device with four strings to allow polyphonic playing. Also, the installation of sensors proved unreliable, and the gyroscope was prone to drifting and, therefore, would lose its centre position, making it difficult to predictably and accurately control.

MDP Evaluation of Prototype 1

BazerBow Prototype			Prototype 1 (Original)
Mimetic Design Principles	Mimetic Gestures	1	There is a good balance of size of gesture and additional modulating gestures. However, in this design there is no intended inclusion of inter-modal features.
		2	The initial gestures provide a simple connection to guitar-like playing whilst the combined motion and proximity sensors provide goal-oriented complex gestures.
		3	The basis of guitar suggests musically significant gesture.
	Mimetic Affordance	4	The initial gestures and pressure sensor gestures have fixed mapping to their relative expected effects of note production, vibrato and pitch bend. However, the motion sensor and proximity sensors provide potential for more complex mappings.
		5	This prototype needed more attention to the aesthetics, in particular the headstock and visible cables.
		6	This device provided the balance of basic functionality with more complex capabilities of control yet remained simple in the limitation of its functions.
	Mimetic Appropriation	7	This device is capable of playing various styles, but is limited by being monophonic.
		8	This first BazerBow had reliability issues with one of the pressure sensors and the motion sensor.
		9	The device provides good basic features. The performance of features is limited by the reliability issues. More specific attention needed to include delighter features.

Figure 6.8: MDP Evaluation of Prototype 1 (Original)

6.3.2 Prototype 1(B) — Upgraded

Figure 6.9:
Playing Prototype 1B

Implemented but not deemed functional	Functional but could be optimised	Functional and fully optimised
💬	■	✓

			BazerBow Prototype
			Prototype 1 (After Upgrades)
Mimetic Design Principles	Mimetic Gestures	1	■
		2	✓
		3	✓
	Mimetic Affordance	1	✓
		2	■
		3	✓
	Mimetic Appropriation	1	■
		2	■
		3	💬

Figure 6.10:
Prototype 1B Evaluation

Figure 6.11: Prototype 1B

Figure 6.9 shows an upgraded version of the first prototype. In reality, the upgrades were applied after prototype 2 was completed and during the development of prototype 3. With version 3 incomplete and my dissatisfaction with prototype 2 (Section 6.3.3), I decided to remedy some of the issues with prototype 1 so that it could be used. Although not in chronological order, this version is presented here as it makes logical sense to discuss in direct relation to the original.

These upgrades included replacing the headstock with a slimmer wood varnished finish and logo engraving. The analogue motion sensor was replaced with a more reliable digital version. The erratic pressure sensor was replaced, and much of the soldering was redone. Wooden caps were added to hide the exposed cables. Also, the microcontroller unit (MCU) was replaced with a smaller one that provided bespoke firmware capabilities and a Bluetooth MIDI connection. The original MCU had fixed firmware that produced data that required further manipulation on a computer before being compatible with standard MIDI devices and software. Creating my own firmware allowed the device to produce standard MIDI data, connecting the instrument directly to other MIDI devices. The Bluetooth capability has also allowed me to experiment with wireless connections.

MDP Evaluation of Upgraded Prototype 1B

BazerBow Prototype			Prototype 1B (Upgraded)
Mimetic Design Principles	Mimetic Gestures	1	No change from the original.
		2	No change from the original.
		3	No change from the original.
	Mimetic Affordance	4	No change from the original.
		5	The replacement of the headstock and hiding of cables improved the overall aesthetics of the device. However, there is room for improvement.
		6	No change from the original.
	Mimetic Appropriation	7	No change from the original.
		8	The intermittent issues with the pressure sensor were remedied and the digital motion sensor was a significant improvement in producing accurate, precise and reproducible gestures.
		9	Performance improved due to improved reliability but still needing to consider further the delighter features.

Figure 6.12: MDP Evaluation of Prototype 1B (Upgraded)

6.3.3 Prototype 2 — Big BazerBow

Figure 6.13:
Playing Prototype 2

Implemented but not deemed functional	Functional but could be optimised	Functional and fully optimised
💬	■	✓

			BazerBow Prototype
			Prototype 2
Mimetic Design Principles	Mimetic Gestures	1	■
		2	✓
		3	■
	Mimetic Affordance	1	■
		2	💬
		3	■
	Mimetic Appropriation	1	✓
		2	💬
		3	■

Figure 6.14:
Prototype 2 Evaluation

Figure 6.15: Prototype 2

Prototype 2 (Figure 6.15) was built to introduce four-string polyphony. It also included more control features. The four-string sensors made the neck too wide compared to average guitars and prototype 1, so it was not as comfortable to play. The aesthetics of this prototype was compromised by my lack of woodworking knowledge and accommodating the technology. As well as the FSR sensors being wider than needed, the internal PCB space requirements were much greater than the first prototype, which produced a much larger and more cumbersome device. The unintentional need for batteries exacerbated the size due to the device requiring more power than anticipated. As can be seen in Figure 6.13, the larger construction proved much heavier and cumbersome to move and, therefore, needed a strap to play comfortably, unlike the smaller prototype 1.

Figure 6.16: Prototype 2 — Side View

The functionality was increased by adding two more sets of position and pressure sensors on the top edge to be played by the thumbs. Also, four small buttons on the right hand were added to provide sustain features and a larger button above them to add programme change (Figure 6.16). However, I found that this additional functionality made the prototype much more complex and confusing to play and, consequently, less intuitive and mimetic.

To improve the overall build quality and finish of prototype 1, the body of this version was built using the more accurate method of machining from templates. However, the overall design was affected detrimentally by accommodating the necessary technology. Screw holes visible at the front were to be covered with wooden caps, which never materialised due to various issues.

MDP Evaluation of Prototype 2

BazerBow Prototype			Prototype 2
Mimetic Design Principles	Mimetic Gestures	1	Although more gestural control has been added, inter-modal gestures have not been introduced.
		2	Initial gestures are simple with more complex gestural control added.
		3	The compromised and complex design is less effective than prototype 1, in producing observable, significant gestures.
	Mimetic Affordance	4	The additional gestures are confusing and disruptive to the mapping strategy.
		5	The compromised design was not aesthetically intended, as a consequence is not as effective as the upgraded prototype 1.
		6	The addition of sensors created an imbalance with its functionality.
	Mimetic Appropriation	7	The addition of the extra strings provides the capability of polyphonic playing.
		8	This prototype used the analogue motion sensor and fixed firmware MCU and consequently suffers from similar reliability issues as the original prototype 1.
		9	The addition of “sustain” and programme change buttons and their indicator LEDs and the capacity for control (3 modulation controls per string and an additional 7 independent and simultaneous controls) could be considered as delighters.

Figure 6.17: MDP Evaluation of Prototype 2

6.3.4 Prototype 3 — The Goldilocks BazerBow?

Figure 6.18:
Playing Prototype 3

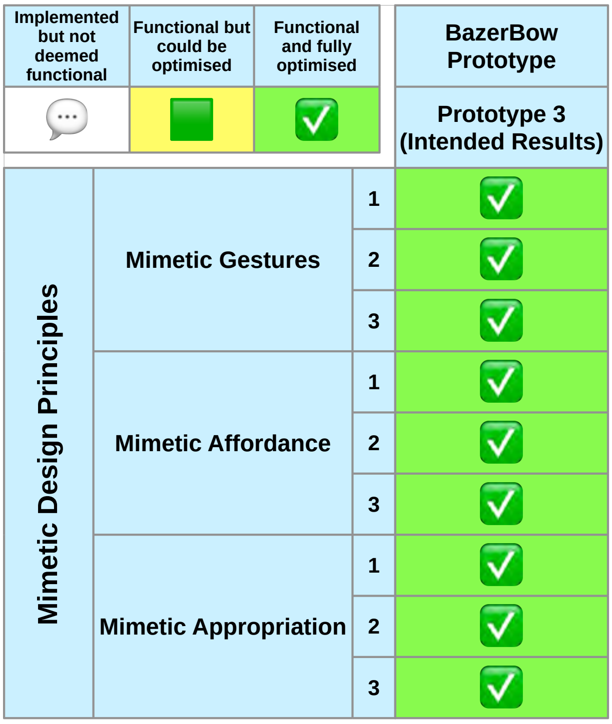

Figure 6.19:
Prototype 3 Evaluation

Figure 6.20: Prototype 3

This prototype intended to remedy the issues of the first and those introduced by prototype 2, notably decreasing the size of the second prototype whilst remaining polyphonic. Another intention of this version was to create multiple devices that could then be sent to various players to test. Producing multiple BazerBows required a method of production that was repeatable as the hand manufacturing was too time-consuming and inconsistent. I created a copy-carver, which essentially works like a pantograph but uses a router instead of a pencil. With this machine and a 3D printed template produced from a CAD file (Figure 6.21), I was able to make the body quicker and more precisely (Figure 6.18 and 6.20).

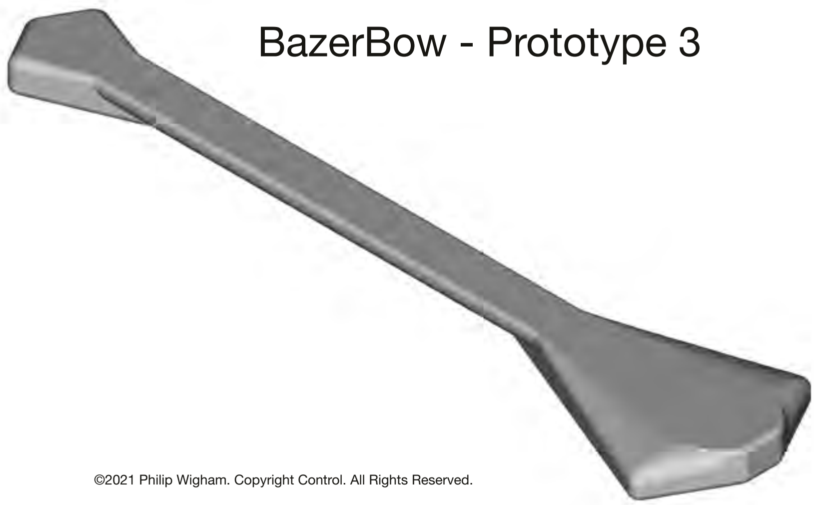

Figure 6.21: Prototype 3 - CAD

The issue of aesthetics and, in particular, size were complex and protracting. The device needed a bespoke PCB, and sensors like the ones used so far were too big, which produced several issues. Designing, prototyping, and creating a PCB were new to me, making a long diversion. Also, although the position and pressure sensors were available at a smaller width, this was a bespoke purchase and required a substantial, unaffordable minimum order. Several alternatives were sought, making for long diversions and are not yet wholly remedied.

This prototype keeps the four strings but a smaller shape and size similar to the first. It also removes the extraneous sensors added to prototype 2, which confused the design. I found that the simplicity of the first prototype outweighed the extra functionality of the second. As can be seen in Figure 6.18 this prototype body can be held in the hand like prototype 1. However, it is intended to have some convenient way of attaching a strap, unlike BazerBow 2, which will increase the flexibility of playing gestures.

The evaluation for this prototype (Figure 6.19) is of course an ideal outcome. A more realistic expectation is the need for more optimisation, particularly for the overall aesthetics, finishing and incorporation of inter-modal and delighter features. Due to the bespoke PCB and accompanying firmware, the stability and reliability will likely need tuning.

MDP Evaluation of the Intended Prototype 3

BazerBow Prototype			Prototype 3
Mimetic Design Principles	**Mimetic Gestures**	**1**	This prototype will include similar gestures as the previous devices. In addition inter- modal gestures are being considered.
		2	The simple initial gestures and goal-oriented gestures will still be evident.
		3	Specific attention to the incorporation of inter-modal gestures and highlighting of small gestures should improve the observable significance.
	Mimetic Affordance	**4**	Has similar mappings of the first prototype reducing the functionality of prototype 2.
		5	Special attention has been taken to ensure that technological issues are solved without compromising the aesthetic design, using prototype 1 as inspiration but using refined production methods.
		6	The functionality has been rebalanced, simplifying prototype 2's capabilities.
	Mimetic Appropriation	**7**	This prototype has four strings and can therefore be used in polyphonic situations.
		8	The production methods have been specifically chosen to create a highly reliable device.
		9	The inclusion of inter-modal gestures and features to exaggerate the small gestures will be delighters as well as updated motion and proximity sensors.

Figure 6.22: MDP Evaluation of Prototype 3

6.4 Comparisons of BazerBows and Conclusions

Implemented but not deemed functional	Functional but could be optimised	Functional and fully optimised
💬	🟩	✅

Mimetic Design Principles			BazerBow Prototype			
			Prototype 1	Prototype 1 (After Upgrades)	Prototype 2	Prototype 3 (Intended Results)
Mimetic Gestures		1	🟩	🟩	🟩	✅
		2	✅	✅	✅	✅
		3	✅	✅	🟩	✅
Mimetic Affordance		1	✅	✅	🟩	✅
		2	💬	🟩	💬	✅
		3	✅	✅	🟩	✅
Mimetic Appropriation		1	🟩	🟩	✅	✅
		2	💬	🟩	💬	✅
		3	💬	💬	🟩	✅

Figure 6.23: All Prototype MDP Evaluations

Figure 6.23 shows the MDP evaluation summaries of all the prototypes. It can be used in answering this research enquiry:

- Do these prototypes incorporate the intended concepts of mimetic design, and how can they be further improved? (Section 2.4).

The aim is to incorporate and fully optimise all nine mimetic design principles, which are projected in prototype 3 but are likely to require further improvements. However, the progression from the first to the third, including the upgraded prototype 1 is apparent. Figure 6.24 shows clearly the relative sizes of each BazerBow and how prototype 3 is closer in size, shape and design to prototype 1. The aesthetics of prototype 3 is a dramatic improvement over the disappointment of prototype 2. Prototype 3 is slightly wider than the first but is more comfortable to hold as the neck fits snugly in the hand. Unfortunately, prototype 1 is too narrow, whilst prototype 2 is too wide. The size of prototype 3 was

Figure 6.24: All Prototypes

partially determined by taking measurements from various guitar necks to determine a comfortable average.

Although the second BazerBow was aesthetically disappointing and was too complex, it did provide scope to explore the functionality of a digital instrument. It does succeed in having multiple simultaneous and independent controls, which, although they require good coordination skills, provide control over a larger number of synthesiser parameters than the other devices. In addition, the sustain buttons were handy. A fourth BazerBow may reintroduce some of these additional features but need to be incorporated differently to ensure the mimetic potential is not affected negatively.

The development of bespoke firmware has been critical to these BazerBows. The fixed firmware severely limited the first two prototypes. These devices required external software to interpret the data before connecting to standard MIDI equipment. The upgraded prototype 1 and prototype 3 benefit from bespoke firmware and therefore produce standard MIDI data. In addition, these instruments can be connected directly to other MIDI instruments or software and can therefore be used with a vast range of equipment.

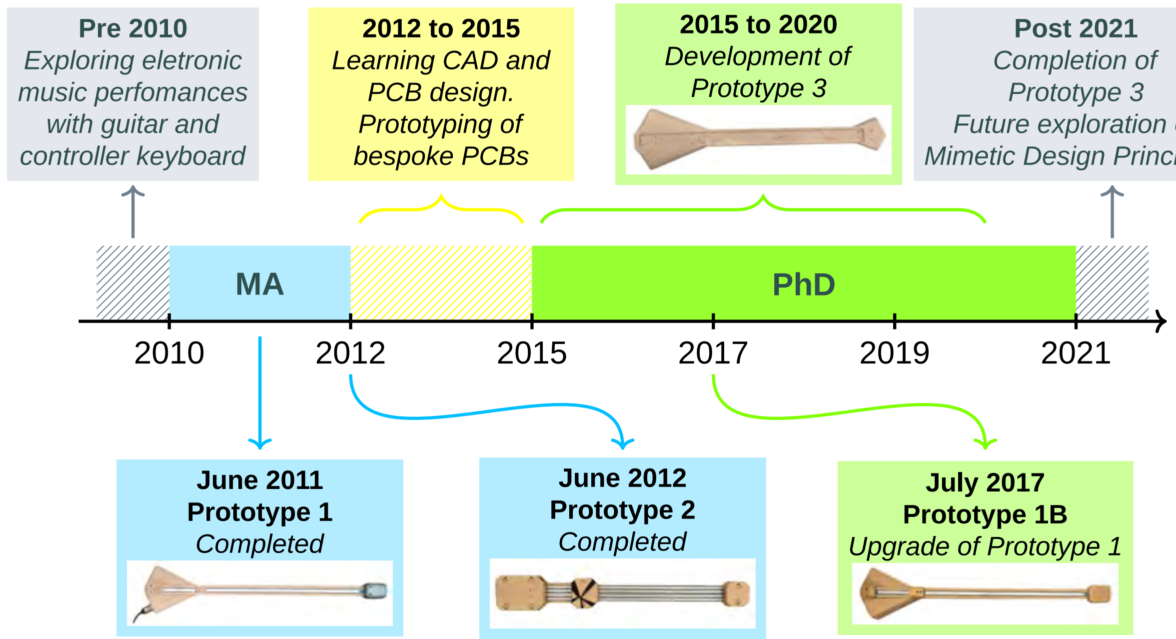

Figure 6.25: BazerBow Prototype Timeline

All three instruments could be connected to a video representation of the playing, magnifying the smaller gestures. Although this inter-modal gestural technique may be beneficial to the mimetic potential, it has not been considered in the evaluations as it is not part of the intrinsic design of the instruments and could equally be applied to all three. A demonstration of the original prototype 1 has a video representation connected to the data, which responds and moves with the BazerBow. An example of this can be seen here: https://research.bazerbow.uk/Video-5/

This research presents an ongoing iterative process, and a snapshot of the various states of prototypes brought about through mimetic design. This work is a continual process of development with the intention of making further diverse prototypes that adhere to the mimetic design principles in the future. Figure 6.25 represents a timeline of this BazerBow prototyping process.

It is important to note that this process is not only to improve the prototypes but as a consequence of their development and in tandem with the other elements of this research enquiry, the mimetic design principles will be revised and improved. A crucial part of developing mimetic design principles is testing the instruments with audience response, discussed in Chapter 7.

Chapter 7

Test Phase | *Examination of Prototypes*

This chapter presents the test phases that were constructed to examine the premise that the BazerBow produces a greater mimetic response than the Ozonic keyboard. The upgraded BazerBow was chosen as it was the most mimetic of the prototypes and the most reliable.

Music was devised to foreground the various gestural elements of the BazerBow deliberately. This music was presented in front of an audience, and their mimetic response was measured in several ways. To thoroughly examine and evaluate the audience's mimetic response and mimetic design principles, it was evident that the nature of comparison and exploration of mimetic design would benefit from a multimodal approach. Each test method aimed to compare each instrument's mimetic levels of engagement, invitation and participation.

There were two test phases, the first a pre-test phase allowing the data collection methods to be trialled and improved. These improvements were then implemented in the main test phase, which consisted of five sessions and 25 participants. Questionnaires and video recordings of the post-performance discussion were utilised to document participant responses. In addition, a bespoke real-time response slider method (Wigham and Challis, 2020) was developed to provide accurate participant response data that was synchronised with the corresponding performance. This method successfully uncovered patterns and correlations of engagement levels with the other data methods.

Videos and data from these tests can be viewed here: https://research.bazerbow.uk/

7.1 The Music

A short piece of music was devised to be performed by the BazerBow and Ozonic keyboard to discover whether mimetic design affected levels of mimetic engagement, and the desire to have a go and to join in. The music was developed and performed using a software synthesiser which provided all the sounds. The chosen sounds were specifically electronic with little sonic acoustic equivalence. These sounds were a deliberate choice as the question was not how can acoustic sounds be digitally replicated and controlled, but how can a DMI, playing modern synthetic sounds, mimetically engage an audience? The instruments were connected to the same software synthesiser to produce identical sounds in the performance so that the instruments were being compared, not the sounds or music.

The performance created for the testing was less than five minutes long and was kept deliberately short, focussing on the different gestural controls of the instruments. The performance was designed to be played as identically as possible with both devices ensuring that comparisons were made between the two instruments and the way the music is performed, not the music itself.

The composition of the music focused on synthesised sounds that responded particularly well to the various control changes so that there were obvious associations with the sonic modulations and the various corresponding performance gestures. The composition initially had four different sections. After the pre-test phase, an additional section was added, extending the piece slightly.

The music was performed twice, once with the BazerBow and again with the keyboard. The order of which instrument was played first was alternated for each test to ensure no bias with the novelty of the initial experience.

Video recordings taken from the Main Test 3 session can be viewed here:[1]

BazerBow Main Test 3 .... https://research.bazerbow.uk/Video-1

Keyboard Main Test 3 .... https://research.bazerbow.uk/Video-2

[1] The camera was aimed to fully capture the audience member, not the performer. The pre-test videos capture the performer, but do not include Section 5 of the music, which is why both sets of videos are included.

7.1.1 Performance Sections

The performance was deliberately devised to focus on the main mimetic design elements of the BazerBow to allow comparisons with the equivalent gestures on the keyboard. The participant data for these performances were examined to determine whether the mimetic design principles impacted mimetic response.

The performance initially had four gestural sections, but after the pre-test phase, a fifth section was added to fully exploit one of the gestural elements (Section 7.3.3). The five sections of the main test performance highlight specific gestural elements. The first and last sections were split into two subsections. The subsections represent the same gestural focus. However, part A has minimal melodic content, whilst part B introduces a melodic element to the section.

- **Section 1A** takes advantage of the large modulating gestures mapped to the filter (continuous controllers CC20 and CC21) on the BazerBow compared with the small modulating gestures of the joystick on the keyboard. The movements in this section are quite slow and deliberate. There is little melodic content in this section.

- **Section 1B** continues to focus on the use of the same gestures but a melodic motif is introduced.

- **Section 2** uses the pitch bend control and continuous controllers CC20 and CC21. However the melodic content focuses on the pitch bend effect.

- **Section 3** focuses on the gesture mapped to continuous controller CC01. This gesture is small and modulating on both devices. This section may have a similar engagement response due to similar mimetic gestures. However, the BazerBow is forward-facing and may be more visible to the audience than the keyboard. Inter-modal features may also cause an increase in engagement in this section.

- **Section 4** utilises continuous controllers CC20 and CC21, but unlike Section 1, the movements are much quicker, erratic and fluctuating. There is no melodic content.

A single note generates a sound effect manipulated and modulated by the moving gestures. The connection between the performance gestures and this complicated, modulating sound is not as apparent in this section. It may cause a perceived dislocation of gesture with the sound, possibly affecting mimetic response.

- **Section 5A (Main Test Only)** begins with the melodic content obscured by a large amount of reverberation and high filter cut-off and resonance. The filter cut-off, resonance and reverberation effect gradually decrease to reveal the melody.

- **Section 5B (Main Test Only)** continues with the melody. However, it focuses on the use of the gesture mapped to continuous controller CC80 (macro 8 and reverberation levels), which is a medium gesture on both instruments. It was expected that the BazerBow would still be more engaging despite the size of the gesture being similar to the keyboard. This expectation is due to the BazerBow gesture being built into the instrument compared with the keyboard utilising an “external” pedal detached from the main instrument body.

7.1.2 Recording Sessions

An Ableton Live session was created to accommodate the live performance of synthesiser sounds (using Native Instrument’s Massive and Ableton plug-in effects) whilst simultaneously recording the MIDI performance data from the instruments and the participants’ real-time response sliders. These recordings allowed the performance data to be synchronised with the real-time slider response and proved to be useful for analysis because the response data could be precisely aligned with the gestures being performed. Ableton Live was also very convenient for mapping custom controllers to the software synthesiser essential to the performances. The Ableton Test session files can be download here: https://research.bazerbow.uk/#files

The recorded data for one of the test sessions can be seen in Figure 7.1.[2] The top four tracks are participant slider data. The “orange” clip is performance data from the keyboard,

[2] All other test session screenshots are in Appendix I.

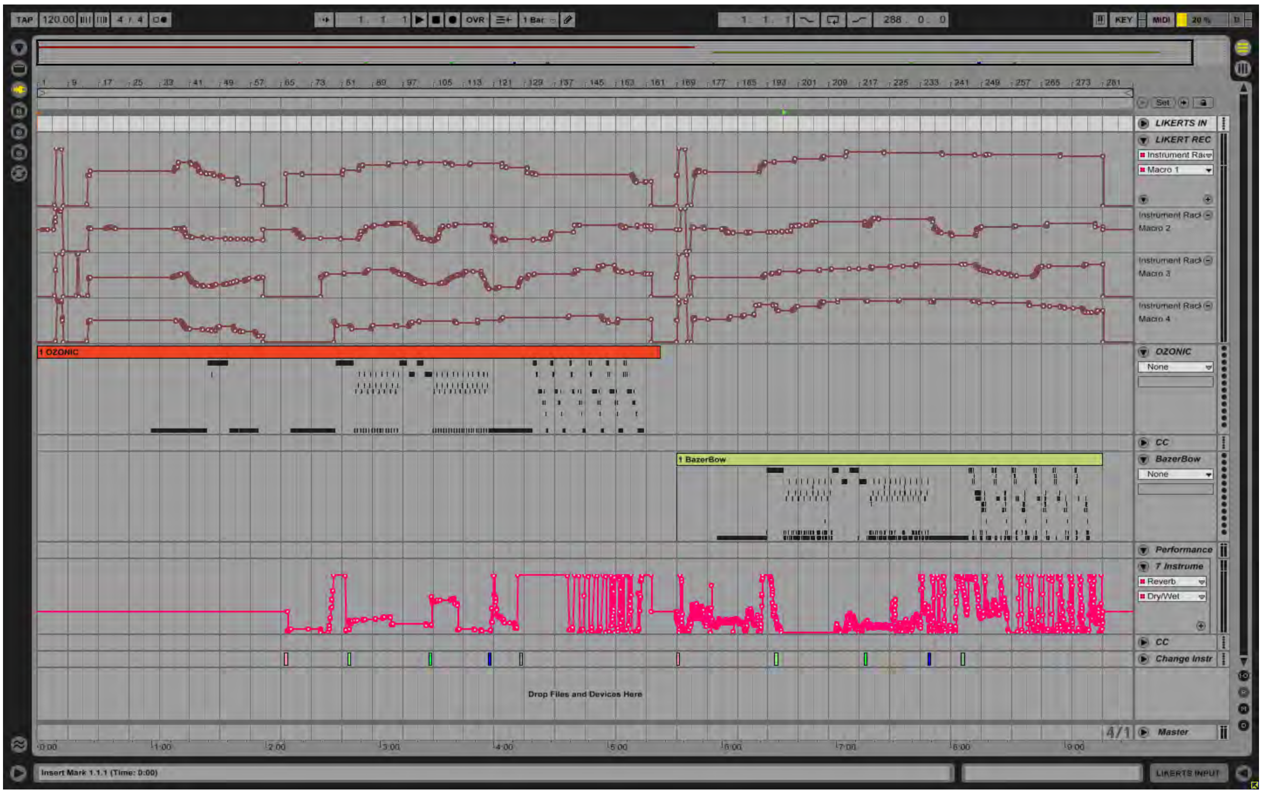

Figure 7.1: Ableton Live Session

and the "green" clip is the BazerBow performance data. These two clips show the notes performed and recorded from the instruments. The pink trace below the performance clips shows the data recording for the dry/wet reverberation control, which was mapped to the continuous controller CC80. The small coloured blocks beneath the pink trace are where the preset synthesiser programme was changed.

The synchronisation of this data can be easily seen with the slider levels to the left above the orange clip corresponding to keyboard performance and the slider data above the green clip to the right with the BazerBow performance.

Playing the pieces to a click track was considered to ensure that the timing of both the performances was accurate. When looking at the data, the performances without the click proved relatively consistent, with the data from each instrument being comparable. Although the testing worked well without a click track, this may be considered for future testing.

7.1.3 Controller Mapping

Both instruments required two mapping stages to connect the performance gestures to the software synthesiser sounds. The first stage occurred in the device hardware, where the sensed performance gestures were mapped to MIDI parameters. In the second stage, this MIDI data was sent to the computer and mapped to the desired synthesiser or digital audio workstation (DAW) parameters. The mappings from MIDI data to the synthesiser were configured similarly for both instruments to make a fair comparison.

Stage 1 Mapping – Gesture to MIDI

The standard MIDI note on/off, which includes initial pitch and note velocity (initial volume of the note), was used to generate sounds from the initial gestures. Modulating gestures were mapped to pitch bend, allowing the initial pitch to be “bent” upwards, similar to bending a guitar string. MIDI note on/off and pitch bend data are recognised standard MIDI controls for which most DAWs and MIDI instruments already have default mapping.

An additional four modulating controller gestures were mapped to MIDI continuous controllers (CC): CC01, CC20, CC21, and CC80. As with pitch bend, CC01, generically named “modulation”, is also universally mapped and recognised by most MIDI instruments. However, due to the vast range of available synthesisers and sounds, this modulation control varies somewhat in the actual sonic effect. Therefore, CC01 was mapped to a custom synthesiser parameter instead of using the default “modulation” mapping. The continuous controllers CC20, CC21, and CC80, do not have any recognised general mapping and consequently were also mapped to custom parameters. Table 7.1 shows the mapping of the MIDI controls to the performance gestures for both instruments. This mapping was used for all the performances.

A separate on/off foot switch was used with both devices during the performances, mapped to change the synthesiser sound programme. Although “programme change” is a recognised standard MIDI feature, this was not used due to the complexities involved in

MIDI DATA	BazerBow Gesture	Keyboard Gesture
Note on/off	Right hand finger touch initiating note on/off; left hand finger touch position selecting pitch (range E2 to C3).	Keys played with fingers.
Pitch Bend	Finger pressure of left hand.	Pitch bend wheel moved by fingers.
CC01	Finger pressure of right hand.	Modulation wheel moved by fingers.
CC20	Rotation of entire instrument in a horizontal axis.	Horizontal axis of small joystick, moved by fingers.
CC21	Rotation of entire instrument in vertical axis.	Vertical axis of small joystick, moved by fingers.
CC80	Movement of right hand above body of instrument (approximate range 10mm to 40mm).	Continuous foot pedal, moved with foot.

Table 7.1: Instrument Gestures to MIDI Control

this particular case, where a smooth transition between different sounds was found to be necessary, (Section 7.2).

Stage 2 Mapping – MIDI to Synthesiser

The MIDI data from both devices were mapped to the same synthesiser “macro” parameters and DAW controls, providing a fair and direct comparison of the instruments’ performance features and mimetic capabilities.

Figure 7.2 shows the control panel for Native Instrument’s “Massive” (Native Instruments, 2020) synthesiser control panel. In the bottom right, there are eight yellow “macro” controls. These controls can be assigned to as many synthesiser parameters as desired, allowing complex sound manipulation.

Massive has a larger simplified panel view of these macros, which provides direct access to MIDI mapping. Figure 7.3 shows this panel view, the eight macro knobs with a descriptive name above and the mapped MIDI control underneath. As can be seen, the macro parameters 1, 3, 4 and 8 are mapped to continuous controllers CC01, CC20, CC21 and CC80, respectively.

Figure 7.2: Native Instruments “Massive” Control Panel

Figure 7.3: Native Instruments “Massive” Macros

The synthesiser parameter names are custom titled and were part of each programme setting. The macro controls varied depending on the programme selected, although there is some consistency. For example, parameter 3 (mapped to CC20) tended to control some part of the filter, usually the cut-off frequency.

Table 7.2 shows the mapping of MIDI continuous controllers to synthesiser programme parameters used in the performances.

		Synth Parameters Mapped to CC			
Section	**Programme**	**CC01**	**CC20**	**CC21**	**CC80**
1A	Poisonous Vapor	Color	Puddles	Cutoff	Flt Att
1B & 2	Ice Glitter	Wt-Pos	Cutoff	Reso	Mod Amt
3	Monolit	Formant	HighPass	Filter FM	St. Spread
4	Orbit Charon	Pitch	Cutoff	Scream	Mod Amp
5A & 5B	Attack Disto	WT-Pos	Damping	Reso	Release

Table 7.2: Synthesiser Programme Mapping

In addition to the mapping of synthesiser macro 8, continuous controller CC80 was also mapped to the “dry/wet” control of an additional reverberation effect plug-in external to the synthesiser. This mapping also allowed the gestures assigned to CC80 to control the amount of reverberation added to the synthesiser signal. This mapping was featured in sections 5A and 5B of the performances.

The BazerBow had an additional controller gesture mapped to continuous controller CC02, which could have been utilised. However, having already substituted the knob control for a pedal on the Ozonic due to performance difficulties, no further controls were used for the testing. The two devices needed to generate the same sonic performances as possible for a fair comparison of the gestural control producing those performances and the mimetic responses. And so, although the BazerBow had the potential for further gestural control, the controls were limited to the restraints of the keyboard to ensure similar performance capabilities.

7.2 Pre-Test Phase

Having prepared the instruments and devised the performance, it was necessary to carefully choose a range of methods for collecting, recording and documenting the mimetic response of an audience. After a thorough review of testing methods, the best options were trialled in a pre-test phase. This trial allowed for the evaluation and improvement of these tests before moving on to the main test phase.

After considering different methods for examining mimetic potential and mimetic response, particularly EEG (Mehta and Kliewer, 2014; Koelsch, 2011; Burge and Siebert, 2010; Lindenberger et al., 2009), EMG (Tanaka, 2015), heart rate monitors and pressure sensors (to detect participant posture), it was apparent that other methods were more practical. A quantitative testing method was still considered important in addition to the qualitative methods of questionnaires and video. Although the EEG, EMG and similar tests would have provided this quantitative data, they were far too complicated to incorporate. The results would also have required specific expertise and have been very difficult to interpret.

A custom-designed real-time response slider (Wigham and Challis, 2020) was specifically developed for use in the test phase to measure mimetic engagement allowing participants to respond during the performances. The captured slider data could then be analysed along with the other data types. The questionnaires were developed into three main areas: demographics, music experience and post-performance response questions. After the trial in the pre-test phase, the first set of questionnaires was revised entirely for the main test phase. Video recordings were taken to allow full synchronisation of slider data with the performance and capture the performer and participants during the test sessions. The post-performance discussions were also videoed. The video recordings were processed in the pre-test phase, which confirmed that the video synchronisation process was unnecessary and that participants were not manifesting observable mimetic participation. However, the video did provide an accurate record of post-performance discussions.

Figure 7.4 is a snapshot of the pre-test phase for the Ozonic keyboard on the left and BazerBow on the right. The pre-test phase provided the necessary evaluation of the methods for the main testing phase. It proved crucial for refining questionnaires, slider data processes, controller mapping, data analysis and performance. Two participants took part in the pre-test, which consisted of demographic and music experience questions, a

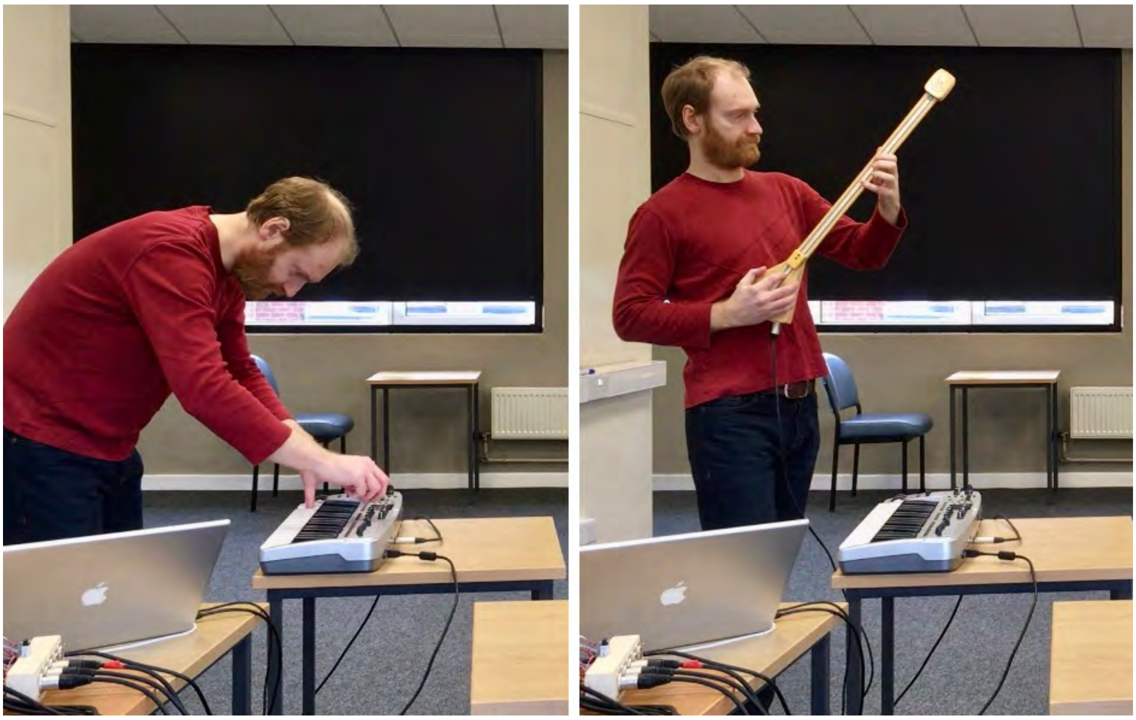

Figure 7.4: Pre-Test Performances

questionnaire about “identification”, post-performance response questions and real-time response slider data. The devised musical piece was performed as similarly as possible on both instruments.

After analysing and discussing the pre-test process and data, improvements were needed for the main test phase. The “identification” questions were challenging to understand in relation to the test context. These questions were replaced with the MUSE questionnaire. The initial demographic questions were replaced with a standard Likert type questionnaire, whilst the original post-performance questions were superseded by mixture of Likert-type and open-ended questions. These questionnaires provided a better representation of demographics, musical experience and engagement and were more complementary to the idea of mimesis.

The slider data proved to work very well producing data that directly informed the improvement of the performance for the main test phase (Section 8.4.1). However, there were some modifications needed in the way the data was recorded and improvements in calibration of the data (Section 7.2.2).

A fifth section was added to the performance to allow better demonstration of the gesture tied to reverberation effects, as this was little utilised in the pre-test. This section also proved a good addition, prompting several interesting participant responses. The performance proved difficult to control and perform on the keyboard, so an expression pedal was added.

7.2.1 Video Data

Video recordings were taken of the audience to look for overt mimetic participation in response to the performances. The recordings also partially captured the performance to enable the performance to be synchronised with the slider data. In addition, the post-performance discussions were recorded.

Video recordings of the pre-test phase can be found here:

BazerBow Pre-Test https://research.bazerbow.uk/Video-3

Keyboard Pre-Test https://research.bazerbow.uk/Video-4

These videos have a screen recording of the synchronised slider data overlaid.

Observing Overt Mimetic Participation

There was little expectation of overt mimetic participation due to the performances having been explicitly composed for examining mimetic response to the instruments. However, as the video was also necessary for recording the post-performance discussions, it seemed prudent to leave the recordings running from the beginning of each session.

The pre-test phase confirmed little movement of the audience while watching each performance. Instead, the participants were focused on the performance whilst responding with the slider. The test performances were composed specifically for examining mimetic response to the instruments. So the overt physical response of the participants was not truly representative of what would be found at a music concert. Future tests to observe any overt physical response of the participants would need a different approach to the music performance, perhaps more similar to a music concert.

Video Data Synchronisation

It was possible to create a screen recording of the Ableton Live session playing the MIDI data with a cursor highlighting the time and position of the recording and the position of the slider data. This video could then be overlaid onto the video recording of the performance. To ensure that the videos were synchronised, each performance began with an audible count-in click created by Live, which was captured by the video recordings. Figure 7.5 shows two points in the BazerBow performance, to the right of the video recording, where the slider data has moved along to the left. The red line shows the exact synchronised slider data points relating to the performance in the video.

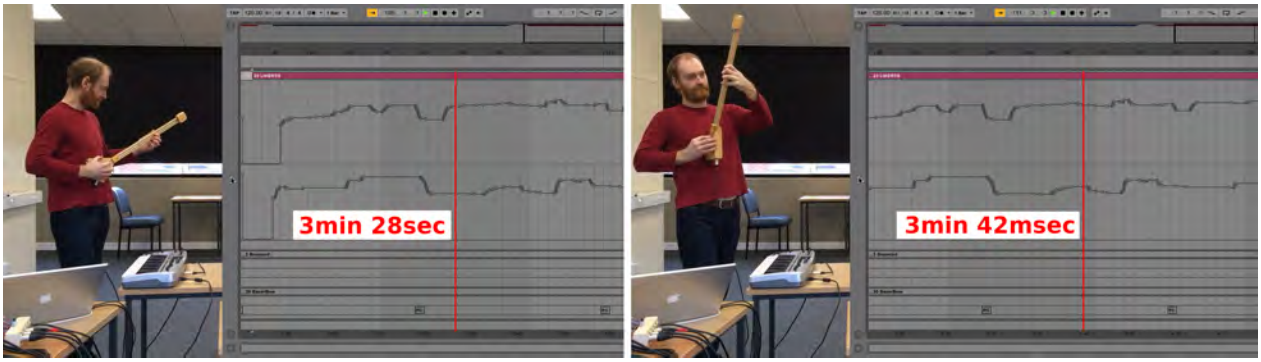

Figure 7.5: Pre-Test Video Slider Synchronisation

The video synchronised well with the slider data. However, it became apparent that it was unnecessary for these tests and data analysis due to the additional MIDI performance data that was also recorded. This performance data and the slider data were converted to CSV[3] and imported into spreadsheets to produce charts for analysis. Figure 7.6 shows one of these charts with the slider data and the corresponding keyboard performance data plotted underneath. These plotted charts show clearly the exact location of the performance gestures in relation to the movement of the participants' sliders. This process was at least as precise and more efficient than following the video to identify each gesture and corresponding slider levels at that moment. The charts also provided a complete overview of the entire performance, illuminating patterns that would have been missed using the video method. However, the video synchronisation did work well and would be

[3]Comma Separated Values. A common text file format for transferring data between various types of software such as a database or spreadsheet.

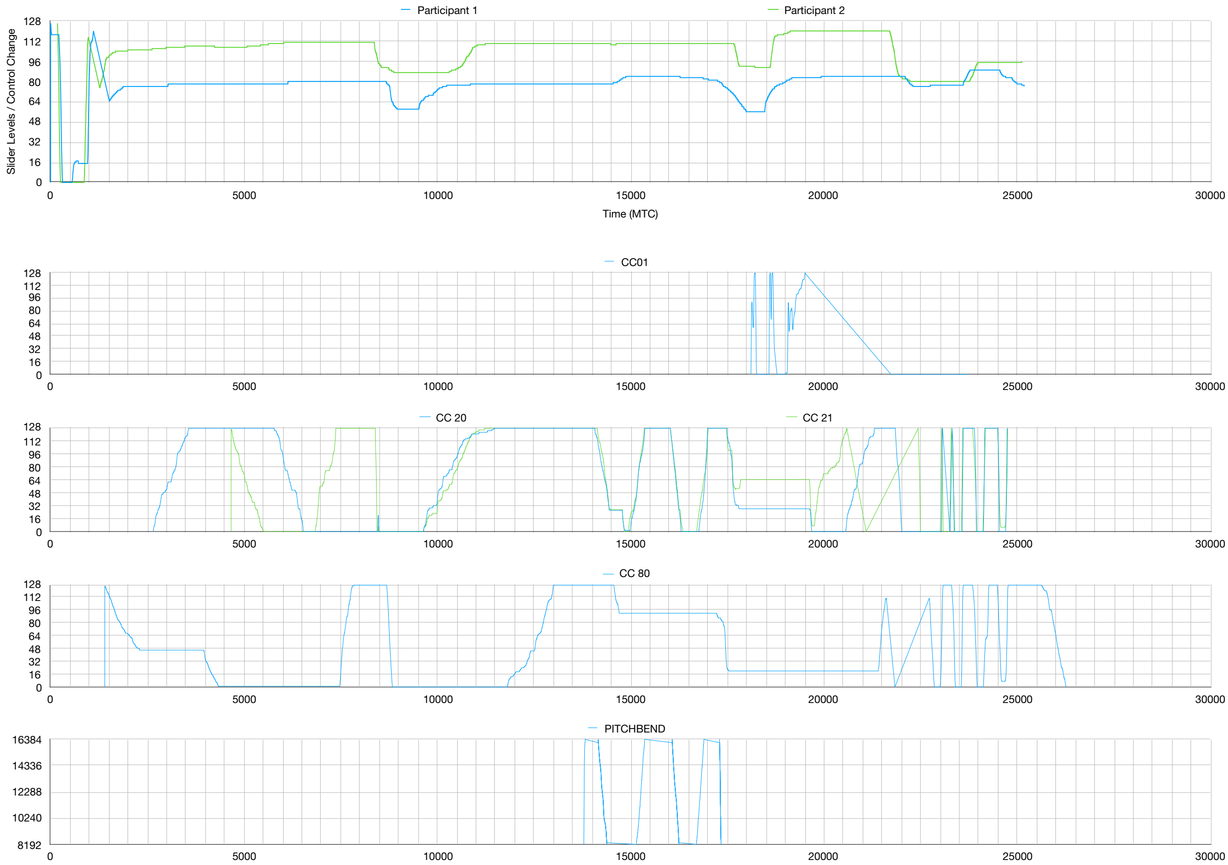

Figure 7.6: Pre-Test Synchronised Slider Data

extremely useful for projects that do not produce any MIDI performance data, such as acoustic instruments, dance, and theatre productions.

Video Analysis

Video cued recall (Morreale, Guidi, et al., 2019; Candy and Edmonds, 2011; Costello et al., 2005) was considered for analysis of the video. This method requires the video to be shown to the participants as they discuss their experience, potentially jogging the memory for discussion. This method was extraneous as the questionnaires and discussions were undertaken directly after the short performances. The participants were also responding to the performances in real-time with the bespoke slider developed to capture changes in engagement immediately. However, this analysis method will likely prove helpful with longer test phases in the future.

The main use for the video recordings was to capture the post-performance discussions at the end of each session, where participants discussed the performance and instruments. These discussions allowed the participants to express opinions and ideas not covered in the questionnaires and provided further insight. The audio was extracted from the video and transcribed using an online service (Otter.ai, 2020) for text analysis and collation with the rest of the data. The video transcripts were reviewed to find any content that related to the ideas of mimetic response which might corroborate with the other data. The transcripts were also analysed using the software Antconc (Anthony, 2019) with varying success (Section 8.1.2).[4]

7.2.2 Real-time Response Slider

A slider input method was designed for this project to complement the video discussions and questionnaire data, enabling the recording of real-time audience response (Wigham and Challis, 2020). Although the questionnaires provided insight into participant experience and perception of the performance, the answers are retrospective and rely on the participant's memories and ability to articulate when and where within the performance they experienced a particular moment. The slider data provided a continuous real-time response for the entire duration of each performance.

A physical slider was devised and built using a linear potentiometer secured in a wooden housing and connected to an MCU via XLR (microphone) cable. The MCU converted the movement of the slider into MIDI continuous control data and sent this to the computer via USB. Ten sliders were built to allow the recording of up to ten responses simultaneously. These were connected to the same MCU, capable of up to thirty-two inputs. The data from the ten sliders was sent to ten different MIDI continuous controllers to allow differentiation of the recorded slider data. Figure 7.7 shows one of the custom built sliders.

[4] Antconc word cloud data can be downloaded here: https://research.bazerbow.uk/#files.

Figure 7.7: Real-time Response Slider

A wireless solution was considered but added too much complexity to the system, although it would have been necessary for large audiences. However, the cabled version worked well for the environment and small participant numbers in the testing phases. The slider housing was made from wood for practical reasons.

Slider Testing Process

At every test session, each participant was provided with a slider. The slider system had a capacity of ten simultaneous sliders with a potential of up to thirty-two. However, the largest group in the main testing phase was seven participants. At the beginning of each test, session participants were asked to consider how engaged they were in the music performance. Then, they were asked to respond continually to the performance by moving the slider up as they felt more engaged and downwards as they felt less engaged, with the centre point being a neutral position of engagement.

Slider Data Capture and Calibration

The MIDI data from the sliders was recorded into an Ableton Live session. An example of the slider data can be seen in Figure 7.8, a screenshot of a Live recording session. The four tracks of slider data were recorded simultaneously with the performance data which can be seen in the green clip below the slider tracks. The Live sessions from all the tests can be found in Appendix I.

Figure 7.8: Test 1A - Ableton Live Recording Session (BazerBow)

Calibration of the slider data before every performance proved crucial for accurate data analysis. Therefore before each performance, the participants were asked to move the slider as far upwards and downwards as comfortably possible, and finally to a central position. This calibration can be seen on the left side of the Live session in Figure 7.8. The calibration data allowed for different hand sizes, holding positions, and starting central positions. When comparing and analysing the data, it was necessary to know the neutral centre position for the slider data and the potential minimums and maximums so the data could be compared fairly. Using a potentiometer with a central detent could help in the future but would need to be tested to ensure that it would work effectively for different sized hands.

Figure 7.9 shows the slider data from the pre-test. The calibration data can easily be distinguished at the beginning of the chart as a quick drop to a minimum, then rise to maximum, then back down to a central point. During the pre-test, the calibration process was performed only once at the beginning of the session. The data showed the necessity for this process to be recorded before both performances, allowing the minimum, maximum and centre points to be re-calibrated before the second performance to accommodate for any change in the participants' hand position that would affect the movement of the slider.

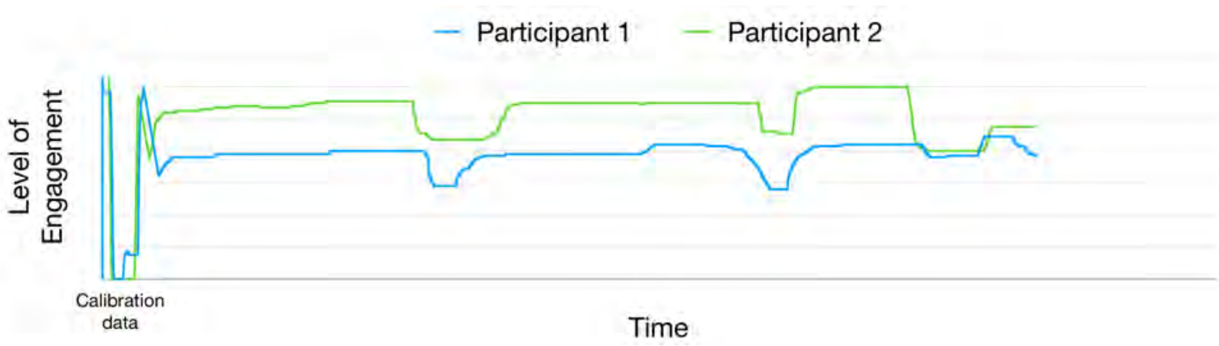

Figure 7.9: Slider Chart from Pre-Test

The slider data was recorded simultaneously with the performance data and was therefore perfectly synchronised. The MIDI data from the sliders was converted to CSV, which was imported into spreadsheets to allow further analysis and comparisons with the other data (Figure 7.6). The calibration data were integrated to produce calibrated percentage engagement levels. These "calibrated" charts were used to look at the minimum and maximum levels of engagement for each performance section and then compared with the corresponding participant data (Section 8.4.4).

Pre-Test Recording of Slider Data

During the pre-test, the slider MIDI data was recorded directly into Ableton Live as MIDI continuous control data, which the slider MCU produced. However, the first slider generated continuous controller CC00, which could not be recorded directly into Live. This issue was circumvented by mapping the continuous controllers from the ten sliders (CC00 to CC09) to ten software "control knobs" (Figure 7.10) within Live. The movement of these knobs was then recorded as automation data. After the testing phase, this automation data was converted back into MIDI data for analysis. This process had no adverse effects on the recording or accuracy of the data, as automation data and MIDI CC data are interchangeable within Live.

Figure 7.10: Software Control Knobs Mapped to Sliders

The real-time response data has been invaluable to this research, in particular, due to its synchronised nature and timing accuracy. It has given real-time insight into the audience responses and provided quantitative data to supplement the qualitative data from the questionnaires and post-performance discussions. The continuous slider data charts provide a visual aid for discovering connections between patterns of engagement levels corresponding to the different performance sections and instrument gestures. These slider patterns aim to corroborate the answers and comments made in the questionnaires and post-performance discussions.

7.2.3 Questionnaires

A combination of questionnaires relating to demographics, music engagement and mimetic response to the performance were designed for the pre-test phase (Appendix D). The recordings of the open discussions complemented these tests, allowing free responses from these discussions in conjunction with direct questions. The following sets of questions were used in the pre-test session.

- Demographic and music experience questions were filled in at the beginning of the session (Figure D.1).
- An initial set of questions was devised using a known psychological framework looking at identity and identification (van Mourik Broekman et al., 2018; Leach et al.,

2008) (Figures D.2 and D.4). The way participants identified with the instruments could be compared and possibly connected with mimetic response.

- Also several questions relating directly to the instruments were added to the identity questions (Figures D.3 and D.5). These additional questions and the identity questions were answered after each performance in response to the corresponding instrument.

- After both performances a set of questions comparing the two instruments was completed (Figure D.6) with the opportunity for participants to add any further comments (Figure D.7).

The pre-test was crucial in improving the questionnaires, facilitating significant revisions for the main testing phase.

7.3 Main Test Phase

The successful pre-test trial of the custom-built real-time response sliders provided confidence in the usability and suitability of this method for the main test phase. It instigated an important improvement to the performance setup. This improvement in the synthesiser programme change provided further insight into the slider data process (Section 8.4.1). The inclusion of the keyboard foot pedal and the addition of section 5 to foreground CC80 gestures also proved to be worthwhile additions to the testing process. Furthermore, the “identity” questions were replaced with the MUSE questionnaire (Chin and Rickard, 2012), aimed at participant music experience and engagement, and an improved post-performance questionnaire. The video recordings provided the audio for the post-performance discussion transcriptions. All these improvements were successfully implemented into the main testing phase. The new and improved demographic (Appendix E), post-performance (Appendix F) and MUSE questionnaires (Appendix G) seemed easier to follow and answer compared with the pre-test questionnaires, which was confirmed by enquiring with the participants after the tests.

There was one technological issue at the beginning of the first test session. The keyboard had buttons close to the joystick controller and, when accidentally pressed, stopped the foot switch from working correctly. In the first test session, the keyboard performance had to be restarted due to this issue (Section 8.4.2). After this test session, the keyboard was reprogrammed to ensure that these buttons could not affect future performances, which remedied the issue.

7.3.1 Music USE Questionnaire

After the pre-test phase, the participants found the questions about “identity” too abstruse, especially in the context of musical instruments, and felt that several of the questions were unanswerable. The questions were difficult to interpret due to the specialised terminology. The problematic wording crucial to this particular test could not be sufficiently adapted to explore mimetic response. These questions were meant to add a psychological profiling that had already been approved and tested in the field. However, having used them in context with the performances, they proved entirely unsuitable for providing meaningful data for examining the effectiveness of mimetic design and were replaced by the MUSE Questionnaire.

The music USE (MUSE) questionnaire (Chin and Rickard, 2012) was developed to look at an individual’s propensity for motor contagion in relation to music. It defines three indices (Section A) and five styles (Section B) of music engagement as seen in table 7.3.[5]

After completing the MUSE questionnaires, they were processed through a scoring system. The results indicate participant proclivities for the different music experience and engagement types. The MUSE indices of musical engagement gave much more detailed profiling of a participant’s experience with musical instruments and performance than simply asking whether they are a “trained” or “professional” musician. As Finnegan’s (2007) research shows, peoples’ musical knowledge and experience can not simply be assigned musician or professional status and using such questions would leave a vast

[5] The MUSE questionnaire can be found in Appendix G

Section	**MUSE Index/Style**
Section A	Index of Music Listening (IML)
Section A	Index of Music Instrument Playing (IMIP)
Section A	Index of Music Training (IMT)
Section B	Cognitive and Emotional Regulation (I)
Section B	Engaged Production (II)
Section B	Social Connection (III)
Section B	Physical Exercise (IV)
Section B	Dance (V)

Table 7.3: MUSE Indices and Styles

amount of participant musical experience hidden. Most people engage in musical activity in one way or another, but many do not receive formal training or earn money from their experience. These experiences are an important way people learn about and perceive music and performance, consequently affecting their mimetic response.

The five MUSE styles of engagement tie in with different ways mimesis and mimetic participation may manifest. This MUSE questionnaire, in tandem with the post-performance questions and slider testing, allowed for the comparison of the natural mimetic tendencies of the participants and the actual evidence of mimesis in the data. Someone more susceptible to cerebral and individual engagement in music may manifest more covert mimetic participation, whilst those with a tendency for more social and physical engagement with music may be more likely to exhibit overt mimetic participation. This concept was important to explore as covert mimetic participation could only be uncovered by data analysis. Although overt mimetic participation could potentially have been visible on the video recordings, this proved not to be the case for the testing phases. Therefore, data analysis was also necessary to expose potential overt mimetic responses.

As the MUSE questionnaire covered music experience and engagement, it completely replaced the original pre-test questionnaire, which covered this area. Retrospectively this worked well, providing good results complementing the other testing methods. However, it lacked one question missed from the original: which instrument(s) the participants were experienced in playing. This is discussed further in Section 8.5.

7.3.2 Post-Performance Questionnaire

After the pre-test, the performance questions were modified to a range of Likert response and open questions. Five of these questions related directly to participant response were analysed as a Likert scale and another two directly comparing the two instruments as Likert type (Appendix F).

The Likert type response is an ordinal scale. The participant chooses from a scale of five or more options. However, there is no ability to further extrapolate participant responses on a gradual interval scale from single Likert responses. Statistical methods do not account for how the participant's response may have been different if presented with a gradual scale rather than the fixed Likert scale and therefore make assumptions which might not be accurate. When several similar Likert type responses are averaged together, they produce a Likert scale which can then be treated as an interval scale and analysed carefully applying non-parametric statistical methods (Joshi et al., 2015; Boone and Boone, 2012; Stevens, 1946; Likert, 1932).

The five sets of Likert type questions for both the BazerBow and keyboard represent an overall "mimetic response" from the participants. These five questions were averaged to create a Likert scale (Joshi et al., 2015; Boone and Boone, 2012; Stevens, 1946; Likert, 1932) referred to as the mimetic index (MI). Questions 7.1 and 7.2, although complementary to the mimetic response questions, use different Likert type answers choosing between the two instruments and so have been analysed separately as Likert type data.

The Likert type responses were converted to numeric values with 1 assigned to "Strongly Disagree", 2 to "Disagree", 3 to "Undecided", 4 to "Agree", and 5 to "Strongly Agree". The same numeric system was also applied to questions 7.1 and 7.2 with 1 'applied to 'Keyboard", 2 to "Mostly Keyboard", 3 to "Both", 4 to "Mostly BazerBow" and 5 to “BazerBow”. This numeric data was used to analyse the Likert responses allowing the calculation of averages and a Likert scale for questions 3.1 to 4.5. It was also used in the averaging distribution method for further analysis.

The Average Distribution Method (ADM) was developed and implemented to examine correlations between the Likert response questions and the MUSE data. This ADM analysis produced a more detailed and illuminating explication and elucidation of the data than purely observational methods (Section 8.3).

Questions 8 to 11 of the post-performance questionnaire were open-ended deliberately to allow the participants the freedom to express their opinions about the instruments. The questions were constructed to illuminate areas of possible mimetic response. As with the videoed discussions, the open questions were analysed manually to look for phrases and responses which pertain to a possible mimetic response. Again, the Antconc software produced a list of the most frequently used words and phrases within the answers.[6]

The demographic and post-performance questionnaires were developed using an online questionnaire service (Online Surveys, 2021) but without the certainty of internet connections and compatible devices, the questionnaires were printed and completed by hand. After the event, these answers were entered into the online survey software to allow conversion to CSV for further manipulation and analysis. The CSV data was imported into a cross table along with the MUSE scores to allow the complete data set for each participant to be analysed as a whole (Appendix L).

7.3.3 The Test Sessions

It was initially planned that the main test would occur across three different phases with an increasing number of participants from two to fifteen. In this case, the participant numbers would have been spread across three different phases and, therefore, smaller samples of no larger than fifteen for the third phase. It was decided that a single main test phase with

[6] Antconc word cloud data can be downloaded here: https://research.bazerbow.uk/#files.

twenty or more participants would be more likely to manifest interesting patterns across the data set than from three separate test phases with smaller sample groups.

The main test sessions took place in different venues convenient to participants. Although the original intention was to proceed with one test session with all the participants, it was decided that a more manageable and beneficial approach would be to split the test into several sessions with smaller groups. Each session followed the same methods and procedure so that the data from all the sessions could be compared and analysed as a complete sample set.

Smaller groupings of three to seven gave the participants more opportunity to voice an opinion in the group discussions, especially the more quietly spoken audience members. Overall the smaller and less formal settings of the test sessions were more beneficial than problematic.

There were twenty-five participants involved across five test sessions. The first test was split into two sessions as the venue, the lounge of one of the participants, could only comfortably accommodate four participants. Therefore, four participants were in the first session and three in the second. The second test session had six participants at the author's home, the third in a secondary school with seven participants and the last had six participants again at the author's home. The data was collected from the 25 participants over the five test sessions with the following group sizes:

- Test 1A: four participants (1 to 4);[7]
- Test 1B: three participants (5 to 7);[7]
- Test 2: six participants (8 to 13);
- Test 3: seven participants (14 to 20);[8]
- Test 4, five participants (21 to 25).

[7]The first two test sessions are referred to as 1A and 1B as they occurred on the same day and at the same venue, but the test was repeated with different participants.

[8]Video recordings from this test session can be viewed here: https://research.bazerbow.uk/#videos

Testing Procedure

Except for the foot pedal for the keyboard and custom keyboard stand, the same hardware setup from the pre-test was used for the main test phase. Speakers were positioned beneath the laptop for both performances so that all sounds emanated from the same position. The video was recorded using two mobile phones from different angles to capture the audience and performer.

After examining the data and video from the pre-test, it was decided that an extra section was needed to highlight the gestures mapped to the continuous controller CC80. In conjunction with this extra section, it was also deemed necessary to use an expression pedal with the keyboard to control CC80. Using a control knob on the keyboard for this purpose proved too difficult whilst simultaneously playing the keys and using the other controls. The BazerBow did not have this problem due to the nature of the initial gesture and modulating gestures which were more easily performed simultaneously and independently. The use of the pedal changed the natural gestural size mapped to CC80 from a small movement of fingers to a medium movement of the foot. The pedal also increased the mimetic potential for this gesture. However, the detachment of the pedal from the instrument's main body may have had an overall negative mimetic effect. Although adding the pedal may have affected the overall mimetic potential of the keyboard, this was seen as a further opportunity to explore the mimetic effects of the different gestures of both instruments rather than having any detrimental impact on the testing process.

Every participant was provided with a slider and clipboard at each test session with a participant information sheet and consent form. These forms were collected and kept separate from the other data to ensure anonymity when completed. The process was described to the participants, and then they were given the demographic and MUSE questionnaires, which they were to read and fill in before the performances.

The slider method was then described, including the calibration process and how the slider response corresponds to their engagement level. The slider calibration levels were then recorded, followed by the first performance. Next, the participants were given the five corresponding MI questions to complete immediately concerning the performance. The slider process was completed again, followed by the second performance on the other instrument. Again the participants immediately responded to the performance by completing the five corresponding MI questions.

They were then asked to complete the remaining post-performance questions (5 to 11), comparing and responding to both performances. After the completion of all questionnaires, there was a time of discussion to allow participants to ask questions and express thoughts and opinions not necessarily covered by the questionnaires. At this time, both instruments were offered for participants to "have a go". The process for each test session was the same, except for the order of the performances. The performance of the BazerBow and keyboard was alternated across the test sessions to highlight any possible effects the order of performances might have on response. The analysis of the data from these test sessions is discussed in Chapter 8.

Chapter 8

Data | *Data Analysis and Anecdotal Evidences*

According to the previous evaluations the BazerBow used in the test phases of this research had more effective mimetic features and superior mimetic potential than the Ozonic keyboard (Chapter 6). Therefore, the BazerBow was expected to generate higher levels of mimetic engagement and a greater desire to have a go and join in than the keyboard. Consequently, the testing and data analysis focus has been on discovering and examining any patterns or correlations in the data that support these suppositions.

The pre-test phase allowed the assessment of the methods and testing processes with two participants. Evaluation from performer and participant perspectives provided essential improvements in all areas of the testing process. These improvements were carried through to the main test sessions.

After the conclusion of the main test phase, other areas of possible improvement were identified, but these were not deemed detrimental to the test data (see 8.5).

Due to the technical nature of the data collection and analysis methods, the following nomenclature and terminology have been used to label and discuss the data.

For analysis and labelling of data, the BazerBow and the keyboard are referred to as M_c and K_c respectively.

The MUSE questionnaire (Chin and Rickard, 2012) consists of a set of questions split into two sections, (Appendix G). Section A provides three “Indices of Music Engagement”,

Section	**MUSE INDEX (Chin and Rickard, 2012)**	**Label**
Section A	Index of Music Listening (IML)	MUSE_{IML}
Section A	Index of Music Instrument Playing (IMIP)	$\text{MUSE}_{\text{IMIP}}$
Section A	Index of Music Training (IMT)	MUSE_{IMT}
Section B	Cognitive and Emotional Regulation (I)	MUSE_{I}
Section B	Engaged Production (II)	MUSE_{II}
Section B	Social Connection (III)	MUSE_{III}
Section B	Physical Exercise (IV)	MUSE_{IV}
Section B	Dance (V)	MUSE_{V}

Table 8.1: MUSE Indices and Labelling

Mimetic Questions	**Label**
3.1 & 4.1	MQ_1
3.2 & 4.2	MQ_2
3.3 & 4.3	MQ_3
3.4 & 4.4	MQ_4
3.5 & 4.5	MQ_5

Table 8.2: Mimetic Questions – Data Labelling

and Section B has five “Styles of Music Engagement”. Table 8.1 shows these MUSE indices and styles and how they are labelled and referred to in the following discussions.

The post-performance questionnaire had twelve questions. Questions three and four contained an identical sub-set of five Likert type questions (Likert, 1932), exploring mimetic response to the performances. Questions 3.1 to 3.5 were responses to the M_c and 4.1 to 4.5 to the K_c. The data from these sub-sets were averaged to generate a Likert scale of mimetic response, which has been analysed along with the individual Likert type data (Likert, 1932; Stevens, 1946). These questions are referred to collectively as the mimetic questions (MQ) as in Table 8.2.

The two devices take advantage of the standard MIDI 1.0 protocol, sending performance control data to MIDI note on/off, continuous controllers and pitch bend. Continuous controllers are referred to as CC followed by the control number, for example, CC01, and pitch bend as PB.

8.1 Video Data

The video recordings captured the post-performance discussions. The transcriptions provided the text of the video recorded discussions which could be further analysed. The audio from the video was transcribed using the online service Otter.ai. This method was efficient but produced errors due to the number of voices needing to be recognised and transcribed. However, it provided an excellent general overview of the discussions for further examination. The automated transcription was scrutinised to discover discussions of interest. These discussions were then verified and transcribed manually to reduce transcription errors.

8.1.1 How Many "Had a Go?"

Part of the post-performance discussion process was to invite participants if they would like to have a go of either of the controllers. Sixteen participants chose to have a go of the M_c, but no one chose to have a go of the K_c, which may have been due to the novelty factor of the M_c. However, twelve of the participants were not familiar with the K_c, and so for nearly half the participants, the K_c could also be considered novel.

8.1.2 Word Cloud Analysis of Transcripts

Word cloud analysis, using the Antconc software, was chosen for the video transcriptions due to the unstructured and verbose nature of the post-performance discussions.[1] However, it was very inconclusive, as the word count was out of context, i.e. "interesting" could be "less interesting" or "more interesting". Also, there was no way for the software to separate the M_c and K_c comments, unlike the post-performance questionnaire, which

[1]The Antconc data for the video transcriptions can be found here: https://research.bazerbow.uk/#files

split the answers explicitly between the M_c and K_c, The observational methods, therefore, provided better quality analysis in this case.

8.1.3 Observations from Transcripts

The video transcripts were examined thoroughly to determine any comments or discussions relevant to the nature of this enquiry, i.e. in reference to the mimetic ideas of “involvement” (engagement) “invitation” (“have a go”) and “inclusion” (“join in”), empathy, communicative musicality and mimetic participation. The complete raw transcripts can be found in Appendix H.

The following are selected quotes from each test session, which are thought to point to mimetic response. The time represents the time stamp of the audio extracted from the video used for transcriptions. Uncertainty of words transcribed is presented in square brackets.

Test 1A - Participants 1 to 4

As participant 1 was having a go of the M_c they suggested that:

> “It’s surprisingly harder to play than it looks.” (5:12)

Whilst participant 3 counters with a comment directed at participant 1:

> “I think it’d be easier than you think to pick it up. Have you got used to how it worked?” (7:13)

Test 1B - Participants 5 to 7

During test 1B, Participant 7 said:

> “. . . it’s interesting, like you say, I’ve not really thought about it before when you just got two things in two different shapes or whatever. And then you get a different perception of it when actually the data’s exactly the same. . . ” (0:01)

At 3:09, participant 6 tried the M_c followed by participant 5 at approximately 4:00.

Test 2 - Participants 8 to 13

When comparing the two performances participant 8 felt that they:

> "...didn't sound the same." (0:04)

Participant 8 then admits to having their eyes closed during the K_c performance:

> "You should have told me not to close my eyes when you were playing the keyboard." (3:10)

They then went on to say:

> "I think you would need to be a musician, maybe to play the BazerBow where you could be a technician err to play the err 'cause you know it's a different feel for that. It is more like an inter... instrument than this is." (9:11)

Whilst watching participant 8 playing an "acoustic guitar" sound with the M_c participant 10 asked:

> "So if you play the other one on the guitar, what does that sound like?" (15:16)

And after hearing the same guitar sound (and pitch) played on the K_c declared:

> "It's not the same is it?" (15:27)

This discussion led to the realisation that the M_c had a fixed MIDI note volume whereas the K_c had varying note volume relating to how hard the keys were pressed (Section 8.5).

At 12:20, participant 8 tried out the M_c then participant 9 (at 13:16), then participant 8 had another go at 15:00.

Test 3 - Participants 14 to 20

In discussing the K_c, participant 20 stated that:

> "...I'm most critical of, often, when I'm looking at people performing experimental music, even if they perform on another instrument, several performance come to mind is that they tend to do a lot twiddling with their heads down." (7:14)

And continued with

> ...your head is down, you're engaged there. It's very introverted. It's not outward-looking." (7:14)

In referring to the K_c, participant 14 suggested that:

> "the parameters on that depending on what your doing on the fly with the knob is is more accurate, isn't it?" (11:00)

With participant 20 disagreeing:

> "no I don't necessarily think so" (11:12)

And participant 14 further explaining the previous comment:

> "there's more excitement in that in the way that like [everything] [with] the gyro, you could go a bit too far just like a violinist could, but that excites me. Whereas you could argue with that, you could turn it to its maximum, so say it was set to a tone it's more accurate. I find that more exciting." (11:14)

And ending with the comment referring to the M_c:

> "I find that more exciting and respectful" (11:42)

Referring to the K_c Participant 18 suggested that:

> "…when you were on this I was just watching you on like your hands if that makes sense." (11:50)

With an affirmation from participant 20:

> "It's got theatre about it." (11:55)

Participant 18 then, referring to the M_c concludes with

> "…but I was watching you when you were playing that." (11:56)

Participant 19 then discusses the simplicity of the M_c design:

> "To me the simplicity was the beauty of it." (12:49)

With participant 20 agreeing:

> "It does have a real simplicity about it as well though doesn't it?" (13:59)

Participants were asked if they wanted a go of either controller and when asked "Do you want a go of the keyboard?" there was an instant and positive "no" from participant 20!

Participant 14, (a music teacher at the secondary school), then makes comments about how kids might respond:

> "I get the thing about guitar, but sometimes having a shape like especially to a kid, there's less values. If you said go and play the keyboard, there'd be [several] kids that wouldn't play it 'cause their brain was saying they're not qualified to play it. Where if it's something they don't recognise saying you didn't go too far replicating the guitar. . . like you say they're more intuitive to create aren't they" (24:52)

Concluding that the M_c

> "That's got more values." (25:31)

The participants sat in a semicircle in a music teaching room in this test. After participant 20's initial go of the M_c, it was passed around the circle from participant 14 back to participant 20. No one wanted to try the K_c.

Test 4 - Participants 21 to 25

Participant 21 discussed his thoughts about the instruments:

> "...with the keyboard is, you're reliant much more on just listening to the sound or the music that's being created. Where obviously the BazerBow the performance is more engaging." (5:46)

Participant 24 then said:

> "definitely more outward facing isn't it, 'cause you're you're you're sort of looking out to your audience rather than like head down and sort of fiddling with buttons. . . " (6:04)

Participants 21, 22 and 23 tried the M_c.

8.1.4 Summary of Video Data

The post discussions confirmed several points of mimetic design.

- The balance of simplicity of design but complex control is difficult to achieve but important to mimetic design. The simplicity should be initially encouraging to new players whilst the complexity stimulates experienced players that spend time mastering the complete instrument. The comments across the tests were suggestive that the BazerBow was successful in this regard. Particularly, in Test 1A, participants thought it should be easy to play but found it difficult to master some of the controls.
- The difficulty of precise playing on the BazerBow was discussed in Test 3. This perceived difficulty brought about an appreciation of the virtuosity necessary for accurate performance.
- Several comments suggested the participants felt that the instruments sounded different, although they used the same synthesiser to produce the sounds. Test 2 participants took time to explore this point specifically. This difference ties in with inter-modality, implying that what is visible can change the actual perception of what is heard.
- Comments from Test 2 illuded to the BazerBow being accepted and discussed as an instrument, which is important to the aesthetics of mimetic design.
- There were several comments across Tests 3 and 4 suggesting that the keyboard playing was head down, whilst the BazerBow was forward-facing. One participant commented on how they focussed on the hands for the keyboard performance but on the performer, as a whole, with the BazerBow, which seems to corroborate the gestural mimetic concept of the BazerBow designed to engage.
- An interesting discussion took place in Test 3 with one of the music teachers. They felt that keyboards and other traditional instruments could be intimidating to students as there is a possible expectation to produce a particular sound. However, in referring to

the BazerBow, they suggest it is "more intuitive to create" with and might encourage students to experiment, which is significant evidence of mimetic design aimed at inclusion.

Another evidence from the videos was the fact that sixteen participants tried out the BazerBow, but none of the participants wanted to try the keyboard when invited. This evidence is indicative of the mimetic potential of the BazerBow and how it instigates mimetic engagement and invitation, concluding in the desire to participate, which in the case of participants who tried the BazerBow was overt participation.

8.2 Questionnaire Data

The three questionnaires used in the main test phase covered demographics, music experience and engagement (MUSE), and post-performance responses split into Likert type (Likert, 1932) and open-ended questions. The cross-table for demographics, MUSE scores and post-performance data, including full transcripts of responses to questions 8 to 11, can be found in Appendix L.

8.2.1 Cross Table of Data

The data from the post-performance and MUSE questionnaires were put into cross tables for analysis. Participant numbers were applied to all participants' data for collation. The participant numbers have been used to initially organise the data in an arbitrary order as a control for comparisons.

Conditional formatting has been applied to the MUSE calculation data to assist identification of patterns. The cells are coloured from shades of red, representing the lowest numbers, through yellows, to green the highest numbers. Figure 8.1 is presented here to show, specifically, the clearly visible colours.[2]

[2] A larger more legible version can be found in Appendix L.1.

Participant Number	4. Age	5. Gender	6. Education: What is the highest degree or level of school you have completed? If currently enrolled, highest degree received.	7. Income: How would you describe your income level?	Index of Music Listening (IML)	Index of Music Instrument Playing (IMIP)	Index of Music Training (IMT)	I (Cognitive and Emotional Regulation)	II (Engaged Production)	III (Social Connection)	IV (Physical Exercise)	V (Dance)
1	25 - 34	Male	Masters degree or equivalent	above average	20	66.5	2	32	38	15	11	5
2	25 - 34	Male	Higher education	average	3	0	1	30	0	8	12	0
3	25 - 34	Female	Degree or equivalent	below average	10	0.78125	6	29	23	11	8	7
4	35 - 44	Male	Degree or equivalent	below average	5	0	0	23	0	11	9	2
5	25 - 34	Male	Degree or equivalent	average	5	0.5	1	27	10	9	11	2
6	25 - 34	Female	Higher education	average	5	10	3	33	26	12	11	8
7	25 - 34	Male	Degree or equivalent	average	12	0	3	32	7	12	12	8
8	65 - 74	Female	Degree or equivalent	above average	5	60	2	23	26	8	10	8
9	65 - 74	Male	Doctoral degree	above average	2	8	0	9	18	8	0	0
10	65 - 74	Female	GCSEs or equivalent	average	5	0	2	19	0	10	0	2
11	65 - 74	Male	A Level or equivalent	above average	10	0	0	25	0	0	3	0
12	75 +	Male	Degree or equivalent	average	3	0.09375	2	23	17	6	2	4
13	65 - 74	Female	Other qualifications	average	3	0.0625	2	31	6	10	13	10
14	35 - 44	Male	Degree or equivalent	above average	10	40	4?	33	40	13	11	5
15	45 - 54	Male	Degree or equivalent	average	10	100	10	33	43	13	9	0
16	35 - 44	Female	Degree or equivalent	average	5	1	3	33	30	10	1	6
17	18 - 24	Male	A Level or equivalent	above average	10	0	2	16?	3?	12?	10?	0?
18	25 - 34	Female	Degree or equivalent	average	15	24	5	32	41	11	13	8
19	45 - 54	Male	Masters degree or equivalent	above average	25	450	9	33	43	9	12	5
20	45 - 54	Male	Doctoral degree	above average	15	441	10	29	40	5	7	4
21	45 - 54	Male	Masters degree or equivalent	above average	15	0.125	3	33	1	11	12	1
22	65 - 74	Male	Higher education	average	4	10	2	22	22	10	9	4
23	18 - 24	Male	A Level or equivalent	below average	15	28	8	30	42	14	11	7
24	45 - 54	Female	GCSEs or equivalent	average	10	0.078125	5	30	3	10	15	3
25	35 - 44	Female	Degree or equivalent	average	2	0.36458333333333	5	17	13	6	5	10
Averages				Average MUSE Values	8.96	49.62	3.58	27.54	20.38	9.67	8.63	4.54

Figure 8.1: Cross Table Colour Coding — Demographic and MUSE Data
(See Appendix L.1 for a larger version)

Similarly the Likert response data is colour coded: a red background representing "Strongly Disagree"; red text is "Disagree"; yellow text is "Undecided"; green text for "Agree"; and green background representing "Strongly Agree". This colour coding immediately highlights the distribution of Likert responses, which can be seen in Figure 8.2.[3] This page of the cross table includes the data from questions three to seven, and between questions six and seven are columns for the participant mimetic index for both instruments and the mimetic index differentials (Section 8.2.5).

The cross table was used for initial observational analysis. However, it was still unclear if there were any correlations between the Likert responses and MUSE or demographic data, so additional analysis methods were employed.

[3]A larger version can be found in Appendix L.2.

	4. After having seen the BazerBow performance please answer the following questions:					4. After having seen the Keyboard performance please answer the following questions:											
Participant Number	3.1. I would like to "have a go" of the BazerBow...	3.2. I found the performance on the BazerBow engaging...	3.3. I found the BazerBow visually appealing...	3.4. I can imagine playing the BazerBow...	3.5. I would like to "join in" with the BazerBow performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	4.1. I would like to "have a go" of the Keyboard...	4.2. I found the performance on the Keyboard engaging...	4.3. I find the Keyboard visually appealing...	4.4. I can imagine playing the Keyboard...	4.5. I would like to "join in" with the Keyboard performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	5. Have you experienced the BazerBow before?	6. Have you experienced a MIDI controller keyboard before?	BazerBow Average Score (3.1 to 3.5) MI	Ozonic Average Score (4.1 to 4.5) MI	Mimetic Index Differential (MID)	7.1. Which do you think was more suited to playing the types of sound you heard?	7.2. If you could "have a go" which would you choose?
1	Strongly Agree	Strongly Agree	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Agree	Strongly Agree	No	Yes	4.60	3.80	0.80	Mostly Keyboard	Mostly BazerBow
2	Undecided	Strongly Agree	Strongly Agree	Strongly Disagree	Disagree	Strongly Disagree	Undecided	Strongly Disagree	Strongly Disagree	Strongly Disagree	No	No	3.20	1.40	1.80	Mostly BazerBow	BazerBow
3	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.80	0.20	BazerBow	Mostly BazerBow
4	Agree	Agree	Undecided	Agree	Disagree	Disagree	Disagree	Undecided	Agree	Agree	No	Yes	3.40	3.00	0.40	Both	Mostly BazerBow
5	Strongly Agree	Strongly Agree	Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.20	3.80	0.40	Mostly BazerBow	Both
6	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Agree	Agree	No	No	4.60	4.00	0.60	Mostly BazerBow	BazerBow
7	Undecided	Agree	Agree	Disagree	Undecided	Undecided	Agree	Agree	Agree	Undecided	No	No	3.20	3.60	-0.40	Mostly Keyboard	Mostly Keyboard
8	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Undecided	Undecided	Undecided	Disagree	No	No	4.80	3.00	1.80	Both	Mostly BazerBow
9	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Disagree	Agree	Agree	No	No	4.60	3.60	1.00	Mostly BazerBow	BazerBow
10	Undecided	Strongly Agree	Strongly Agree	Undecided	Agree	Agree	Undecided	Agree	Disagree	Undecided	No	No	4.00	3.20	0.80	Mostly BazerBow	Both
11	Undecided	Agree	Strongly Agree	Undecided	Disagree	Agree	Agree	Agree	Agree	Strongly Agree	No	No	3.40	4.20	-0.80	Both	Mostly Keyboard
12	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Undecided	Disagree	Agree	Undecided	Yes	Yes	4.20	2.80	1.40	Mostly BazerBow	BazerBow
13	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Disagree	Undecided	Disagree	Undecided	Disagree	Yes	Yes	4.80	2.40	2.40	BazerBow	Mostly BazerBow
14	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Agree	Agree	No	Yes	5.00	4.20	0.80	Mostly BazerBow	Mostly BazerBow
15	Strongly Agree	Agree	Agree	Undecided	Disagree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	3.60	3.60	0.00	Both	Mostly BazerBow
16	Agree	Strongly Agree	Agree	Agree	Agree	Agree	Strongly Agree	Undecided	Agree	Agree	No	Yes	4.20	4.00	0.20	Mostly BazerBow	Both
17	Undecided	Strongly Agree	Agree	Undecided	Agree	Undecided	Agree	Disagree	Undecided	Undecided	No	Yes	3.80	3.00	0.80	Mostly BazerBow	BazerBow
18	Strongly Agree	Strongly Agree	Strongly Agree	Undecided	Strongly Agree	Undecided	Agree	Undecided	Undecided	Agree	No	No	4.60	3.40	1.20	Mostly BazerBow	BazerBow
19	Strongly Agree	Agree	Agree	Agree	Agree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	4.20	3.60	0.60	Mostly BazerBow	BazerBow
20	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.60	0.40	Both	BazerBow
21	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Undecided	Disagree	Strongly Disagree	Undecided	Disagree	Yes	No	4.80	2.20	2.60	Both	BazerBow
22	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.40	3.80	0.60	BazerBow	BazerBow
23	Strongly Agree	Undecided	Agree	Strongly Agree	Undecided	Agree	Undecided	Strongly Agree	Strongly Agree	Agree	No	Yes	4.00	4.20	-0.20	Mostly BazerBow	BazerBow
24	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Disagree	Agree	Agree	Disagree	No	Yes	4.60	3.00	1.60	Mostly BazerBow	BazerBow
25	Agree	Agree	Strongly Agree	Agree	Undecided	Disagree	Agree	Agree	Disagree	Disagree	Yes	No	4.00	2.80	1.20	Both	BazerBow
Averages	4.44	4.60	4.56	3.84	3.80	3.36	3.60	3.16	3.68	3.40			4.25	3.44	0.81	3.68	4.24

Average Mc Likert score 4.25 — Average Kc Likert score 3.44 = Differential 0.81

Figure 8.2: Cross Table Colour Coding — Mimetic Response and Likert Data
(See Appendix L.2 for a larger version)

8.2.2 Demographic Questions

The nature of recruiting participants created testing groups that had particular demographic biases. The test group 1A and 1B were aged 25 to 34 whilst group 2 were 65 to 75+. Group 3 was organised through a music teacher and was situated in the comprehensive school. Consequently, the participants were part of, or related to, the music department and therefore had higher MUSE learning, training and engagement levels than average. This group was not detrimental to the project and, in fact, aided the analysis of demographic relationships within the data.

The demographic data were analysed in conjunction with the other data, particularly the post-performance questionnaire and slider data. The most salient points are presented below:

- The participants represented a spread of ages from 18 to 75+ years, with the exception that no participant was 55 to 64 years old.

- There were 36% female and 64% male participants.
- All participants had some form of education, 44% with a degree or equivalent. The rest spread across GCSE to Doctoral levels.
- The majority of 52% described their income as average, with 36% describing it as above average. The remaining 12% felt their income was below average.
- 60% of participants were full-time employed, 24% retired, 8% part-time employed and 4% for both self-employed full-time and self-employed part-time.

The cross table for the demographic data shows no apparent patterns except that one hundred percent of participants aged 65 and above (7 participants - 28%) strongly agreed that the M_c is "visually appealing". Three of this age group disagreed that the K_c was "visually appealing" whilst two were undecided, and only two agreed. Within this age range for this group, there was a strong preference for the visual appeal of the M_c. There did not seem to be any other patterns or strong connections when examined with the other data. However, it was still necessary to collect this data to rule out any demographic biases.

8.2.3 MUSE Questions

The MUSE questionnaire (Chin and Rickard, 2012)(Appendix G) was provided with a scoring sheet to calculate MUSE scores for the three "Indices of Music Engagement" and five "Styles of Music Engagement" for each participant (Table 8.1).

The cross table (Figure 8.1) shows the distribution of MUSE scores. The averages for each MUSE engagement index and style are at the bottom of the columns. There are six scores with a question mark that were excluded because the questionnaires were incomplete.

These scores were fully analysed with the slider data and the Likert response questions from the post-performance questionnaire. Similar correlations with the MUSE scores were found with both the slider and Likert response data, in particular $MUSE_{IMIP}$ and $MUSE_{II}$, (Sections 8.3 and 8.4).

8.2.4 Post-Performance Questions

The post-performance questionnaire consisted of 11 questions. Participants were asked to answer questions 3.1 to 3.5 after seeing the M_c performance and questions 4.1 to 4.5 after the K_c performance. As the order of performances between the M_c and K_c was alternated for test sessions, care was taken to guide the participants to the appropriate questions, especially when the K_c performance was first as the questions 4.1 to 4.5 were then to be answered before questions 3.1 to 3.5. These questions were also labelled with the relative performance device to ensure they were responded to at the correct time. The additional questions 5 to 11 were then answered after seeing both performances.

Questions 1 and 2

Questions 1 and 2 were identification questions: "date" and "slider" number. Each slider was labelled with an assigned number. The test session date allowed the questionnaire data to be collated with the corresponding slider data while keeping the data anonymous.

Questions 5 and 6

Questions 5 and 6 were simple yes/no questions to determine whether the participant had previously experienced the BazerBow or Ozonic keyboard. This question looked for any effects of previous experience on mimetic response. For example, the novelty of either device may have created greater initial engagement.

Four participants had previously experienced the M_c before, while thirteen had seen a similar K_c before. The answers to questions 8 to 11, and the video discussions, revealed comments suggesting that the M_c was "new", "unusual" and "modern" and the K_c as "expected", "familiar", "normal" and 'traditional". All but one of these comments were made by participants with experience of the K_c, and none with the M_c.

Some previous knowledge and experience of instruments will probably affect the mimetic response. However, nearly 50% of participants had no experience with the K_c, and only four had seen the M_c before; this does not entirely explain the difference in mimetic response between the two instruments. Considering all the data is necessary to provide a complete picture of these initial observations.

8.2.5 Analysing Likert Response – Questions 3, 4 and 7

The data from Likert-type questions 3, 4 and 7 have been compared with the corresponding demographic and MUSE data to find any correlations that evidence mimetic response. Different types of analysis for the Likert responses have been considered. The typical non-parametric statistical methods used for the analysis of ordinal data may have been applied. However, due to the small sample size of twenty-five participants, any analysis would have been statistically insignificant (VanVoorhis and Morgan, 2007). A custom averaging distribution method (ADM) of analysis has been developed and implemented to expose patterns in the data. This method applies averaging across two data sets to find any correlations, mainly between the MUSE data and the Likert response data. The ADM analysis is discussed in Section 8.3.

Initial observations of the colour-coded cross table provided points of interest to comment on and study further. The Likert responses are also presented using diverging stacked bar charts, the preferred method for presenting Likert data (Heiberger and Robbins, 2014; Robbins and Heiberger, 2011). The cross table and bar charts clearly show the data distribution and an overall bias towards the M_c.

Mimetic Questions (MQ) 3.1 to 4.5 and Mimetic Index (MI)

Questions 3.1 to 4.5 enabled a comparison between the M_c and K_c using Likert type questions which when combined through averaging produced a Likert scale (Likert, 1932; Stevens, 1946) for mimetic response for each instrument. Questions 3.1 to 3.5 pertained to the M_c and 4.1 to 4.5 to the K_c. These are the mimetic questions (MQ). MQ_1 to MQ_5 have been averaged together to provide a Likert scale, referred to as the Mimetic Index (MI) for further analysis. These questions were answered by the participants directly after watching the corresponding performance. Questions 3.1 to 4.5 were constructed using the five responses: “Strongly Disagree”; “Disagree”; “Undecided”; “Agree”; “Strongly Agree”.

The cross table (Figure 8.2) shows clearly the more favourable response to the M_c with much more green “Strongly Agree”, whilst the K_c has more red “Strongly Disagree”. All the MI questions favoured the M_c with more participants choosing “Agree” or “Strongly Agree” and less choosing “Disagree” or “Strongly Disagree” for the M_c compared with the K_c.

Figure 8.3 presents diverging stacked bar charts for each MQ and averages for both instruments. The red colours represent the negative response, the grey a neutral response and the blues a positive response. The MQ data has been converted to percentages to present the negative/positive responses to each question clearly. There is a clear bias towards the right dark blue side. MQ_4 and MQ_5 have the smallest biases towards the M_c but still clearly show a larger dark blue area of the “Strongly Agree” responses and a higher overall positive percentage. The average also shows a strong bias towards the M_c, with a positive percentage of 88.4% compared with 69.2% for the K_c and a negative percentage of -11.6% and -30.8%, respectively.

Although the cross table and charts are very persuasive in showing a more significant mimetic response to the M_c they do not clearly show any patterns between these responses and the corresponding MUSE data. This data was examined in greater detail by applying an averaging distribution method charted to show relationships between the Likert data and MUSE scores (Section 8.3).

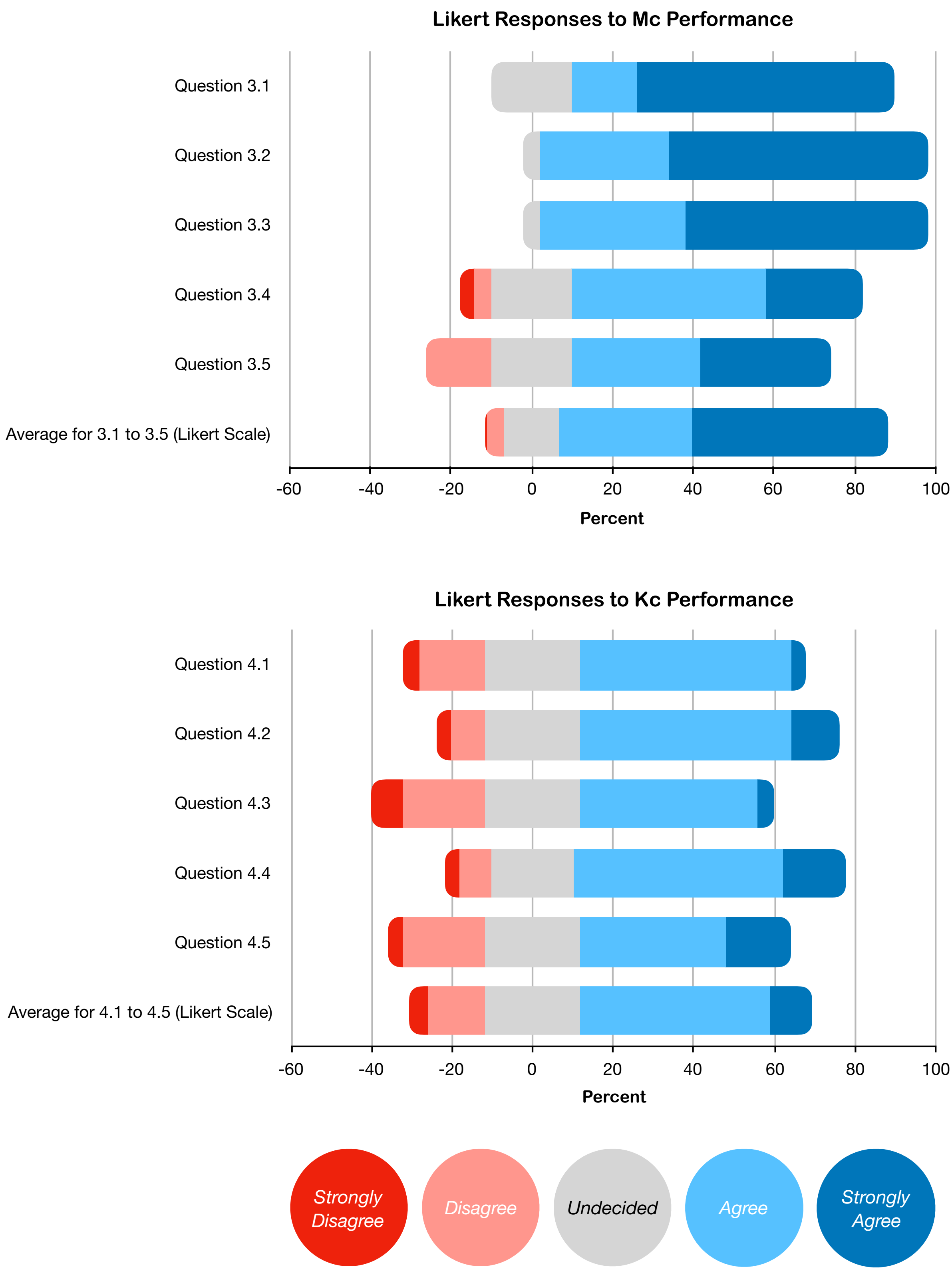

Figure 8.3: Likert Responses for Questions 3.1 to 4.5

MQ Question	**M_c Average**	**K_c Average**	**MQ Bias**
MQ_1	4.44	3.36	1.08
MQ_2	4.60	3.60	1.00
MQ_3	4.56	3.16	1.40
MQ_4	3.84	3.68	0.16
MQ_5	3.80	3.40	0.40
Averages of MQ_1 to MQ_5	4.25	3.44	0.81

Table 8.3: Likert Response Averages

Averages for Mimetic Index Questions 3.1 to 4.5

Table 8.3 shows the total participant average for each MQ and instrument. The third column represents a bias calculated by subtracting the K_c averages from the M_c averages. A positive bias shows a greater level of "agreement" towards the M_c than for the K_c. The participant averages show that for MQ_1, MQ_2 and MQ_3 the M_c has a bias greater than one, which represents a whole step higher in agreement than the K_c. Although MQ_4 and MQ_5 are positively biased towards the M_c the small figures (< 0.5) are relatively less significant. The overall MQ bias is 0.81 towards the BazerBow.

Mimetic Index and Mimetic Index differentials

The average for the five related mimetic questions, for M_c and K_c, has been calculated for each participant to generate the mimetic index (MI). These two averages have been subtracted to generate a mimetic index differential (MID) representing any MI bias towards either controller. A positive MID shows a potential bias towards the M_c and a negative number towards the K_c. Zero shows an equal response.

Table 8.4 shows the MI and MID for the 25 participants. The MID shows three negative results, the largest at -0.8, representing an average mimetic response biased towards the K_c. One participant has an MID of zero, showing no preference, and the other twenty-one participants have a positive MID preference for the M_c. These positive responses range from 0.2 to 2.6. Anything below 0.5 may be considered a neutral bias. Anything above 0.5 is closer to a whole step in the average Likert response. Therefore, an MID of 2.6

represents an average mimetic response of over two “Likert” steps of agreement for the M_c compared with the K_c. There are seven participants with an MID equal to or above one (and below two) and two with an MID greater than two.

Participant Number	**MI** M_c	**MI** K_c	**MID**
1	4.60	3.80	0.80
2	3.20	1.40	1.80
3	5.00	4.80	0.20
4	3.40	3.00	0.40
5	4.20	3.80	0.40
6	4.60	4.00	0.60
7	3.20	3.60	-0.40
8	4.80	3.00	1.80
9	4.60	3.60	1.00
10	4.00	3.20	0.80
11	3.40	4.20	-0.80
12	4.20	2.80	1.40
13	4.80	2.40	2.40
14	5.00	4.20	0.80
15	3.60	3.60	0.00
16	4.20	4.00	0.20
17	3.80	3.00	0.80
18	4.60	3.40	1.20
19	4.20	3.60	0.60
20	5.00	4.60	0.40
21	4.80	2.20	2.60
22	4.40	3.80	0.60
23	4.00	4.20	-0.20
24	4.60	3.00	1.60
25	4.00	2.80	1.20
Average	4.25	3.44	0.81

Table 8.4: Mimetic Index and Mimetic Index Differentials

Questions 7.1 and 7.2

Questions 7.1 and 7.2 had a Likert response as follows: “Keyboard”; “Mostly Keyboard”; “Both”; “Mostly BazerBow”; or “BazerBow”. These questions allowed the participants to directly compare the instruments regarding suitability for the sounds being played and their desire to have a go. Unlike the mimetic questions, the Likert response is a choice between the two instruments, and because of this difference, questions 7.1 and 7.2 were not included in creating the MI Likert scale (Likert, 1932; Stevens, 1946).

Question 7.1 shows a preference for the M_c. Only two participants favoured the K_c. However, with the majority of the responses being “Mostly BazerBow” it is not as strongly favoured as in question 7.2.

Question 7.2 shows that a clear majority would choose to “have a go” with the M_c. Thirteen participants would prefer to “have a go” of the M_c whilst only two would choose “Mostly Keyboard”. This result was confirmed when participants were asked if they would actually like to have a go of either instrument, with sixteen trying the M_c, and none, the K_c.

The average Likert response for 7.1 was 3.68, i.e. between “Both” and “Mostly BazerBow”. The average for question 7.2 was 4.24, somewhere between “Mostly BazerBow” and “BazerBow”.

Figure 8.4 shows a diverging stacked bar chart for questions 7.1 and 7.2. The response to both questions show a strong bias for the M_c with positive percentages of 78% and 86% and negative percentages of -22% and -14%, respectively.

The data were analysed using the same averaging distribution method as the MI questions to find any connections between the response to these questions and the MUSE scores (Section 8.3.1).

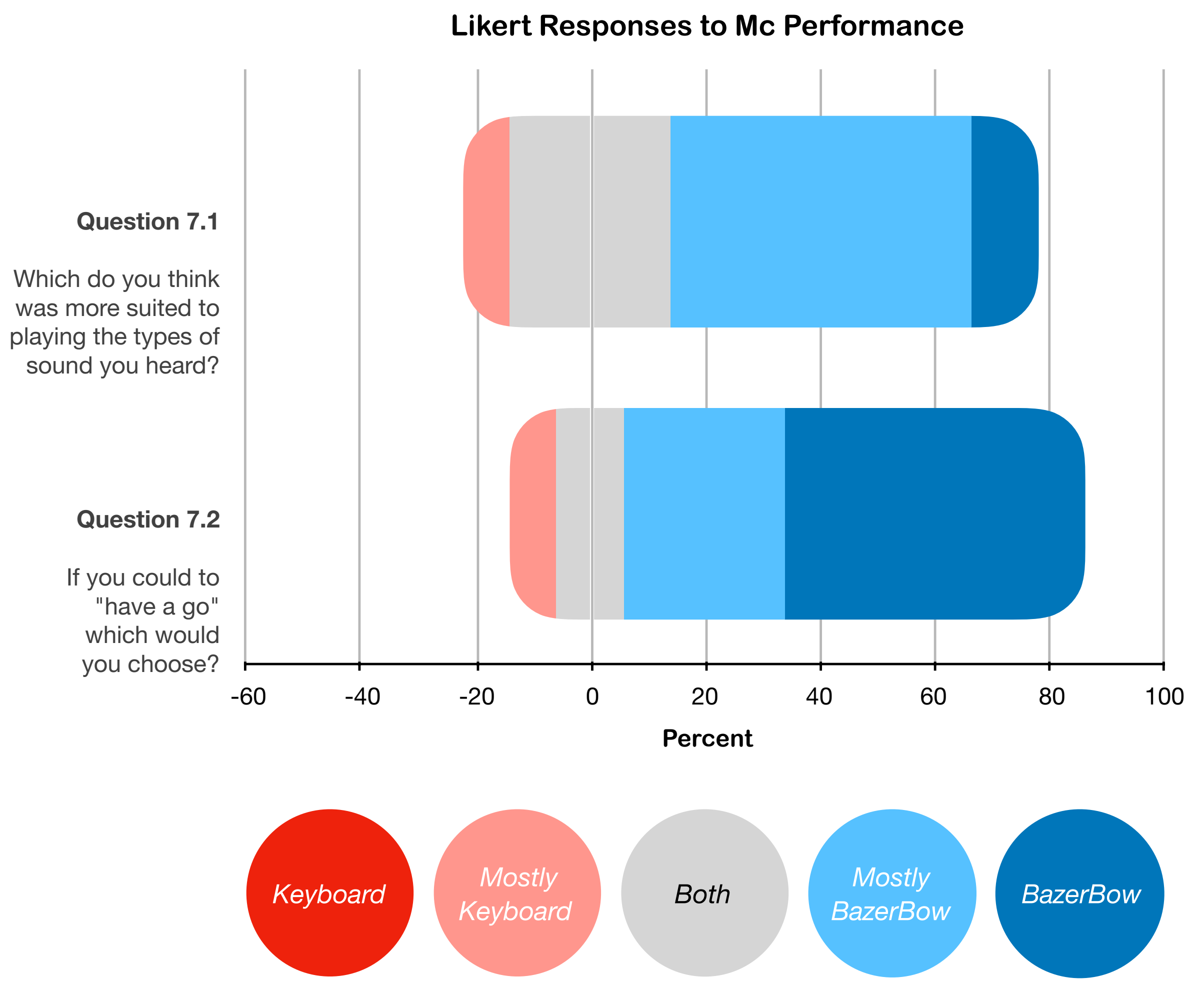

Figure 8.4: Likert Responses for Questions 7.1 and 7.2

8.2.6 Open Ended Questions 8.1 to 11

Questions 8.1 to 11 were open-ended to capture participant responses that the other questions might have missed. These responses were analysed for phrases that pointed to mimetic response which might affirm the mimetic design principles. The answers to these questions were also analysed using the software Antconc. This software provides a comprehensive set of tools for searching and analysing text, and for this work, the word frequency analysis proved the most useful in conjunction with the original text (Section 8.2.7).[4]

Questions 8 to 10 were split into two, the first part (e.g. 8.1) responding to the M_c performance the second (e.g. 8.2) the K_c performance. Question 11 was open to any other comments, giving the participants the freedom to express any ideas not covered by the other questions.

Participants with a negative MID (with a greater K_c mimetic response) were 7, 11, and 23. However, for these participants, none of the open-ended responses seemed to prefer one instrument over the other. Interesting to note that participant 7, although responding to question 8.1 (for the M_c), did not have an answer for their favourite moment from the K_c performance (8.2).

Question 8.1 – M_c

"8.1 What was your favourite/most memorable moment from the BazerBow?"

Out of the 25 participants, 19 responded to question 8.1 by mentioning or referring to the movement or gesture of the M_c with 14 specifically using words and phrases derived from "move". Three of the participant's (6, 16 and 22) responses explicitly referred to the "sound" despite having been instructed that the devices were connected to the same sound synthesiser. Participants 5, 15, 17 and 25 mentioned the hand gesture control of CC80 as their favourite moment. Participant 10's favourite moment was "Most of it".

[4]Complete Antconc data for the open questions can be found here: https://research.bazerbow.uk/#files

Question 8.2 – K_c

"8.2 What was your favourite/most memorable moment from the Keyboard?"

Participants 4 and 7, having responded to 8.1, did not leave a response for the corresponding question 8.2. Participants 5, 16 and 21 referred to the "sound" produced. Participant 8 described having "my eyes closed – focus on sound" for the K_c performance. Elaborating during the post-performance discussions, participant 8 described that they were more interested in the sounds than the visual performance of the K_c and closed their eyes to focus entirely on the sound. When experiencing the same M_c performance, this participant described how it was visually interesting, and so, in this case, they were engaged in watching.

Participants 6, 17, 18, 23 and 25 referred to the foot pedal control of CC80 as their favourite K_c moment. Participants 17 and 25 had also found the same point of the M_c performance as their favourite. Participant 9 found the K_c "Less visually appealing and less engaging for me" whilst participant 20 thought that the K_c "Allowed more insight into the combination of control".

Question 9.1 – M_c

"9.1 What do you find most interesting about the BazerBow?"

Participants 2, 5, 6, 8, 9, 11, 12, 19, 22, 24 and 25 all referred to some visual aspect of the instrument. Participants 3, 7, 10, 12, 15, 17, 18, 19, 21, 22, 23 and 24 referred to movement of the M_c, whilst 18 and 19 referred specifically to the movements of the initial gestures. Participants 11 and 25 were particularly interested in the minimalist simplicity of the M_c and 4, 14, 15, 16, 20, 21 and 23 were interested in how it is played and how it works.

Question 9.2 – K_c

"9.2 What do you find most interesting about the Keyboard?"

Participants 2, 3, 8, and 12 found nothing particularly interesting, declaring "Not Much!", "…nothing particular stood out", "Not a lot!", and "None". Participants 4, 10, 13, 15, 16, 17 and 25 were most interested in the pedal section (CC80). Participants 4, 5, 7, 15, 19, 23 and 24 mentioned the controls, buttons and knobs as most interesting about the K_c. Participant 11 mentioned the complexity of the K_c as interesting. However, this participant had also mentioned their interest in the simplicity of the M_c. Participant 9 found the K_c "Less expressive as a result of less visual aspect" and participant 20 "Less interested because I understood the nature of these controls." Participant 6 believed that the K_c "Can create many sounds". However, whether this refers to the modulation of the sound or the actual production of the sounds is uncertain.

Question 10.1 – M_c

"10.1 How would you describe the BazerBow?"

Participants 10, 11 and 18 described the "sound" of the M_c. Participants 3, 4, 12, 14, 21 and 23 used "interesting" to describe the M_c, whilst 6, 7, 16, 17 and 22 used "futuristic" and "sci-fi". Participants 1, 19, 21 and 24 described the M_c as visually appealing, and 2, 5, 7, 8, 9, 11 and 18 likened it to a guitar. Participants 3, 15, 17, 22 and 23 used the similar terms "new", "unusual" and "modern" to describe the M_c. Participant 1 thought that the M_c "Looks good, looks like it would be 'fun' to play. Way into playing music?", and participant 20 commented that it was "Innovative - strongly communicative re - gesture" whilst participant 21 described it as "More interesting to look at and watching the performance is more engaging."

Question 10.2 – K_c

"10.2 How would you describe the Keyboard?"

Participants 1, 19, 21, 23, and 24 described the K_c as less "interesting", "accessible", "engaging" and "visual engaging". As with the M_c, participant 10 referred to the sound to describe the K_c. Participants 3, 4, 15, 17 and 20 used the words "expected", "familiar", "normal" and 'traditional" to describe the K_c. Participant 2 described the K_c as a "Computerised keyboard".

Question 11

"11. Please add any further comments here:"

The comments of participants 2, 3, 5, 14, 15, 21, 22 and 25 were positive towards the M_c. Participants 9, 10 and 19 described the difference in sound between the two performances even though they used the same sound generator. They experienced a perceived difference in the sound of the performances. Participant 20 asked "...What skills are adaptive...?".

8.2.7 Open Question Word Cloud Analysis

Although observations of the text provided satisfactory analysis, the software Antconc was also used to examine the text from questions 8 to 11. Antconc produced "word lists " which showed the frequency of words used across the participant responses. This analysis needed to be referred back to the original text as finding common words without context was misleading.[5]

The word count analysis for the M_c shows 17 instances of the words "instrument" and "sound". There were collectively 21 instances of "movement", "movements" and "moving". Also, "interesting" occurred 8 times and "guitar" 12 times. "More" and "like" occurred 6 times, and there were 0 instances of "less".

[5] Antconc word cloud data can be downloaded here: https://research.bazerbow.uk/#files.

The word count analysis for the K_c shows 13 mentions of “keyboard”, 6 of “pedal” and 5 of “control”. There were 6 instances of “interesting” or “interested”, 5 of “more” and 9 of “less”. The phrases containing “interesting” or “interested” occurred 6 times for the responses to K_c with three of these instances proceeded by “less”. It has therefore been necessary to take care when considering this analysis without context. However, these word clouds provided a simple overview of the language used in conjunction with each instrument. There seems to be a greater consensus with how participants responded, described and discussed the M_c than the K_c. There were more similarities in the words referring to the M_c than the K_c.

8.2.8 Summary of Questionnaire Data

Basic observations from the cross table of data[6] showed a more positive Likert response toward the M_c which was corroborated by comments from open-ended questions. However, there were no clear connections or patterns with the MUSE and demographics data at this point. An averaging distribution method (Section 8.3) was developed to examine any possible connections between the questionnaire data, particularly the Likert-type data with the MUSE data. This ADM enabled further analysis of the observations from the cross-table data to uncover any patterns.

8.3 Averaging Distribution Method (ADM)

Analysing the data using ADM provided a more in-depth look at the distribution of Likert responses against the MUSE scores. The colour-coding in figures 8.1 and 8.2 gives an initial overview of the distribution of responses, but connections to the MUSE data are more difficult to see. Looking at the distribution of above-average participant responses is beneficial regardless of how negative or positive the responses are. The distribution may still correlate even if it is more negative or positive overall. For example, if the response to

[6]The cross-table for demographics, MUSE scores and post-performance data can be found in appendix L including full transcripts of responses to questions 8 to 11.

a question is mostly "Disagree" a particular MUSE index or style may affect how negative the response might be. ADM analysis does not, therefore, show whether the response is positive or negative as it is relative to the average. The overall positive or negative responses can be seen directly on the cross table. The ADM data shows any bias in distribution that the Likert responses have concerning each MUSE score.

The Likert responses above the average were counted below and above the median for each MUSE index and style. These two numbers were then subtracted to represent the ADM distribution of "above average" responses across the MUSE data. If the above-average Likert responses were evenly distributed across the MUSE scores, the ADM would be close to zero. A positive number would represent a positive correlation, i.e. the higher the MUSE data, the more "above average" Likert responses. Conversely, a negative number expresses the opposite, where a higher MUSE score would have fewer "above average" Likert responses. Any bias highlights a potential correlation between the MUSE score and Likert responses. For example, a positive bias of ten would show that nearly half of the participants that gave a higher than average Likert response also had higher corresponding MUSE scores.

The median has been used as the "centre point" of the MUSE data to separate the Likert responses into lower and upper halves for each MUSE index and style. It was possible to split the two halves into twelve with the middle thirteenth row as the centre. However this simpler method created problems with $MUSE_{IML}$, $MUSE_{I}$ and $MUSE_{III}$. In these three cases, the MUSE score at the thirteenth central row had the same score above and below. As the MUSE data is ordered by score, there is no way of further ordering the data when the scores are the same. Therefore, these scores have been rejected as their order concerning the Likert response could unintentionally skew the data.

ADM Example Using $MUSE_{IML}$ and MQ_1

Participant Number	4. Age	5. Gender	6. Education: What is the highest degree or level of school you have completed? If currently enrolled, highest degree received.	7. Income: How would you describe your income level?	Index of Music Listening (IML)	Index of Music Instrument Playing (IMIP)	Index of Music Training (IMT)	I (Cognitive and Emotional Regulation)	II (Engaged Production)	III (Social Connection)	IV (Physical Exercise)	V (Dance)
9	65 - 74	Male	Doctoral degree	above average	2	8	0	9	18	8	0	0
25	35 - 44	Female	Degree or equivalent	average	2	0.364583333333333	5	17	13	6	5	10
2	25 - 34	Male	Higher education	average	3	0	1	30	0	8	12	0
12	75 +	Male	Degree or equivalent	average	3	0.09375	2	23	17	6	2	4
13	65 - 74	Female	Other qualifications	average	3	0.0625	2	31	6	10	13	10
22	65 - 74	Male	Higher education	average	4	10	2	22	22	10	9	4
4	35 - 44	Male	Degree or equivalent	below average	5	0	0	23	0	11	9	2
5	25 - 34	Male	Degree or equivalent	average	5	0.5	1	27	10	9	11	2
6	25 - 34	Female	Higher education	average	5	10	3	33	26	12	11	8
8	65 - 74	Female	Degree or equivalent	above average	5	60	2	23	26	8	10	8
10	65 - 74	Female	GCSEs or equivalent	average	5	0	2	19	0	10	0	2
16	35 - 44	Female	Degree or equivalent	average	5	1	3	33	30	10	1	6
3	25 - 34	Female	Degree or equivalent	below average	10	0.78125	6	29	23	11	8	7
11	65 - 74	Male	A Level or equivalent	above average	10	0	0	25	0	0	3	0
14	35 - 44	Male	Degree or equivalent	above average	10	40	4?	33	40	13	11	5
15	45 - 54	Male	Degree or equivalent	average	10	100	10	33	43	13	9	0
17	18 - 24	Male	A Level or equivalent	above average	10	0	2	16?	3?	12?	10?	0?
24	45 - 54	Female	GCSEs or equivalent	average	10	0.078125	5	30	3	10	15	3
7	25 - 34	Male	Degree or equivalent	average	12	0	3	32	7	12	12	8
18	25 - 34	Female	Degree or equivalent	average	15	24	5	32	41	11	13	8
20	45 - 54	Male	Doctoral degree	above average	15	441	10	29	40	5	7	4
21	45 - 54	Male	Masters degree or equivalent	above average	15	0.125	3	33	1	11	12	1
23	18 - 24	Male	A Level or equivalent	below average	15	28	8	30	42	14	11	7
1	25 - 34	Male	Masters degree or equivalent	above average	20	66.5	2	32	38	15	11	5
19	45 - 54	Male	Masters degree or equivalent	above average	25	450	9	33	43	9	12	5
Averages				Average MUSE Values	8.96	49.62	3.58	27.54	20.38	9.67	8.63	4.54

Figure 8.5: Cross Table Sorted by $MUSE_{IML}$ Scores

The cross table ordered by the arbitrary participant number can be seen in Figures 8.1 and 8.2. Figure 8.5 shows the same cross table rearranged in order of $MUSE_{IML}$ scores from lowest to highest, as the colours confirm. Figure 8.6 shows the corresponding Likert response data ordered by the same $MUSE_{IML}$ scores. In this case, the average for question 3.1 is 4.44, which is between “Agree” (4) and “Strongly Agree” (5). Therefore all responses that were “Strongly Agree” are included as above average. Counting the “Strongly Agree” responses on the cross table, there are six in the top half of the table corresponding to the lowest scores for $MUSE_{IML}$, and there are ten in the bottom half of the highest $MUSE_{IML}$ scores. However, in this case, the $MUSE_{IML}$ scores are affected using the median. The median for the ordered $MUSE_{IML}$ data is ten. Excluding the six median scores the lower half now has six above-average Likert responses, with four removed for being found on

	4. After having seen the BazerBow performance please answer the following questions:					4. After having seen the Keyboard performance please answer the following questions:											
Participant Number	3.1. I would like to "have a go" of the BazerBow...	3.2. I found the performance on the BazerBow engaging...	3.3. I found the BazerBow visually appealing...	3.4. I can imagine playing the BazerBow...	3.5. I would like to "join in" with the BazerBow performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	4.1. I would like to "have a go" of the Keyboard...	4.2. I found the performance on the Keyboard engaging...	4.3. I find the Keyboard visually appealing...	4.4. I can imagine playing the Keyboard...	4.5. I would like to "join in" with the Keyboard performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	5. Have you experienced the BazerBow before?	6. Have you experienced a MIDI controller keyboard before?	BazerBow Average Score (3.1 to 3.5) MI	Ozonic Average Score (4.1 to 4.5) MI	Mimetic Index Differential (MID)	7.1. Which do you think was more suited to playing the types of sound you heard?	7.2. If you could "have a go" which would you choose?
9	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Disagree	Agree	Agree	No	No	4.60	3.60	1.00	Mostly BazerBow	BazerBow
25	Agree	Agree	Strongly Agree	Agree	Undecided	Disagree	Agree	Agree	Disagree	Disagree	Yes	No	4.00	2.80	1.20	Both	BazerBow
2	Undecided	Strongly Agree	Strongly Agree	Strongly Disagree	Disagree	Strongly Disagree	Undecided	Strongly Disagree	Strongly Disagree	Strongly Disagree	No	No	3.20	1.40	1.80	Mostly BazerBow	BazerBow
12	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Undecided	Disagree	Agree	Undecided	Yes	Yes	4.20	2.80	1.40	Mostly BazerBow	BazerBow
13	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Disagree	Undecided	Disagree	Undecided	Disagree	Yes	Yes	4.80	2.40	2.40	BazerBow	Mostly BazerBow
22	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.40	3.80	0.60	BazerBow	BazerBow
4	Agree	Agree	Undecided	Agree	Disagree	Disagree	Disagree	Undecided	Agree	Agree	No	Yes	3.40	3.00	0.40	Both	Mostly BazerBow
5	Strongly Agree	Strongly Agree	Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.20	3.80	0.40	Mostly BazerBow	Both
6	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Agree	Agree	No	No	4.60	4.00	0.60	Mostly BazerBow	BazerBow
8	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Undecided	Undecided	Undecided	Disagree	No	No	4.80	3.00	1.80	Both	Mostly BazerBow
10	Undecided	Strongly Agree	Strongly Agree	Undecided	Agree	Agree	Undecided	Agree	Disagree	Undecided	No	No	4.00	3.20	0.80	Mostly BazerBow	Both
16	Agree	Strongly Agree	Agree	Agree	Agree	Agree	Strongly Agree	Undecided	Agree	Agree	No	Yes	4.20	4.00	0.20	Mostly BazerBow	Both
3	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.80	0.20	BazerBow	Mostly BazerBow
11	Undecided	Agree	Strongly Agree	Undecided	Disagree	Agree	Agree	Agree	Agree	Strongly Agree	No	No	3.40	4.20	-0.80	Both	Mostly Keyboard
14	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Agree	Agree	No	Yes	5.00	4.20	0.80	Mostly BazerBow	Mostly BazerBow
15	Strongly Agree	Agree	Agree	Undecided	Disagree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	3.60	3.60	0.00	Both	Mostly BazerBow
17	Undecided	Strongly Agree	Agree	Undecided	Agree	Undecided	Agree	Disagree	Undecided	Undecided	No	Yes	3.80	3.00	0.80	Mostly BazerBow	BazerBow
24	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Disagree	Agree	Agree	Disagree	No	Yes	4.60	3.00	1.60	Mostly BazerBow	BazerBow
7	Undecided	Agree	Agree	Disagree	Undecided	Undecided	Agree	Agree	Agree	Undecided	No	No	3.20	3.60	-0.40	Mostly Keyboard	Mostly Keyboard
18	Strongly Agree	Strongly Agree	Strongly Agree	Undecided	Strongly Agree	Undecided	Agree	Undecided	Undecided	Agree	No	No	4.60	3.40	1.20	Mostly BazerBow	BazerBow
20	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.60	0.40	Both	BazerBow
21	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Undecided	Disagree	Strongly Disagree	Undecided	Disagree	Yes	No	4.80	2.20	2.60	Both	BazerBow
23	Strongly Agree	Undecided	Agree	Strongly Agree	Undecided	Agree	Undecided	Strongly Agree	Strongly Agree	Agree	No	Yes	4.00	4.20	-0.20	Mostly BazerBow	BazerBow
1	Strongly Agree	Strongly Agree	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Agree	Strongly Agree	No	Yes	4.60	3.80	0.80	Mostly Keyboard	Mostly BazerBow
19	Strongly Agree	Agree	Agree	Agree	Agree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	4.20	3.60	0.60	Mostly BazerBow	BazerBow
Averages	4.44	4.60	4.56	3.84	3.80	3.36	3.60	3.16	3.68	3.40			4.25	3.44	0.81	3.68	4.24

Average Mc Likert score 4.25 — Average Kc Likert score 3.44 = Differential 0.81

Figure 8.6: MUSE$_{\text{IML}}$ Scores Ordered Mimetic Response Data

the median. The ADM is now zero, showing no correlation between MUSE$_{\text{IML}}$ scores and Likert responses to question 3.1.

Control Chart for ADM

In a random order of Likert responses, as represented by the participant number, it would be expected that “above average” responses would be equally distributed across the lower and higher half of participant numbers.

A control chart was created using the participant numbers in place of MUSE scores, plotting the ADM data against the participant numbers to create a control for comparison (Figure 8.7). As can be seen, the plot does not rise above three or go below minus two. As expected, the arbitrary nature of the participant number produces a relatively even spread of above-average responses. The participant number control chart provides a basis for comparing the other charts. Anything above three or below minus three can be seen as

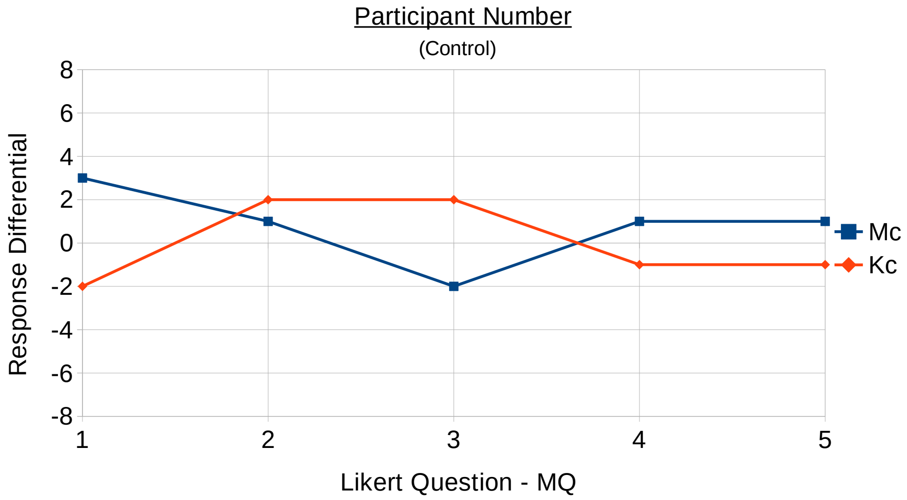

Figure 8.7: ADM - Participant Number (Control)

a possible correlation with the data showing a negative or positive bias—the greater the number, the greater the potential significance of the relationship.

When the data is reordered according to one of the MUSE indices or styles, these above-average scores can then be recounted to show any bias. For example, if the data is sorted according to the first MUSE index $MUSE_{IML}$ and there is no correlation between this and the Likert responses, a similar even distribution would be expected. However, suppose there is a more significant number of higher than average mimetic responses in the lower or higher half of the table. In that case, this biased distribution may point to a possible connection between the data—the greater the bias, the more likely the connection.

8.3.1 ADM Analysis of Questions 7.1 and 7.2

The Likert questions 7.1 and 7.2 were treated separately due to their comparative nature. They are presented as individual Likert-type data rather than included within the Likert scale (mimetic index) of the other five MQ Likert questions. Question 7.1 asks "Which do you think was more suited to playing the types of sounds you heard?" and question 7.2 "If you could "have a go", which would you choose?". They are composed so that the choice of answer directs a comparison between the M_c and K_c, starting with "Keyboard", then "Mostly Keyboard", "Both", "Mostly BazerBow" and finally "BazerBow".

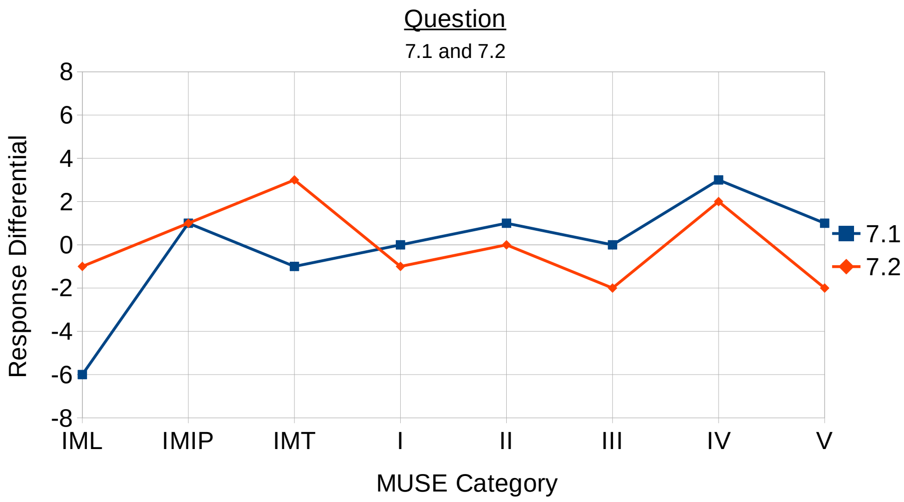

Figure 8.8: ADM - Questions 7.1 and 7.2 with MUSE Data

Although the cross table (Figure 8.2) clearly shows a definite bias towards the M_c for both questions 7.1 and 7.2, the ADM analysis provides further detail for correlations with these Likert response questions and the MUSE data.

Figure 8.8 shows the ADM for questions 7.1 in blue and 7.2 in red plotted against the eight MUSE scores. The most significant point of -6 occurs for question 7.1 and $MUSE_{IML}$. The rest of the points are no greater than +-3 and therefore insignificant. The shapes for questions 7.1 and 7.2 interestingly follow a similar path for the MUSE scores, especially the five MUSE styles.

8.3.2 ADM Analysis of Mimetic Questions

The MUSE data and Likert responses for MQ_1 to MQ_5 were analysed using ADM across eight charts, each representing the ADM analysis for each MUSE index and style. They plot the ADM values for each Likert question (MQ_1 to MQ_5) with blue representing the M_c and red the K_c.

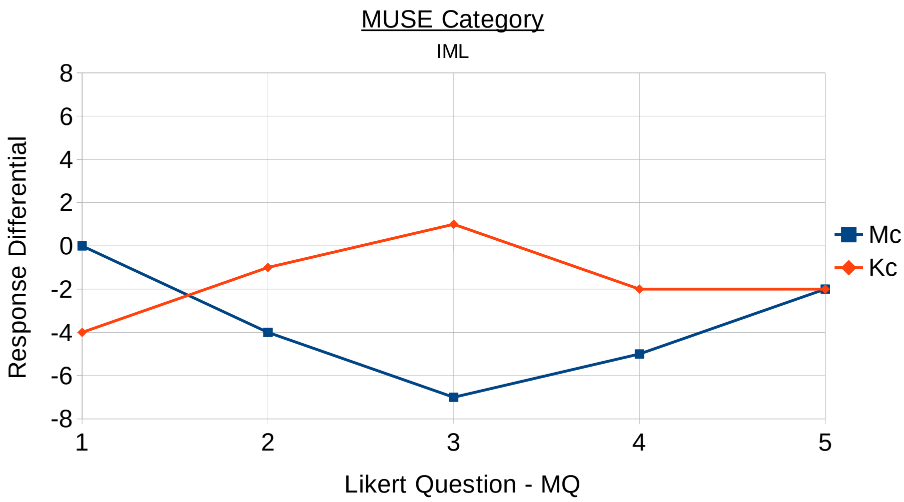

Figure 8.9: ADM - MUSE_{IML}

MUSE_{IML} (Figure 8.9) – The M_c trace shows a significant dip for MQ_3 of -7 and a lesser dip of -4 and -5 for MQ_2 and MQ_4 respectively. The K_c has a single significant dip of -4 for MQ_1.

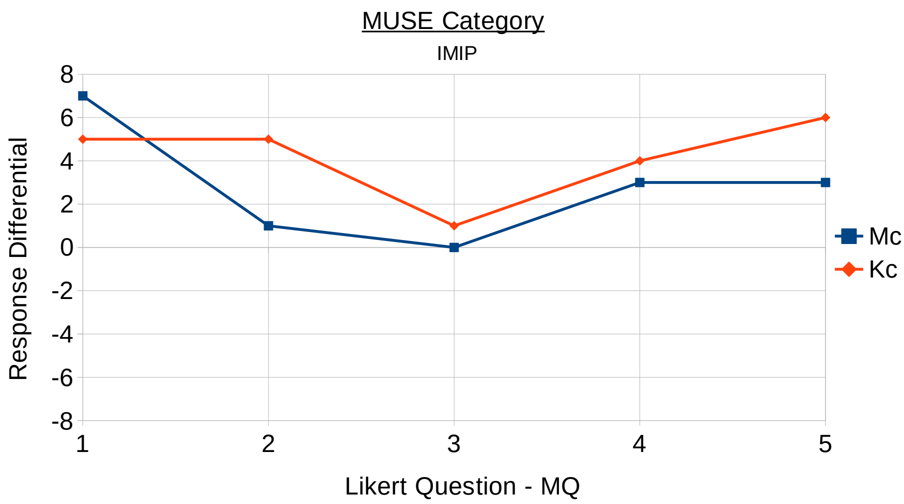

Figure 8.10: ADM - $\text{MUSE}_{\text{IMIP}}$

$\text{MUSE}_{\text{IMIP}}$ (Figure 8.10) – The two traces have a similar trajectory for $\text{MUSE}_{\text{IMIP}}$, with peaks of +7 and +5 at MQ_1 for M_c and K_c respectively. The K_c also has peaks of +5 for MQ_2, +4 for MQ_4 and +6 for MQ_5. There are no further significant peaks for the M_c. $\text{MUSE}_{\text{IMIP}}$ seems to have a greater influence over Likert responses to the K_c.

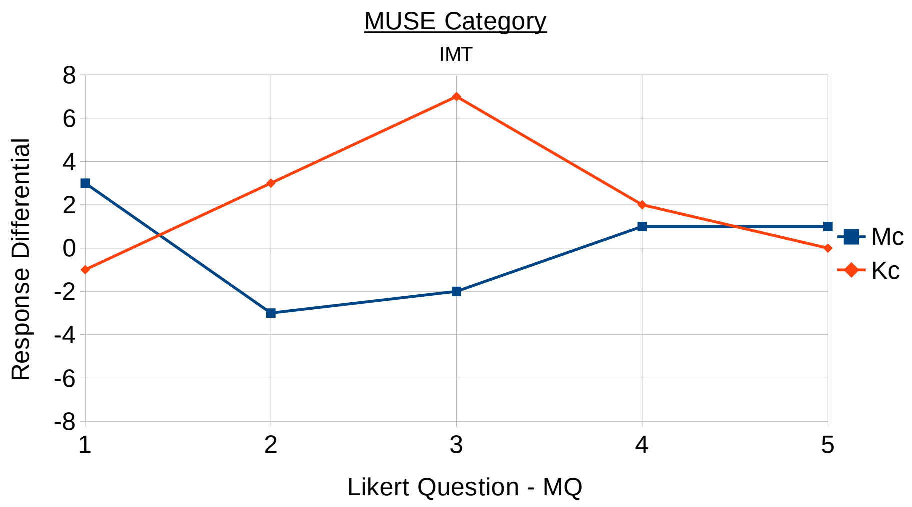

Figure 8.11: ADM - MUSE$_{IMT}$

MUSE$_{IMT}$ (Figure 8.11) – There is a single significant peak for the K_c of +7 for MQ_3, with no significant results for the M_c.

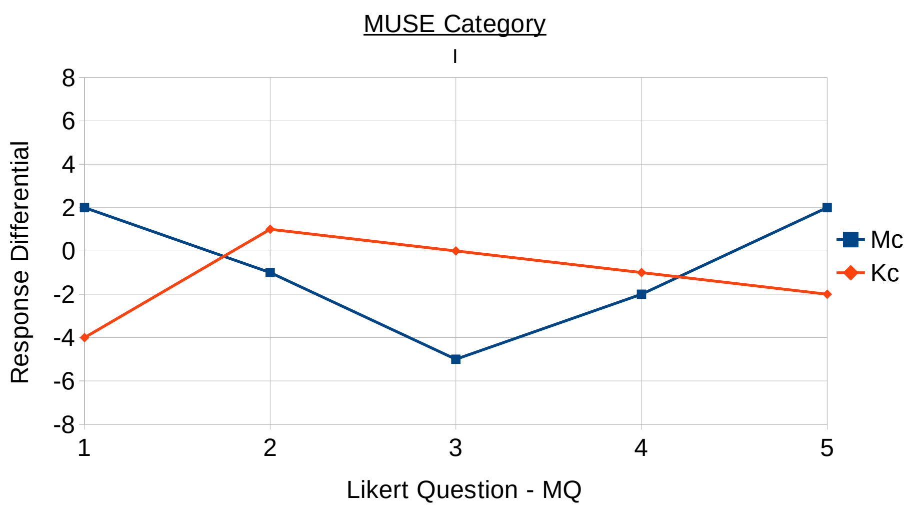

Figure 8.12: ADM - MUSE$_I$

MUSE$_I$ (Figure 8.12) – There is a low point of -4 at MQ_1 for the K_c and -5 at MQ_3 for the M_c. There are no other significant points.

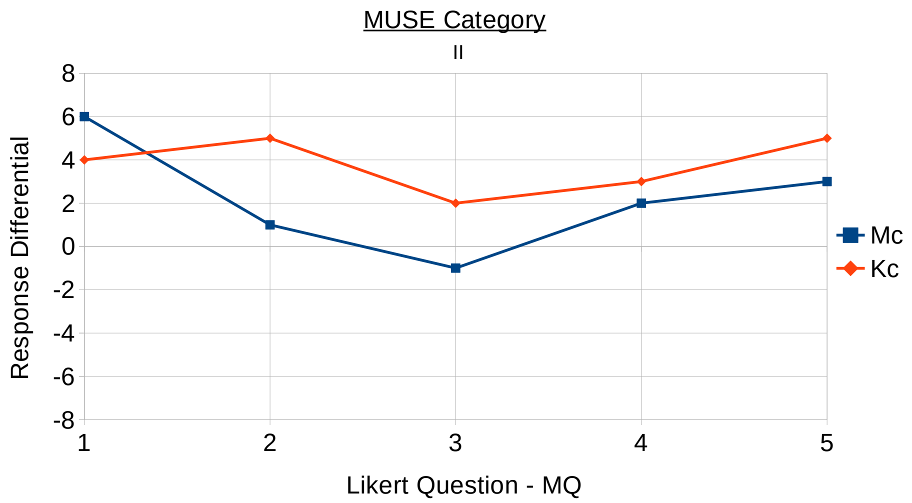

Figure 8.13: ADM - MUSE_{II}

MUSE_{II} (Figure 8.13) – The M_c trace has a peak of +6 for MQ_1. The K_c trace has peaks of +4, +5 and +5 for MQ_1, MQ_2 and MQ_5 respectively.

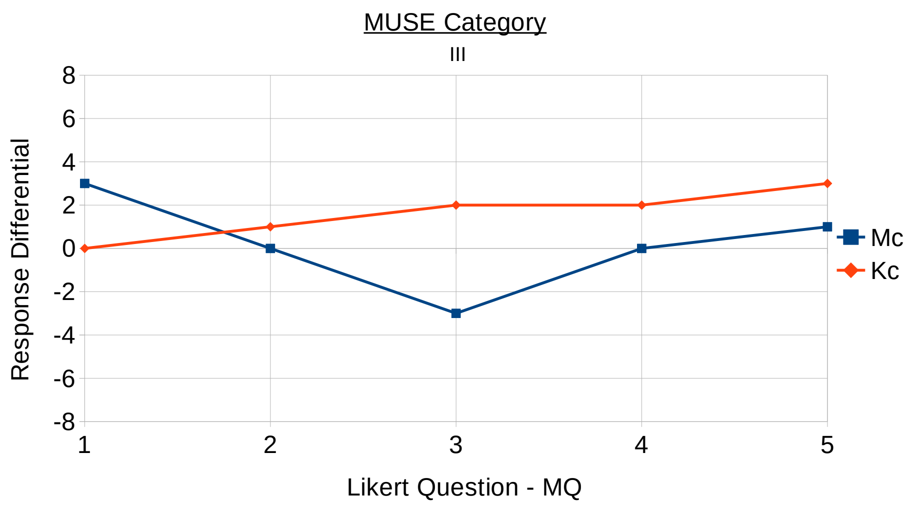

Figure 8.14: ADM - MUSE_{III}

MUSE_{III} (Figure 8.14) – There are no significant points for either devices for MUSE_{III}.

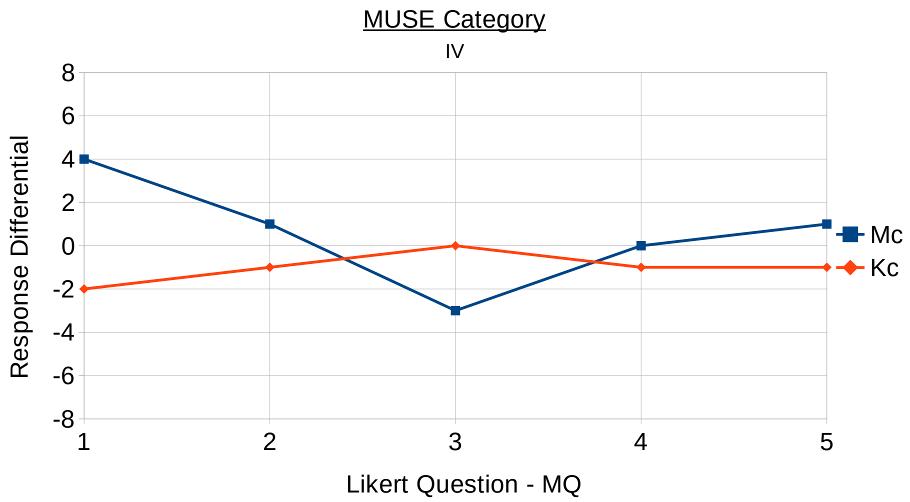

Figure 8.15: ADM - $\mathrm{MUSE}_{\mathrm{IV}}$

$\mathbf{MUSE}_{\mathbf{IV}}$ (Figure 8.15) – The only significant point for $\mathrm{MUSE}_{\mathrm{IV}}$ is +4 for MQ_1 and the M_c.

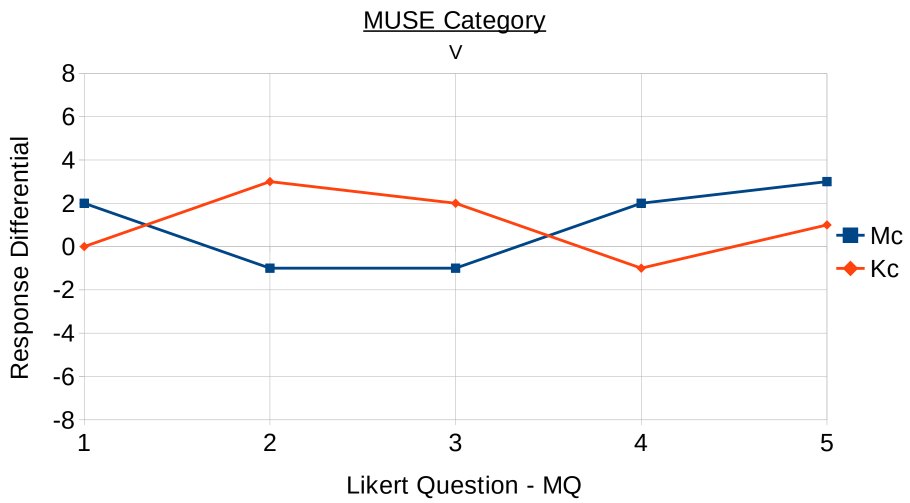

Figure 8.16: ADM - $\mathrm{MUSE}_{\mathrm{V}}$

$\mathbf{MUSE}_{\mathbf{V}}$ (Figure 8.16) – There are no significant points for either devices for $\mathrm{MUSE}_{\mathrm{V}}$.

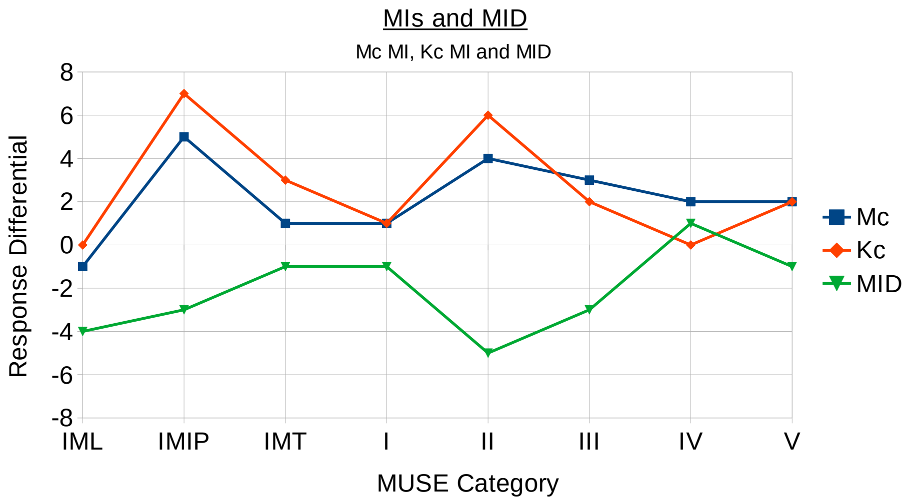

Figure 8.17: ADM Analysis of MI and MID

The charts for $MUSE_{IML}$, $MUSE_{IMT}$ and $MUSE_{I}$ have similar shaped graphs with the M_c trace moving down to a low point at MQ_3 then rising up again, creating a U-shape. The K_c has an inverted, n-shape to that of the M_c, (Figures 8.9, 8.11 and 8.12).

The MUSE indices section A has more significant data points than the MUSE styles section B having a maximum negative of -7 for $MUSE_{IML}$ and MQ_3. There is also a maximum positive of +7 for $MUSE_{IMIP}$ and MQ_1 and $MUSE_{IMT}$ and MQ_3. $MUSE_{II}$ has the most significant peak for MUSE styles of +6 for MQ_1. These represent the most significant correlations and although other points are larger than the control of +-3 are less significant and therefore less conclusive.

ADM Analysis of MI and MID

Figure 8.17 shows the MI and MID data plotted against the MUSE scores using ADM. The blue line represents MI for the M_c, the red for K_c and the green line represents the MID. The Y-axis represents ADM values, while the x-axis represents the eight MUSE indices and styles.

There are peaks for both instruments for $MUSE_{IMIP}$ and $MUSE_{II}$. Greater scores in these areas seem to promote a more positive response for both devices. The MID trace shows a negative result for $MUSE_{II}$ suggesting that the participants with a higher MUSE score for MUSE_{II} were also those with a lower MID (the participants who had a similar MI for both instruments). There are also negative MID results for MUSE_{IML} and MUSE_{IMIP} but with less significant levels.

8.3.3 ADM Analysis of Demographic Data

Generating charts for comparison of the Likert response against the demographic questionnaire was, for the most part, very inconclusive and potentially misleading due to difficulties in averaging the ordinal demographic data (Stevens, 1946). Therefore ADM analysis of demographic data has not been included.

8.3.4 Summary of ADM

Although inconclusive, the ADM analysis has shown significant connections between the Likert responses and the MUSE scores for MUSE_{IMIP} and MUSE_{II}. When considered with the other complementary examination methods of data, ADM analysis adds another facet, providing a complete picture of a complicated scenario. This technical analysis has pointed to patterns that would otherwise have remained obscure.

8.4 Real-time Response "Slider" Data

The slider and performance data was converted to CSV and plotted on charts. These charts were then visually examined for any obvious patterns. Figure 8.18 shows the chart from the converted MIDI data. Dividing lines have been added to split the charts into the calibration data and performance sections. The slider chart at the top includes the traces for all participants at each session. In this case, test 1A had four participants. The four charts below the main slider chart include the performance data, representing CC01, CC20 and CC21 (on the same chart), CC80 and PB. These charts show clearly the gestural focus for each section. The engagement levels for each gestural section from both instruments have been studied and compared using these graphs.[7]

8.4.1 Pre-Test Slider Data

The slider data method revealed patterns in the data that would otherwise not have been unearthed with other data methods on their own. The pre-test slider data highlighted dips of engagement in the same places for both participants that were not apparent with the post questionnaires or videoed discussions. Furthermore, the analysis showed that these dips occurred each time there was silence when the synthesiser programme changed. This data was illuminating as neither participant mentioned their disengagement due to the sounds changing, realising this occurred only after looking at the real-time slider data. After removing these silences, the main test phase slider analysis showed no more dips concurrent with the synthesiser programme change.

The pre-test analysis of slider data (Figure 7.6) highlighted that both participants' engagement levels had dipped in the same three places, which occurred for both instruments. However, it is more defined for the keyboard. Furthermore, it was clear that these dips occurred precisely when the synthesiser programme was being changed. There would be a short silence as the next synthesiser programme loaded at these points. A separate synthesiser plug-in "instance" for each of the five programmed sounds was used to remedy this issue (see Table 7.2 for the synthesiser programmes). Each of these sounds was pre-loaded before the performance and were immediately available when needed, without creating any silence while waiting for the programme to load. In this case, the foot switch controlled the selection of each synthesiser instance one after the other. Ableton Live was programmed to allow the previous sound to sustain until the notes were released whilst the next sound was selected, ensuring no unnecessary silence between programme changes.

[7] The charts from all performance sessions can be found in appendix J.

Figure 8.18: Test 1A M_c Slider Chart

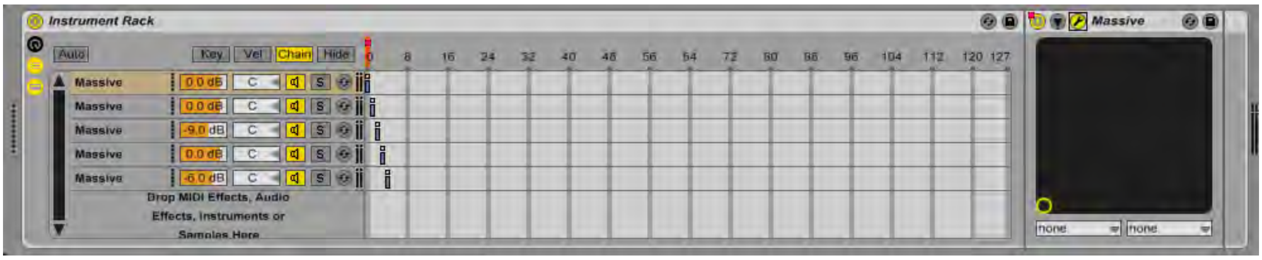

Figure 8.19: Synthesiser Programme Chain

Figure 8.19 shows the five instances of the "Massive" synthesiser plug-in loaded in Ableton Live. The programme "chain" is shown with the small blue blocks next to each synthesiser instance on the chain grid. The vertical orange line above these blocks selects which synthesiser to play. This selector was mapped to the foot switch. When the selector moved to the next position, the sounds from the previous selection continued to sound until they received a MIDI note-off signal. After that, the sound remained inactive until selected again, allowing the sounds to continue even when a different synthesiser programme was selected. The transition between sections could then be performed without any silence.

The pre-test analysis of the real-time response slider data allowed these dips to be precisely positioned within the performances. The revised programme selection mapping was used during the main testing phase. There was no evidence of similarly positioned dips for any participant for either of the instrument performances, which was very likely due to implementing the modified programme mapping.

This process has provided an interesting glimpse into the possibilities and effectiveness of the real-time response sliders. The slider data gave an insight into participant responses, which was not revealed with any other data collection or analysis method.

8.4.2 First Test Session Realignment of Slider Data

The first test session on K_c was restarted due to a technical issue with the keyboard settings and foot switch failing to initiate the synthesiser programme change, (Section 7.3). The performance was stopped after the first section. The calibration process was not performed on restart. This break in the performance can be seen in Figure 8.20, where the drop in

Figure 8.20: Test 1A - Edited Slider Data

all slider data to minimum shows where the recording was paused. This situation was not intentional or ideal but only occurred once. However, to deal with this data, it was felt that the first section from the first performance, with the original calibration data, should be used in conjunction with the restarted data from the point where the performance was paused. Therefore, the data from the restarted performance was deleted from its start to the point where the original performance was stopped. This deleted area is highlighted in Figure 8.20. This "stitched" data from the two performances represents the best compromise for this situation. Realistically the data was unlikely to have differed without the restart in performance and so was considered usable for analysis.

8.4.3 Observed Patterns in Slider Data Charts

There were eleven participants that had very similar slider traces for both performances. These participants had higher than average levels for the MUSE$_{IMIP}$ and MUSE$_{II}$ scores. Table 8.5 shows these eleven participants, their MUSE$_{IMIP}$ and MUSE$_{II}$ levels, their group

Participant No.	IMIP	MUSE II
1	66.5	38
5	0.5	10
6	10	26
8	60	26
14	40	40
16	1	30
17	0	3
18	24	41
19	450	43
20	441	40
25	0.36	17
Average	99.40	30.70
All Participant Average	49.62	20.38

Table 8.5: Similar Slider Traces for Both Performances

average and the overall participant average. As can be seen in Table 8.5 the $\text{MUSE}_{\text{IMIP}}$ group average is 49.78 greater than the overall participant average, and the MUSE_{II} group average is 10.32 larger.

8.4.4 Analysis of Slider Data Engagement Levels

Similar traces were easily observed. However, to discover more patterns, the slider data was fully calibrated and then analysed for each performance section looking at the participant minimum and maximum engagement levels.

Calibrated Percentage Engagement Level (CPEL)

As the pre-test showed, recording slider calibration data was necessary before each performance. This captured changes in the minimum, maximum and centre levels between each performance. Out of the twenty-five participants, seven had a reduced range of minimum or maximum movement of the slider. Most participants were close to the actual centre (64) for the midpoint and had similar midpoints for both performances. However, there were examples where this was not the case, and the calibration data proved essential to enable a genuine comparison of both performances.

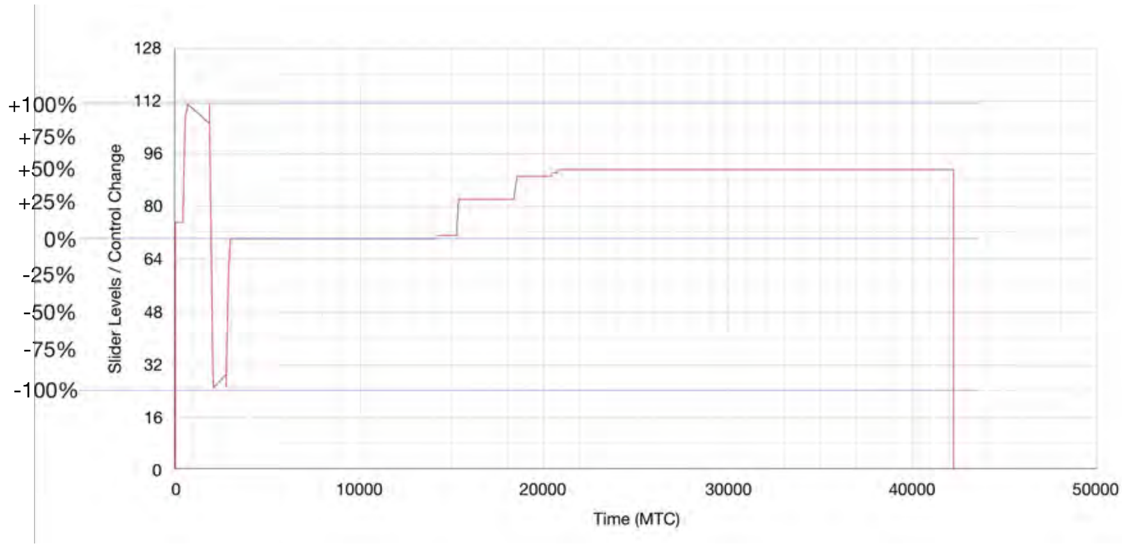

Figure 8.21: Calibrated Percentage Engagement Level

The slider data was converted to a +/- percentage scale with the calibrated midpoints at 0%. Each participant's calibrated minimum and maximum levels were used to produce a relative scale with a minimum at -100% and a maximum level at +100%. However, when introducing the calibrated minimum and maximum levels, care was taken because their corresponding participants sometimes exceeded them during the performances. In these cases, the largest actual minimum and maximum levels were used instead of the calibration level. On this percentage scale, any level with a positive percentage displays a positive engagement level in relation to the calibrated midpoints. Conversely, a negative percentage shows a negative engagement level below the midpoint (Figure 8.21).

This Calibrated Percentage Engagement Level (CPEL) provided a more readable scale for examination and analysis and a more direct data comparison. In addition, incorporating the participant calibration data into the slider data presented a fully calibrated scale allowing for a fairer comparison of engagement levels.

Minimum and Maximum Engagement Levels

The MCU firmware used to produce MIDI data only created data as the sliders were moved, so stationary sliders generated no MIDI data. There was no sampling of the data at regular intervals, which meant averaging the data was not easily possible across the performance period. Regular sampling could have been achieved using bespoke firmware (Section 8.5) but would have been more complicated to set up.

Instead of averaging the slider engagement data, the minimum and maximum levels for each performance section were plotted for each participant. This analysis allowed for a systematic search for the more extreme changes and positions in engagement and enabled comparisons of engagement levels for each of the gestural sections and between the two instruments.

Significant Dips in Engagement

The minimum and maximum engagement levels recorded across the entire performance have been plotted, looking for significant low and high engagement levels. Figure 8.22 shows these levels for the M_c and Figure 8.23 for the K_c. They show clearly a higher minimum and maximum level for the M_c than the K_c. Twenty-four of the participants have a maximum engagement level above +50% compared with fifteen for the K_c and six participants for the M_c having a minimum engagement level below -50% compared with eleven for the K_c.

Three groups were analysed based on significant negative engagement levels below -50%. Firstly those participants that only had low levels for K_c. Secondly, those with only low levels for the M_c, and thirdly those participants with significant low dips in engagement

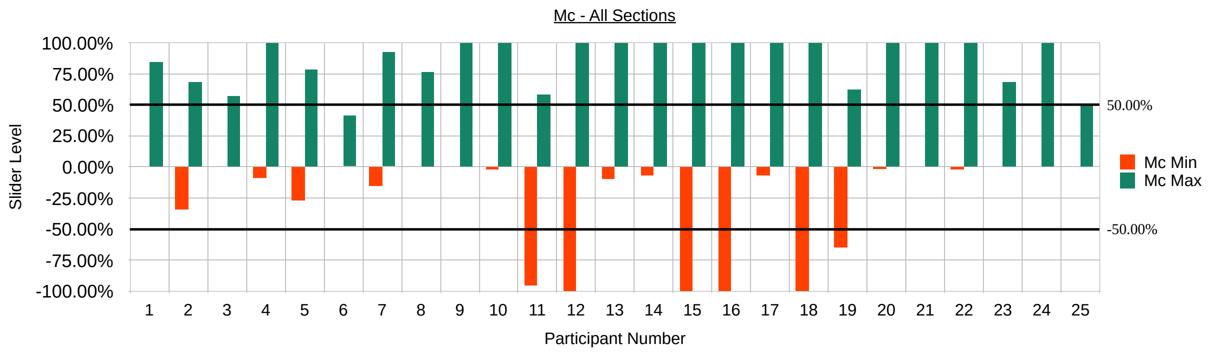

Figure 8.22: M_c - Min/Max Levels Across All Sections

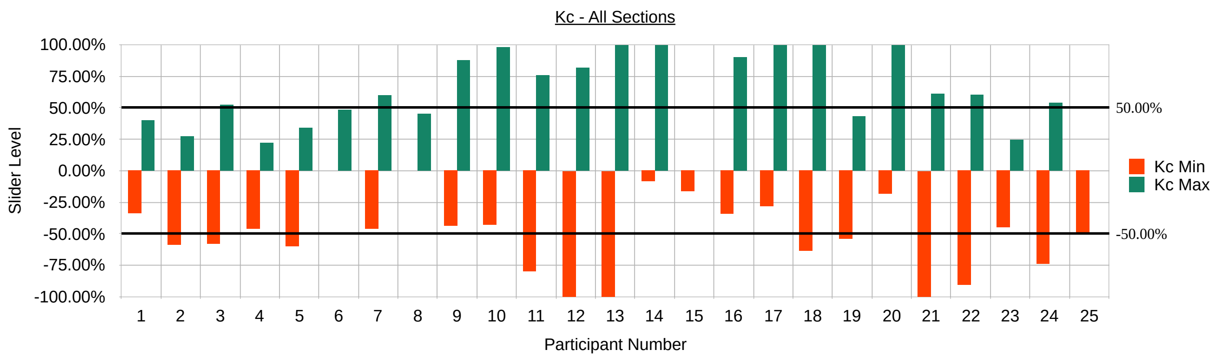

Figure 8.23: K_c - Min/Max Levels Across All Sections

Participant No.	IMIP	MUSE II
2	0	0
3	0.78	23
5	0.5	10
13	0.06	6
21	0.13	1
22	10	22
24	0.08	3
Average	1.65	9.29
All Participant Average	49.62	20.38

Table 8.6: Dips in Engagement Levels - K_c only

levels for both the K_c and M_c. These three groups of participants were further analysed with the corresponding MUSE scores. The analysis showed correlations with $MUSE_{IMIP}$ and $MUSE_{II}$. However, there were no significant differences or patterns for the other MUSE indices or styles for any of these three groups.

Dips in Engagement for K_c Only

Table 8.6 shows participants with low dips in engagement for the K_c only, their $MUSE_{IMIP}$ and $MUSE_{II}$ scores, the average scores for this group and the average scores for all participants. It can be seen that these participants scored significantly lower for these two MUSE scores than the participant average. The group average for $MUSE_{IMIP}$ is 1.65 compared to the participant average of 49.62, and the group average for $MUSE_{II}$ is 9.29 and the participant average of 20.38.

Dips in Engagement for M_c Only

Table 8.7 shows the two participants with significant low engagement levels for only the M_c. The same two MUSE indices show that these participants score higher than average, particularly for $MUSE_{II}$, with $MUSE_{IMIP}$ scores only slightly higher than average.

Participant No.	IMIP	MUSE II
15	100	43
16	1	30
Average	50.5	36.5
All Participant Average	49.62	20.38

Table 8.7: Dips in Engagement Levels - M_c only

Participant No.	IMIP	MUSE II
11	0	0
12	0.09	17
18	24	41
19	450	43
Average	118.52	25.25
All Participant Average	49.62	20.38

Table 8.8: Dips in Engagement Levels - Both M_c & K_c

Dips in Engagement for K_c and M_c

As seen in Table 8.8, for participants recording significant low engagement levels for both K_c and M_c, $MUSE_{IMIP}$, scores are significantly higher than average with a group average of 118.52 compared with a participant average of 49.62. $MUSE_{II}$ is also higher than average but not as significant. The $MUSE_{IMIP}$ average is skewed due to the inclusion of 450 compared with the three smaller scores of 0, 0.09 and 24.

Average Minimum and Maximum Levels of Engagement

Figures 8.24 and 8.25 show the average of minimum and maximum levels across all the sections for each participant for the M_c and K_c respectively. This averaged level indicates the overall engagement level compared to the minimum and maximum levels discussed above. Again these figures show clearly that the average engagement levels for the M_c are mainly positive for both minimum and maximum levels with small negative minimum

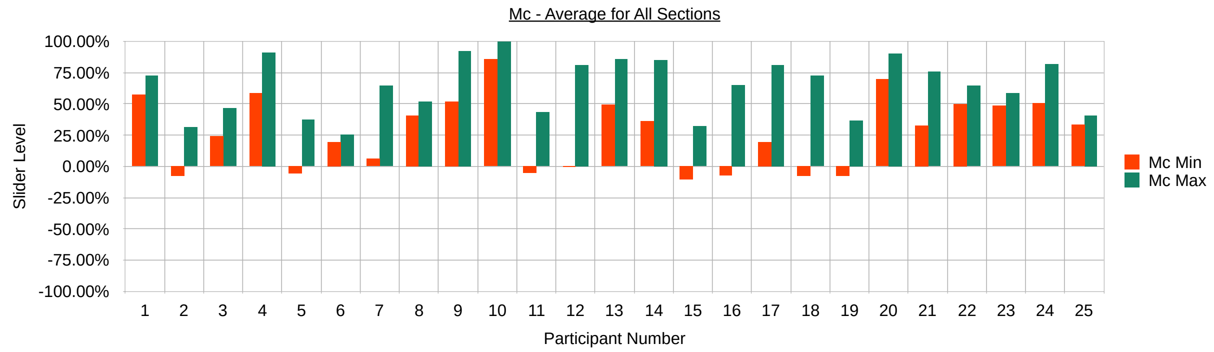

Figure 8.24: M_c - Min/Max AVERAGE Levels Across All Sections

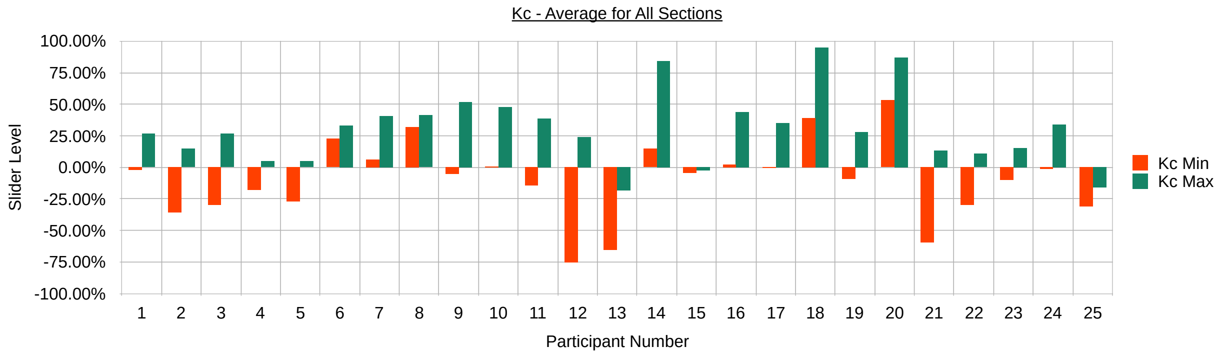

Figure 8.25: K_c - Min/Max AVERAGE Levels Across All Sections

values for seven participants. The average maximum levels of seventeen participants are above +50% with only four for the K_c. The average minimum levels for the K_c show three participants below -50% with another thirteen that have negative values.

Participant Average for Average Minimum and Maximum Levels

Figures 8.26 and 8.27 show the participant average for minimum and maximum levels of engagement for each section. Figure 8.26 shows data from the M_c and Figure 8.27 from the K_c. On the charts, blue represents participant average for minimum levels and red shows maximum levels. The average maximum engagement for both the M_c and K_c are all above zero for all sections. However, the M_c levels are significantly higher for all sections, with all sections above +50%, except section 1, whilst all sections for K_c are below 50%. The M_c and K_c have similar minimum “dipped” values for the first section, both below zero showing a negative engagement. However, for the following sections, the M_c minimum

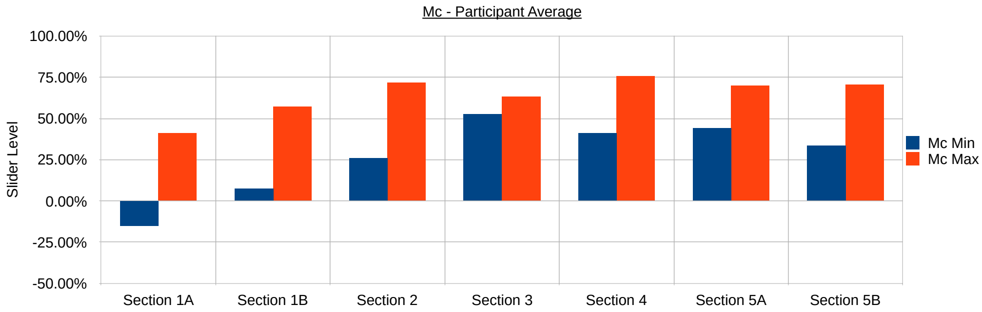

Figure 8.26: M_c - Participant Average

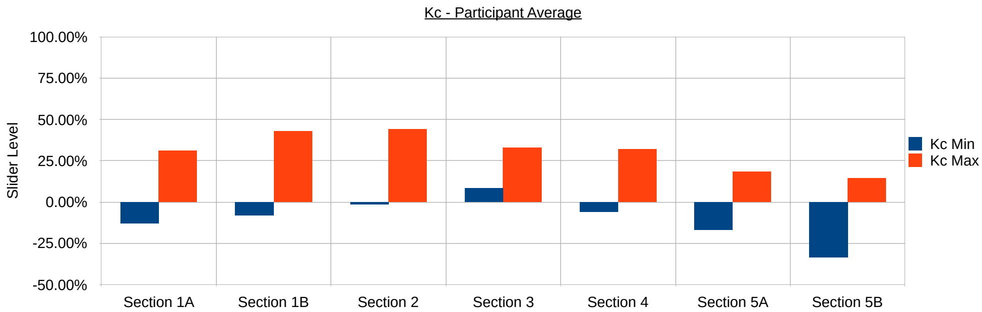

Figure 8.27: K_c - Participant Average

values are all above the zero point (positive engagement), whereas the K_c minimum levels show negative engagement in all sections except section 3.

Figure 8.28 shows the average minimum, and maximum engagement levels for all participants averaged across all sections of the performance for the M_c and K_c. The M_c has positive minimum and maximum engagement levels whilst K_c has a negative engagement minimum and a significantly lower positive maximum level than the M_c.

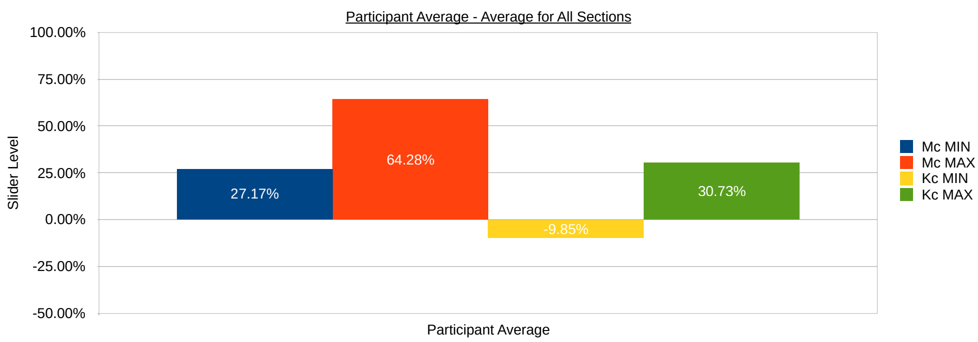

Figure 8.28: Participant Average for All Sections

8.4.5 Sectional Analysis of Slider Data

The figures in Appendix K show the CPEL minimum and maximum levels for each section, for both devices. It is clear that for the M_c sections 3, 4, 5A and 5B were the most engaging with only one significant (less than 50%) negative engagement level. The K_c has significant low engagement levels in every section. The M_c charts show significant high engagement levels across all test participant groups for all sections. The K_c has less significant-high engagement levels for each section than the M_c.

Participants 14 to 20 show high levels for the K_c across all sections. This group was hosted at a music department in a comprehensive school, with participants being mainly from musical backgrounds. This pattern was studied further, as well as looking for other patterns harder to observe, using the ADM technique to compare the sectional slider data with the MUSE scores (Figure 8.29).

There are significant dips (below 50%) for the K_c in section 5A for participants 2, 3, 12, 13, 21 and 22. These participants represent three test sessions that all began with the K_c. This data is the most noticeable point relating to which instrument was performed first. There is, however, no other data to confirm that this is nothing more than a coincidence. The demographic groupings for each test session may have affected this result.

Min and Max Levels Across Sections

Figures 8.26 and 8.27 show clearly a greater overall M_c slider engagement level across all sections than the K_c. The only average CPEL level that favours the K_c is in section 1A, where the average minimum CPEL level for the K_c is -12.94% and for the M_c is -15.15%. All other average minimum and maximum CPEL levels across all sections are higher for the M_c. The M_c has only one point of negative engagement level in section 1A. In contrast, the K_c has negative levels for all sections except section 3.

The most noticeable observable differences between the instruments are for sections 5A and 5B, with the M_c maintaining high engagement levels, slightly lower than the previous sections. However, the K_c levels are lower than the earlier sections, with negative levels of engagement in both sections, particularly section 5B.

The non “melodic” sections 1A, 4, and 5A have the lowest engagement levels for the K_c except section 5B, but this is not the case for the M_c where sections 4 and 5A have high levels of engagement. Section 1A does, however, have the lowest engagement for the M_c although the average maximum CPEL is positive.

ADM Sectional Analysis of Slider Data

ADM was applied to the slider data and showed the distribution of the minimum and maximum peaks across each MUSE index and style. The data was split into each performance section so that the participant slider responses could be compared and analysed with each gestural element of the performance. Due to occurring post-performance, the other data methods are not as easily compartmentalised into separate sections. The response slider data allows the sectional analysis due to its real-time nature.

This ADM data has been charted to show the distribution of minimum and maximum slider peaks for both instruments. Figure 8.29 shows seven rows of charts, each row representing a performance section. The charts on the left of the page are of the K_c data and the M_c on the right. These charts are best considered as a whole, not individually. Therefore they are presented on the same page for easy comparison.

The bars represent two parts of the ADM calculation. The blue represents the minimum dips recorded whilst the green shows the maximum peaks. A larger bar shows a greater bias towards the corresponding MUSE score. A more negative blue and a more positive green represent a stronger correlation between positive slider engagement and a higher MUSE score—conversely, the more positive blue and negative green show negative slider engagement with higher MUSE scores. Blue and green levels that are both positive or negative show that the minimum and maximum peaks are both biased towards the MUSE score.

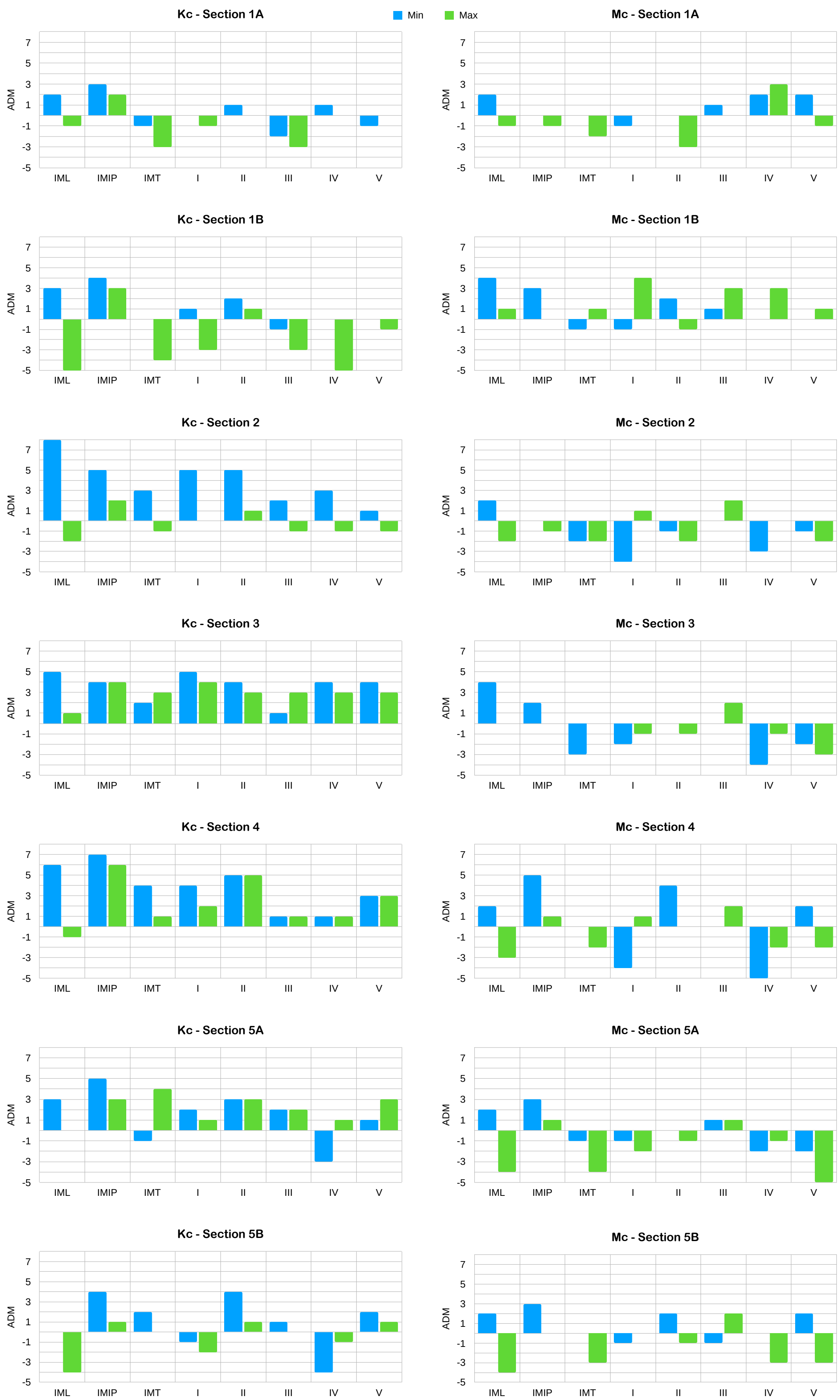

Figure 8.29: ADM Analysis of Slider Data

It can be seen from these charts that, in general, there are larger bars for the K_c especially for sections 2, 3 and 4, than the M_c. The most significant ADM levels across all the charts are for the K_c, Section 2, $MUSE_{IML}$ and for Section 4, $MUSE_{IMIP}$ and $MUSE_{II}$. All three cases are mostly positively related to the higher MUSE scores.

The $MUSE_{IML}$ levels in section 2 have an ADM of -8 for the dips, showing a positive relationship with $MUSE_{IML}$ scores and engagement levels. The ADM -2 for maximum levels, in this case, is largely insignificant.

The K_c for section 4 has an ADM combined min/max level of 13 and 10 for $MUSE_{IMIP}$ and $MUSE_{II}$ with a positive correlation showing significant relationships between high scores in $MUSE_{IMIP}$ and $MUSE_{II}$ and higher slider engagement levels for this section.

Although the other chart levels are less significant, some elements of interest exist between these charts. Whilst the K_c has mainly positive ADM levels, the M_c has more inverted ADM levels, especially in sections 2 and 4. Also, the different ADM levels for $MUSE_{IV}$ for the M_c show positive ADM correlations in Sections 1A and 1B but negative correlations for the other sections. This data for the K_c follows a similar but opposite trend except for Section 1A. $MUSE_V$ has a similar pattern to $MUSE_{IV}$ but not quite as pronounced throughout all the sections.

8.4.6 Summary of Real-time Response Slider Data

The real-time response slider data has added an important facet to the methods of examination used in the testing providing genuine illumination that would have remained hidden without this technique. The slider data suggests that the engagement levels for the M_c were higher overall than the K_c and were maintained throughout all sections and that higher MUSE scores correlated to higher engagement levels for the K_c. The results of the slider data, although not entirely conclusive on their own, add to the collective knowledge of the data set, bolstering the patterns and correlations that support the premise that mimetic design principles are connected with an elevated mimetic response.

8.5 Future Improvements of Testing Methods

Although the relatively small sample size of participants cannot be taken as statistically significant evidence, the patterns and correlations found in the data give a clear indication of the potential value of mimetic design principles. Future testing could include larger samples of thirty or more participants that could exploit more traditional statistical analysis methods. A longer performance would also provide additional new insights into mimetic design.

Several potential development areas, discussed below, became apparent when carrying out the performances, data collection and processing, and although not detrimental to this project, will be considered in future research.

8.5.1 Performance Improvements

A further section was added to expose the gestures mapped to CC80, which was a hand gesture on the M_c and the foot pedal on the K_c. There was a noticeable absence of overt mimetic participation in the video recordings. This absence was likely due to the short length and unnatural test-like scenario of the performances and participant involvement in slider operation during the performances. However, the slider data was more important to the test phases, so the performance was a suitable compromise that produced a range of usable data. Future tests could include a longer music concert looking specifically at overt mimetic participation.

8.5.2 M_c Fixed Volume

The music was performed as similarly as possible with each instrument. However, the M_c was set in the firmware to produce a fixed volume when initiating the sound, whilst the initial volume of the K_c varied depending on how hard the keys were hit. There was no significant detrimental effect on the test phase overall, as it was impractical to create an identical performance due to the physical and gestural differences of the instruments. However, it would be prudent to ensure this is remedied in the future.

8.5.3 Questionnaire Improvements

The questionnaires were modified, developed and improved after the pre-test phase. However, the replacement of custom questions by the MUSE questionnaire relating to musical experience and engagement removed the question about which instrument a participant had experienced. This question would have provided some additional profiling of the data but has not affected the overall results of the test phases. It may be included in future testing.

The MUSE scoring system would benefit from adjustments to improve the data ranges. In particular, the $MUSE_{IMIP}$ calculation is quite complex and creates a wide range of data. The very high scores seemed disproportionate to the low ones and affected any averaging calculation.

The $MUSE_{IV}$ and $MUSE_{V}$ had a relatively low range, possibly due to having fewer questions relating to these scores than the other MUSE styles and indices. Consequently, these scores seem somewhat diluted. In future tests, the $MUSE_{IV}$ and $MUSE_{V}$ scores could be combined to create an overall “physical movement” style, which could then be used to look for patterns of mimetic response relating to general physical engagement with music.

After analysing the results, it was clear that MQ_4 and MQ_5 could be reworded to be more explicit. The intention of these questions was to expose any potential mimetic participation experienced by the participants. However, as this can often be covert and subconscious, these questions would not necessarily reveal this type of response. Also, the contrived nature of the performance may have inhibited the response to join in because, in a sense, the question is asking would you like to join in with this test performance?

8.5.4 Slider Improvements

The slider data may have been produced using a sampling technique which would have allowed averaging of the data. This technique required a particularly complex technical adjustment in the firmware and so was not implemented in this case. However, it would be considered in future.

The possibility that participants may forget during the performance that they should be responding with the slider was considered. However, as the test performances were less than five minutes, there was no evidence in the slider data that any participant had “forgotten” to move the slider. This issue would need to be considered further in a testing context where the performance is longer and in a more normal situation such as a music concert or dance performance.

8.6 Anecdotal Evidences—Stories About the BazerBow

The following anecdotes are included as evidence in addition to the data gathered from the testing phase. Each story shares the three stages of mimetic cognition, ultimately ending with some form of participation, but they have been chosen to highlight each of those stages.

A 60th Birthday Party

At the 60th birthday of a friend, his 80-year-old mother had a go of the BazerBow. She had minimal experience with any musical instruments. However, it seems she was initially mimetically engaged, therefore and involved sufficiently to choose to try out the instrument. Her playing style was very exploratory, especially with the motion sensors, continually moving the BazerBow around and over her head whilst listening to the responding sounds. This instant mimetic engagement is essential to mimetic design and facilitating initial involvement in the BazerBow.

Another Dancer

After presenting the BazerBow at an MA showcase (https://research.bazerbow.uk/Video-5) a dancer began playing the BazerBow. At this point, the room was empty and large enough to allow the dancer to move freely. It was fascinating to watch the dancer's movements modulate the sound and, in turn, see their dance react to the sound. This continual feedback of modulated sound and movement continued for about twenty minutes. The dancer was present during the presentation and was familiar with the instrument before playing it. This presentation caused the dancer to want to know more about the instrument. He was invited to learn, a crucial aspect of mimetic invitation and communicative musicality.

"Air BazerBowing"

This anecdote is something that I, as the designer, experienced sometime after completing the first prototype. I had been rehearsing a demonstration piece on this BazerBow for a few weeks. Whilst listening to some music that had a synthesiser solo, I began subconsciously "air BazerBowing" realising it a few moments later. My knowledge and experience playing the BazerBow led to a fully manifested overt mimetic participation. The final inclusive stage of mimetic design is to evoke and promote mimetic participation. Although I designed and built the BazerBow, this experience is still encouraging to me as I found myself connecting to electronic music via the BazerBow rather than what would have previously been the keyboard.

8.7 Discussion of Data Analysis and Anecdotal Evidences

The multimodal approach to examining mimetic design principles has provided a range of complementary data that provides a clear attestation of the relationship between mimetic design principles and mimetic response when considered as a whole. Further research and development of the testing methods, will provide greater confidence, in the future.

The anecdotal stories present experiences that depict the stages of mimetic cognition and, therefore, evidence the mimetic potential of the BazerBow and the potential of mimetic design. This evidence is significant within the context of the corroborative testing phases.

The data presented shows a clear bias towards the BazerBow with all methods of examination and analysis. The cross table (8.2) shows clearly a preference for the BazerBow for all five of the mimetic questions, questions 7.1, 7.2 the MI and MID. The slider data showed more significant and more sustained levels of engagement for the BazerBow, whilst the open questions and discussions were corroborative. The ADM and sectional analysis provided additional evidence of mimetic design. It is worth looking at the data and these patterns in the context of the three I's.

8.7.1 Evidence of Involvement

MQ_2 specifically enquired about engagement, and was in favour of the BazerBow. Question 9 revealed that 4 participants found nothing interesting about the keyboard, but participant 20 found the BazerBow "innovative" and "strongly communicative re. gesture" and participant 21 said that the BazerBow was "more engaging" whilst the keyboard was "less engaging to watch". Several comments referred to the more introverted and down-facing nature of the keyboard and the "fiddling" and "twiddling" of the controls. Where the BazerBow was forward-facing and engaging to watch as an instrument. A discussion with P14 showed an appreciation of virtuosity regarding the BazerBow as they felt it would be more difficult to play accurately than the control knobs.

The slider data also specifically targeted the idea of engagement. This data showed a much higher and sustained level of engagement for the BazerBow. A particularly interesting point to the data came from the sectional analysis that showed the BazerBow maintained high engagement levels for the non-melodic sections 4 and 5A, compared to the reduced levels on the keyboard. Despite these reduced levels, several participants found the pedal the most interesting part of the keyboard (Section 5 highlighted the pedal).

The ADM sectional analysis found that there could be a link between the $MUSE_{IV}$ score and the different sections of music. The BazerBow had a positive ADM correlation between $MUSE_{IV}$ and Sections 1 and 2, but negative for section 5. The inverse seems to be the case for the keyboard. $MUSE_{IV}$ refers to physical movement and music. Sections 1 and 2 exhibited some of the largest movements of the BazerBow compared with very small movements of the keyboard controls. However, section 5 exhibited the largest keyboard movements on the pedal and the smaller medium gestural hand movements on BazerBow.

8.7.2 Evidence of Invitation

When invited to try either the BazerBow or Keyboard, 16 participants chose to play the BazerBow whilst none chose the keyboard. This preference was confirmed by the response to MQ_1 which strongly favoured the BazerBow. The BazerBow was novel to 21 participants, and the keyboard was novel to 12 participants. Therefore, although the novelty might have a bearing, the instrument design is likely to have been influential. The BazerBow invites people to have a go but also invites learning. Seven participants wondered how the BazerBow worked, showing an invitation for learning, a core concept of communicative musicality.

Another aspect of invitation is the aesthetics of the instrument. There are several references to participants finding the BazerBow visually appealing, which is confirmed by MQ_3, which strongly favoured the BazerBow. Participant 8 closed their eyes for the entire keyboard performance as they were “more interested in the sounds”, and participant 21 suggested that the keyboard was “more reliant on the sounds”. The various answers and comments discussed the BazerBow as an instrument. However, for some, the keyboard seemed more computer-related, with participant 2 describing it as a “computerised keyboard”. From these results, the participants found the BazerBow more visually appealing than the keyboard and considered it an instrument.

Question 7.1 favoured the BazerBow, suggesting that the participants found it more suitable for the sounds being played. This result was significant because the BazerBow was designed to play electronic sounds, which I had previously been playing with the keyboard. However, this question needs further exploration to identify why this is the case and whether it was the instruments' aesthetics or the gestures.

Several comments and discussions pointed to the instruments sounding different despite being connected to the same synthesiser. These comments suggest inter-modality and that each instrument's sound was perceived differently due to the visual aspect. This concept is also crucial to mimetic design, so it was interesting to find participants experiencing inter-modality with these instruments.

Question 7.2 was biased towards the BazerBow, confirming the opinion that the BazerBow was more inviting, with 20 participants favouring the BazerBow with only 2 preferring to try the keyboard. However, despite this preference, neither of these participants actually tried the keyboard when given the opportunity.

8.7.3 Evidence of Inclusion

Questions MQ_4 and MQ_5 also favoured the BazerBow, but not as strongly as the other mimetic questions. Comments from Test 1 suggested that the BazerBow was "harder than it looks" to play and that "it'd be easier than you think". The mimetic design aimed to make the BazerBow initially intuitive but also challenging to master. However, when these participants tried to play the BazerBow, they found it more complicated than they first thought.

The BazerBow did seem to be simple to several other participants, with P19 stating that "the simplicity was the beauty of it". Participant 20 agreed, and participant 1 suggested that the BazerBow is "fun to play [a] way into playing music". Participant 11 also liked the simplicity of the BazerBow but commented that they liked the complexity of the keyboard. The inclusion of a mimetic instrument relies on being simple and intuitive to approach, but with the facility for complex control of sounds.

There was a specific discussion with participant 14 (a music teacher), who suggested that music students find keyboards and other traditional instruments intimidating as there is an expectation of producing a certain quality of playing. However, they commented that the BazerBow is far enough removed from the guitar design that it would encourage students to play.

The slider data showed that 11 participants had similar traces for the instruments and higher $MUSE_{IMIP}$ and $MUSE_{II}$ scores. This pattern is corroborated by the 7 participants who only had significant dips of engagement with the keyboard and had lower $MUSE_{IMIP}$ and $MUSE_{II}$ scores. Also, Test 3 had generally higher levels of engagement for the keyboard. This test was based in the music department of a school. Consequently, the participants had much higher MUSE scores. There was also an ADM connection between these same two MUSE scores and MQ_5 for the keyboard, confirming the same pattern. This data strongly correlates with engagement levels and $MUSE_{IMIP}$ and $MUSE_{II}$ scores. People with more music engagement and experience playing instruments can engage more equally with the keyboard. However, this prior musical knowledge and experience are less necessary for engagement with the BazerBow.

The overall participant MI's and MID favoured the BazerBow, with 21 participants with positive values. The ADM analysis for MID levels also confirms the connections between higher levels $MUSE_{IMIP}$ and $MUSE_{II}$ and a lower MID. An equal response to both instruments is linked to higher levels of these MUSE scores.

The sectional slider analysis also highlighted a link between $MUSE_{IMIP}$ and $MUSE_{II}$ and the keyboard during section 4. This section uses non-melodic fast modulating electronic sounds controlled by a small joystick on the keyboard but the entire movement of the BazerBow. The BazerBow maintained engagement throughout this section regardless of the music experience of the participants. A certain level of music experience seems necessary for participants to remain engaged in the non-melodic playing of the keyboard.

8.7.4 General Discussions

The concept of mimetic participation, especially covert participation, was difficult to ascertain. Question MQ_4 and MQ_5 need reworking to provide more in-depth conclusions. This area may also need longer performances to provide greater insight. However, the complete data set and anecdotal stories convincingly confirm the concepts of mimetic design showing the BazerBow to be more involving, inviting and inclusive than the keyboard. Participant comments refer to the keyboard as “less engaging”, less “visually appealing” and “less accessible” confirming that the keyboard was found to be less involving, inviting and inclusive.

The data provides a conclusive and affirmative answer to the research question:

- Does the BazerBow possess mimetic potential and therefore provoke a mimetic response from an audience? (Section 2.4).

The BazerBow clearly shows mimetic signs of audience involvement, invitation and inclusion. The data also confirmed the mimetic evaluation (Chapter 6) that the BazerBow would possess greater mimetic potential than the keyboard.

Chapter 9

Conclusions

This thesis represents a personal journey from my earlier experiences that highlighted some issues of digital music performance to the creation of the BazerBow, to address some of these problems. Before starting my PhD, I had no original intention of making instruments, but I now find myself an instrument designer and maker. As I began to explore instrument design, it became apparent that my inspiration could be drawn from a large body of work. Therefore, I needed to narrow my areas of interest down to a manageable amount.

My early research led me to Cox's (2016) research into mimetic cognition, particularly his concept of mimetic participation. Cox's research seemed to me to be complemented by the areas of action understanding (Maes et al., 2014), communicative musicality (Malloch and Trevarthen, 2009) and empathy (Szalavitz and Perry, 2010). These areas are not necessarily typical to instrument design, with other research areas more prominent within the Digital Musical Instrument (DMI) community. However, these three areas formed my critical literature and began to inform the following research.

I then began to consider the concepts of gesture, affordance and appropriation concerning mimetic theories and the common issues of audience engagement, aesthetics, expression, longevity and popularity. Consequently, this work led me to think in terms of the three I's (Section 5.1). The concepts of involvement, invitation and inclusion seemed to tie my research together by three threads. These ties were initially unintended, but as work progressed, it became more evident that my concepts followed these three lines of thought, with my practice finally consciously and deliberately guided by the three I's.

Figure 9.1 represents this thought process by showing how the three I's align with the other areas of concern. The yellow areas represent the existing research that was influencing my practice. The following green sections represent the areas I began to develop in response to this research and my music practice. In response to the research, I developed the three design concepts of mimetic gesture, affordance and appropriation with corresponding ideas of the mimetic gestural matrix, mimetic affordance mapping and mimetic appropriation pyramid.

Mimetic Theories		DMI Design		Mimetic Design		Prototyping of BazerBows		Examination of Prototypes	
Mimetic Cognition	**Complimentary Theories**	**General DMI Theories**	**Challenges for DMI Design**	**The Three I's**	**Mimetic Design Principles**	**Manufacturing Considerations**	**Prototypes**	**Test Phase Data**	**Anecdotal Evidence**
Mimetic Engagement	Action Understanding	Gesture	Audience Engagement	Involvement	Mimetic Gestural Matrix	Manufacturing issues. Production of multiple quantities. Greater reliability and usability.	Prototype 1 Prototype 2 Various technical developments including manufacturing processes. Improvements in inclusion of mimetic design principles. Prototype 3...	Engagement Levels	A 60th birthday party
Mimetic Invitation	Communicative Musicality	Affordance	Aesthetics and Expression	Invitation	Mimetic Affordance Mapping			Desire to "have a go"	Another Dancer
Mimetic Participation	Empathy	Appropriation	Longevity and Popularity	Inclusion	Mimetic Appropriation Pyramid			Desire to "join in"	"Air BazerBow-ing"

Existing Research	Concepts and Evidences Developed for this Research

Figure 9.1: Mimetic Chart
(See Appendix N for a larger version)

These mimetic design concepts are consolidated in the set of mimetic design principles (Section 5.3), which represent the central focus of this research, pulling on the five prongs of the cycle of development (Figure 2.2). Nine mimetic principles directed the design and creation of the BazerBow prototypes.

The initial experiences with the BazerBow were indicative of mimetic design. There have been several occasions and comments about the BazerBows pointing to a mimetic response, but the three anecdotes presented in Section 8.6 were some of the most demonstrative. However, to discover whether these prototypes truly exemplified the mimetic design principles, I decided to devise a test phase to explore the mimetic response of an audience.

The data analysis from the main test phase conclusively confirmed a more significant mimetic response to the BazerBow than to the keyboard. Of the twenty-five participants, sixteen chose to try the BazerBow, but none the keyboard. Delving further into the data analysis revealed that this was not just because of the novelty but because of the BazerBow's mimetic potential.

The strong connection between music experience and mimetic engagement with the keyboard was evident throughout the data analysis, correlating higher $\text{MUSE}_{\text{IMIP}}$ and MUSE_{II} scores with higher engagement levels with the keyboard, particularly for the non-melodic sections (Section 8.7.1). Conversely, the engagement levels with the BazerBow were unaffected by these MUSE scores, with the audience remaining engaged throughout, including the electronic soundscape sections. This result was significant for me as a music practitioner, as the BazerBow was designed to maintain audience engagement whilst playing non-melodic atmospheric sounds.

In addition to the sixteen participants who played the BazerBow and the conclusive Likert and slider pointing to greater engagement with the BazerBow, it was surprising that a participant had closed their eyes during the keyboard performance. I found this particularly demonstrative of the difference in the visual and gestural engagement between the BazerBow and the keyboard, which is vital to involvement and mimetic engagement.

It was interesting to find comments and hear the discussions about the comparisons of the sound of the instruments and how they sound different, with several participants using sound to describe their experience and differentiate these instruments. These comments and discussions point to inter-modality and the concepts surrounding ancillary gestures (Section 4.4.2), which are essential to mimetic invitation. Several comments referred to how the participant would like to know how the BazerBow worked, indicative of an invitation to learn and, therefore, communicative musicality.

The discussion about how the BazerBow might encourage students to experiment and play due to its intuitive nature was poignant as inclusiveness (Section 5.1.3) is a core mimetic concept, encouraging new players. Another discussion concerning the appreciation of the necessary skill to fully control the BazerBow pointed to the idea of virtuosity (Section 4.3.1). Although the BazerBow was seen as intuitive, a sense of virtuosity is important to encourage continual playing and developing skills with the BazerBow. These discussions on the balance of intuitive play and the possibility for virtuoso playing were backed by comments referring to the simplicity of the BazerBow despite being more challenging to control than expected. This balance is not only essential to mimetic design but for DMI designers in general, often citing Wessel and Wright's (2001:11) statement: 'Low entry fee with no ceiling on virtuosity'. Due to the importance of this balance to inclusion and mimetic participation, it was pleasing that the test phase confirmed that the BazerBow achieved this harmony.

This work combined the mimetic theories with more general DMI design concepts to create the mimetic design principles. The anecdotal evidence and test phase data analysis confirmed that these principles were successfully embedded into the BazerBow prototype.

These mimetic principles provide an additional tool-set for the DMI community to help address the audience in instrument design. These principles also provide a way to evaluate and classify existing DMIs concerning mimetic potential and mimetic response.

Due to the strong underlying reliance on Trevarthen and Malloch's (2009) communicative musicality, which is so fundamental to music therapy, mimetically designed instruments may be particularly effective for therapeutic use contexts. The intuitive mimetic involvement allied with the explorative mimetic invitation and inclusive participation may prove helpful in designing DMIs for music therapists in the future.

The real-time response slider proved effective in recording accurate audience responses providing excellent data for analysis. This slider method may prove helpful in recording audience responses in many other use contexts allowing the recording of continuous audience responses to be precisely aligned with the moment of response. The slider method could be used for further performance research, for example, in dance, theatre, media and interactive gaming.

The small sample of participants led me away from traditional forms of statistical analysis and toward developing the Average Distribution Method (ADM) analysis. This method proved extremely useful in finding links in the data that would otherwise have remained hidden. The ADM analysis could be helpful for other research where traditional analysis may not be practical, or the sample size is too small to produce statistically significant results using the conventional statistical methods.

In general, the mimetic design concepts and process of the cycle of development may be of interest and inspirational to similar interdisciplinary projects looking for a balance between the arts and design processes. As well as being of interest to DMI designers, mimetic design principles may also be of some interest to designers in general. Many of the concepts of DMI design crossover with Human-Computer Interaction (HCI) and Human-Machine Interaction (HMI), and any design involving humans and the digital world may benefit from considering mimesis and mimetic design. Throughout this work, other research areas relevant to mimetic design continue to appear and interest me as an instrument designer. Notably, the areas surrounding 4E cognition might help explain the processes of mimetic cognition further, and research into liveness could provide an additional framework to understand and measure audience engagement. The addition of other research will only strengthen mimetic theories and design and facilitate the improvement in the understanding and development of the mimetic design principles.

Future research will aim to include these ideas into the mimetic design framework. To further this research, additional test phases comparing the three BazerBows would illuminate my evaluation of them, particularly the second BazerBow (Section 6.3.3). Unfortunately, this prototype was not as mimetically successful, and the initial response was not as enthusiastic as the first. Therefore, it would be interesting to explore and confirm why this may be the case. Also, once I have developed a production-ready BazerBow, that fully conforms to the current mimetic design principles, I intend to reproduce it and make it available to a broader music community. Ideally, a range of musicians from different backgrounds will engage with composing and performing to create and compose with the BazerBow, producing longer musical performances to present to the public and larger audiences. The testing procedures and methods would need adjusting to accommodate these performance scenarios, but the data would provide a deeper exploration of the mimetic design principles. However, I designed the BazerBow to perform music and engage audiences with electronic compositions and performances. Therefore, I intend to move from the more formal testing to the practical use of the BazerBow and music performances, which will become more prominent in my future research.

Answers to Research Questions

So I end this PhD thesis by reiterating the research questions (Section 2.4), providing the answers from my lines of enquiry.

Mimetic Theories

- Q. Could further theories be found to help understand the processes of mimetic cognition facilitating mimetic design? (Section 3.5).
- A. Delving further into mimetic cognition (Section 3.1), I found that the areas of action understanding, communicative musicality and empathy helped explain and extend the exploration of mimetic concepts, particularly aligning with the mimetic mechanisms of engagement (Section 3.2), invitation (Section 3.3) and participation (Section 3.4), respectively.

Digital Musical Instrument Design

- Q. Which existing general DMI concepts are important to mimetic instrument design, and what are the common issues that DMI designers attempt to address? (Section 4.5).
- A. The main general areas of DMI design important to my design process were the concepts of gesture (Section 4.3.1), affordance (Section 4.3.2) and appropriation (Section 4.3.3). The important issues of DMI design to me as an instrument designer and that I experienced as a music practitioner were audience engagement (Section

4.4.1), aesthetics and expression (Section 4.4.2), longevity and popularity (Section 4.4.3).

Mimetic Design

- Q. Which design considerations are most important to mimetic design? (Section 5.3).
- A. I conceptualised the main issues I was attempting to address with the three I's (Section 5.1), formulating the concepts of mimetic design to redress these problems. In considering mimetic and DMI theories, I developed the three design concepts of mimetic gesture (Section 5.2.1), mimetic affordance (Section 5.2.2) and mimetic appropriation (Section 5.2.3), and the complementary mimetic design strategies of the mimetic gestural matrix (Figure 5.1), the mimetic affordance mapping (Figure 5.2) and the mimetic appropriation pyramid (Figure 5.3).

Prototyping of BazerBows

- Q. Do these prototypes incorporate the intended concepts of mimetic design, and how can they be further improved? (Section 6.4).
- A. The first prototype, when upgraded (Section 6.3.2), exhibited concepts of mimetic design. However, the second prototype (Section 6.3.3) was not as successful, requiring adjustments to the design and manufacturing process. The third BazerBow (Section 6.3.4) remedies some of the issues found in the second but identifies areas for future development. Whilst improving the aesthetic size issues of the second, this third prototype aimed to incorporate the successful elements of the first BazerBow. Additional aspects of mimetic design were identified and will be explored on a journey towards a production-ready instrument, particularly the incorporation of inter-modal gestural elements. In addition, by definition, delighter features constantly change and, therefore, continually need to be explored with future BazerBow designs.

Examination of Prototypes

- Q. Does the mimetic prototype possess mimetic potential and therefore provoke a mimetic response from an audience? (Section 8.7.4).

- A. The testing phase enabled comparisons between the audience's mimetic response to the BazerBow and keyboard. All the data pointed towards the BazerBow invoking a greater mimetic response, proving that the mimetic design principles effectively imbued the BazerBow with mimetic potential. The evidence from both anecdotal experiences (Section 8.6) and the testing phase data show a positive mimetic response for all the three areas of exploration, namely involvement (Section 8.7.1), invitation (Section 8.7.2) and inclusion (Section 8.7.3).

Mimetic Design Principles	**Mimetic Gestures**	**1**	Balance of size and type of gestures.
		2	Balance of simple direct and layered, goal-oriented (non-normative mimetic) gestures.
		3	Gestures should be observable and musically significant, limiting sound dislocation.
	Mimetic Affordance	**4**	Balance of transparent and multi-parametric mapping.
		5	Consideration of aesthetics and inter-modality in the design, materials, and finishing.
		6	Balance of functions: essential functions, intuitive control, customisable controls, hidden functions and prevented functions.
	Mimetic Appropriation	**7**	Capable of a range of styles and playing scenarios. Simple to approach, complex in mastery.
		8	Capability of allowing performance errors but no system errors.
		9	Inclusion of mimetic “delighter” features to Mencourage the instrument to be “used”.

Figure 9.2: Mimetic Design Principles—2021

These five questions feed a line of enquiry that has facilitated the formulation and continual improvement of the mimetic design principles through an iterative process of development, evaluation and exploration. A current representation of these mimetic design principles is presented in Figure 9.2. Thus mimetic design principles developed as part of this research provide an additional supplementary method to evaluate, classify and design digital musical instruments. The integral focus of these principles, from the audience perspective, furnishes a framework to redress the quandary of the often overlooked spectator in current design (Barbosa, Calegario, et al., 2012; Wu et al., 2016; Lai and Bovermann, 2013).

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Appendix A

Discussion of Current Developments in MIDI

The Musical Instrument Digital Interface (MIDI) (MIDI Association, 2021) was first introduced in the early 1980's as a means to connect separate digital music devices together allowing data to be transferred between the devices. MIDI is the most common connection between digital devices due to the universal compatibility it provides, despite limitations in the MIDI 1.0 protocol. MIDI includes note related data such as note on/off, pitch, velocity (volume) of the note, pitch bend and modulation as well as a range of customisable continuous controllers (CC), some of which have become standardised over time.

The controls for modulation, sustain and expression are the most common of these CCs and are found on many commercial DMIs. A control wheel or joystick for modulation control is usually positioned next to a pitch bend wheel. The MIDI modulation specifically sends data to MIDI CC01 which is commonly recognised by sound generators and is mostly mapped to vibrato and tremolo effects and filter frequencies in synthesisers. The sustain and expression controls are sent to MIDI CC64 and CC11 respectively and are usually presented as sockets for the connection of pedals. This allows keyboard based DMIs to utilise the pedals similarly to a piano. There are a possible 128 CCs in total. Although many of them are defined in the MIDI 1.0 protocol they are not readily recognised by many sound generators or synthesisers. Implementing these extra controls requires custom mapping which varies depending on the devices being used.

The MIDI protocol has remained the same without much alteration for many years, which has led to very good compatibility and standardisation. More recently the limitations of the original MIDI protocol have become more apparent with the introduction of newer digital music technologies. The Open Sound Control (OSC) (OpenSoundControl, 2021) protocol attempts to remedy some of these issues but has not really made any inroads into replacing MIDI.

Pitch bend control as well as most of the other continuous controllers are applied to all notes that are being played. This restriction led to the development of MIDI polyphonic expression (MPE) which allows the controls to be applied individually to each note being played, similar to the pitch bend of a single string on a guitar. Several new DMIs have taken advantage of MPE creating devices with more complex gestural inputs that can be mapped to individual notes. However the sound generator must recognise the MPE protocol to function and is not yet widely implemented.

With new sensor technologies the gestural input of new DMIs would benefit from greater data resolutions than MIDI 1.0 provides. Low MIDI data resolutions cause the raw gestural data to be reduced. The MIDI 1.0 protocol transmits data packets that allow continuous controller data resolution of 7 bits (0 to 127) ranges. There are exceptions the most common being pitch bend which has a resolution of 14 bits (0 to 16383). The new MIDI 2.0 protocol was released in January 2020. It improves many of the issues found with MIDI 1.0. Although it incorporates MPE it also includes a more elegant solution to polyphonic expression and increases the resolution of all data dramatically allowing sensors to be more accurately mapped and tracked to individual notes. It also includes an extensive protocol for backwards compatibility ensuring that all MIDI 1.0 devices will work with MIDI 2.0 devices.

It is likely that this will become the new standard technology for connection and mapping of new DMIs, especially due to the backwards compatibility which is crucial for longevity of new DMIs. MIDI 2.0 provides a framework for development of new and complex multi-gestural DMIs with individual and simultaneous control over sounds. This new protocol provides a basis for complex connections and mappings of DMIs whilst ensuring consistency over time, facilitating longevity for device compatibility.

Despite the progress in MIDI and other digital technologies DMI designers must not forget the history of instrument design in general and the aspirations and desires of musicians and music audiences. A balance needs to be found between technological capabilities and musical possibilities. Musical issues that digital technologies present must be addressed, whilst understanding the issues of the past, to successfully incorporate digital technology into something musically involving, inviting and inclusive.

Appendix B

MGM Evaluations

This appendix contains the mimetic gestural matrix evaluations for the guitar, keyboard and BazerBow prototypes.

Mimetic Gestural Matrix Guitar (Yamaha ERG121)		Gestural Size		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Plucking gesture of right hand.	Movement of left hand over fret board.	Exaggerated strumming gestures can be reasonably large.
	Modulating	Bending strings for pitch bend an vibrato effects on individual strings.	Whammy bar movement creating pitch bend and vibrato on all strings simultaneously.	Plucking gesture of right hand.
	Inter-modal	Ancillary movements of hands and fingers.	The guitar body can be moved to highlight the initial or modulating gestures or independently.	Mobility of guitar provides freedom of movement for player. Exaggerated large movements of the arm to emphasise plucking/ strumming.

Figure B.1: MGM Evaluation of Electric Guitar

Mimetic Gestural Matrix Ozonic Keyboard		Gestural Size		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Pressing of keys with fingers.	Movement of hands over keyboard. This is limited as the keyboard only has 37 keys.	None.
	Modulating	Keyboard aftertouch. Pitch/Modulation wheels. 8 knobs, 9 sliders, 9 buttons and X/Y joystick.	Use of pedal.	None.
	Inter-modal	Ancillary movements of hands and fingers.	The keyboard is limited as it is fixed. Potential to exaggerate playing gestures with larger arm movements.	Potential to exaggerate playing gestures with larger arm movements, but the keyboard is not mobile so large, intermodal gestures are limited.

Figure B.2: MGM Evaluation of Keyboard

Mimetic Gestural Matrix BazerBow 1		Gestural Size		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Note initiation by pressing string with right hand.	Movement of left hand over fretboard to select pitch.	None.
	Modulating	Pressure sensors activate pitch bend and modulation.	Proximity sensor under right hand.	X/Y motion sensor requiring the whole instrument body to be moved.
	Inter-modal	Ancillary movements of hands and fingers.	The BazerBow body can be moved to highlight other gestures but this movement will also be detected by the motion sensor.	Mobility of the BazerBow provides freedom of movement.

Figure B.3: MGM Evaluation of Prototype 1 (Original)

Mimetic Gestural Matrix BazerBow 1 (Upgraded)		Gestural Size		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Note initiation by pressing string with right hand.	Movement of left hand over fretboard to select pitch.	None.
	Modulating	Pressure sensors activate pitch bend and modulation.	Proximity sensor under right hand.	X/Y motion sensor requiring the whole instrument body to be moved.
	Inter-modal	Ancillary movements of hands and fingers.	The BazerBow body can be moved to highlight other gestures but this movement will also be detected by the motion sensor.	Mobility of the BazerBow provides freedom of movement.

Figure B.4: MGM Evaluation of Prototype 1B (Upgraded)

Mimetic Gestural Matrix BazerBow 2		**Gestural Size**		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Note initiation by pressing string with right hand.	Movement of left hand over fretboard to select pitch.	None.
	Modulating	Pressure sensors activate pitch bend and modulation. Small pressure/position sensors for right hand thumb movement.	Proximity sensor under right hand. Large pressure/position sensors for left hand movement.	X/Y motion sensor requiring the whole instrument body to be moved.
	Inter-modal	Ancillary movements of hands and fingers.	The body can be moved, but the larger size makes it more awkward than the previous BazerBow. Includes buttons with indicator LEDs.	Mobility of the BazerBow provides freedom of movement.

Figure B.5: MGM Evaluation of Prototype 2

Mimetic Gestural Matrix BazerBow 3		**Gestural Size**		
		Small	**Medium**	**Large**
Gestural Type	**Initial**	Note initiation by pressing string with right hand.	Movement of left hand over fretboard to select pitch.	None.
	Modulating	Pressure sensors activate pitch bend and modulation.	Proximity sensor under right hand.	X/Y motion sensor requiring the whole instrument body to be moved.
	Inter-modal	Ancillary movements of hands and fingers.	The BazerBow body can be moved to highlight other gestures but this movement will also be detected by the motion sensor.	Mobility provides freedom of movement. Various possibilities of inter-modality are being considered, such as LEDs, connected video technologies and lighting to highlight smaller gestures.

Figure B.6: MGM Evaluation of Prototype 3

Appendix C

MDP Evaluations of Guitar and Keyboard

This appendix contains the mimetic design principle evaluations for the guitar and keyboard.

Electric Guitar			Yamaha ERG121
Mimetic Design Principles	**Mimetic Gestures**	**1**	Good range of gestures. Encourages inter-modality. Mobility encourages movement.
		2	Good direct gestures. Limited layered gestures.
		3	Forward facing therefore good visibility of gestures.
	Mimetic Affordance	**4**	N.A.
		5	Built with different woods and metals and finished.
		6	Essential functions and intuitive control but not easily customised, no hidden feature.
	Mimetic Appropriation	**7**	Very flexible playing.
		8	Very reliable but requires skill to avoid performance errors.
		9	Good basic and performer features but no specific delighter features.

Figure C.1: Guitar Evaluation

Keyboard Controller			M-Audio Ozonic
Mimetic Design Principles	**Mimetic Gestures**	**1**	Requires only small gestures for the majority of control.
		2	Direct gestures connected with keyboard. Extensive range of controls provides potential for goal-oriented gestures, but limited by gestural size.
		3	Upward facing orientation and small gestures limit observability. Very limited mobility and movement of device.
	Mimetic Affordance	**4**	Excellent balance of fixed transparent mapping of keyboard with custom options for multi-parametric mapping.
		5	Plastic materials potentially inhibit mimetic cognition.
		6	Excellent balance of functionality. Customisation can be a little complex.
	Mimetic Appropriation	**7**	Capable of flexible playing and access to unlimited sounds.
		8	Reliable but allowing performance errors. The complexity of the mixture of system and performance controls can lead to accidental system errors.
		9	Good balance of basic and performer features. Although there is an extensive range of controls there is nothing that could really be considered as a delighter feature.

Figure C.2: Keyboard Evaluation

Appendix D

Pre-Test Questionnaires

This appendix contains the original questionnaires used during the pre-test phase.

Pre-Test Demographic and Music Experience Questionnaire

SLIDER NUMBER	
1. Name	
2. Gender	
3. D.O.B.	
4. Do you play an instrument on a regular basis?	
A. Which instrument(s)?	
B. How long have you played this instrument(s)?	
5. Have you taken music instrument lessons?	
A. which instrument(s)?	
B. How long have you had lessons?	
6. Do you listen to music regularly?	
A. How often?	
B. Which genres of music?	
7. Do you partake in any group music activities such as a choir or band?	
A. What kind of activity?	
B. How often?	
8. Do you attend live musical performances?	
A. What type of performance?	
B. How frequently?	
9. Do you earn any income from musical activity/ performance?	
A. What kind of activity/performance?	
B. How often?	
10. Do you partake in or experience any other musical activities such as dancing/dance performance etc..	
A. What type?	
B. How often?	

Figure D.1: Pre-Test Demographic and Music Experience Questions

Pre-Test BazerBow Identity Questionnaire

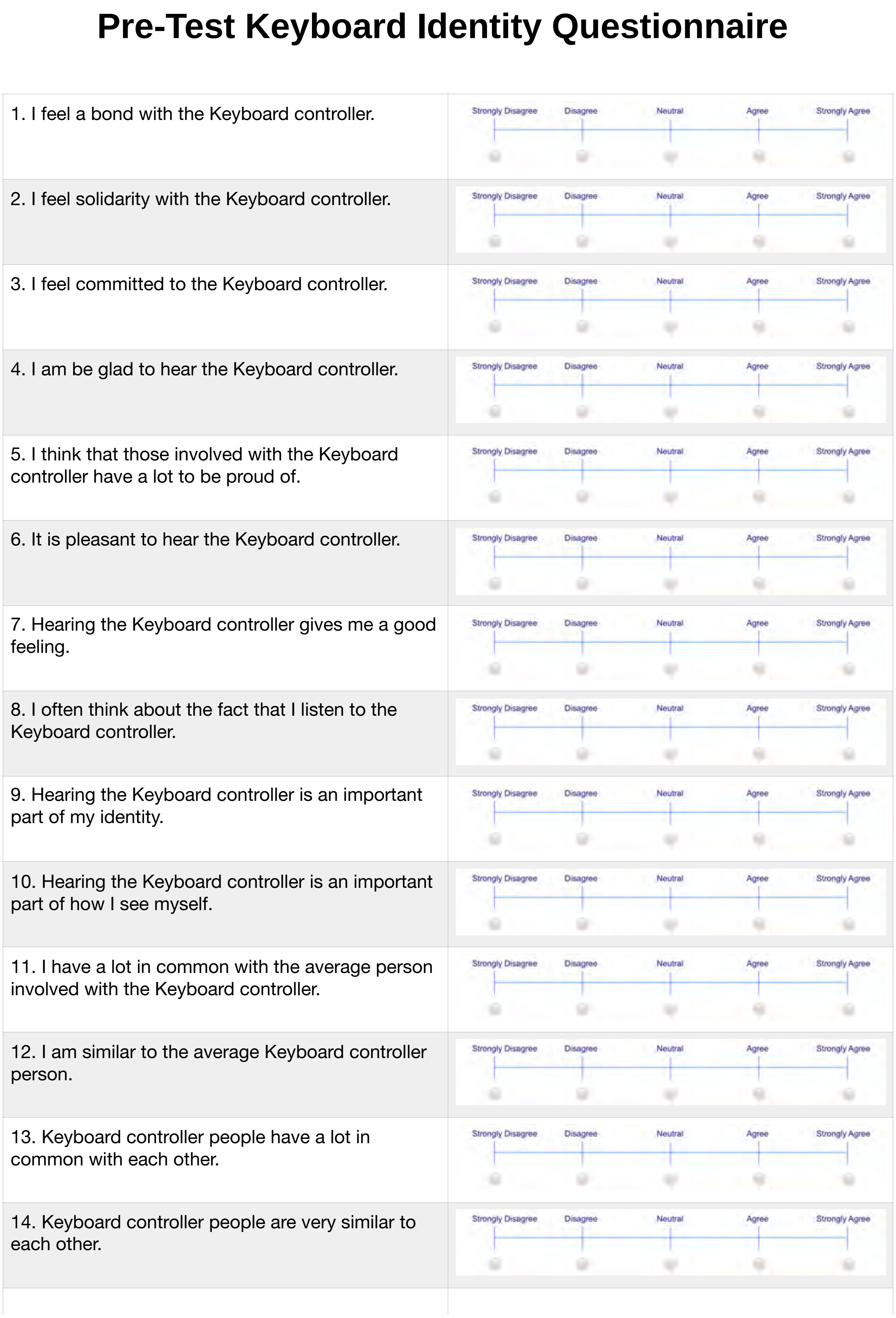
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel a bond with the Mimetic controller.					
2. I feel solidarity with the Mimetic controller.					
3. I feel committed to the Mimetic controller.					
4. I am be glad to hear the Mimetic controller.					
5. I think that those involved with the Mimetic controller have a lot to be proud of.					
6. It is pleasant to hear the Mimetic controller.					
7. Hearing the Mimetic controller gives me a good feeling.					
8. I often think about the fact that I listen to the Mimetic controller.					
9. Hearing the Mimetic controller is an important part of my identity.					
10. Hearing the Mimetic controller is an important part of how I see myself.					
11. I have a lot in common with the average person involved with the Mimetic controller.					
12. I am similar to the average Mimetic controller person.					
13. Mimetic controller people have a lot in common with each other.					
14. Mimetic controller people are very similar to each other.					

Figure D.2: Pre-Test BazerBow Identity Questions

Pre-Test BazerBow Questions

15. I would like to play ("have a go") of the Mimetic controller…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree
16. I found the performance on the Mimetic controller engaging…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree
17. I find the Mimetic controller visually appealing…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree

Figure D.3: Pre-Test BazerBow Questions



Pre-Test Keyboard Identity Questionnaire

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel a bond with the Keyboard controller.					
2. I feel solidarity with the Keyboard controller.					
3. I feel committed to the Keyboard controller.					
4. I am be glad to hear the Keyboard controller.					
5. I think that those involved with the Keyboard controller have a lot to be proud of.					
6. It is pleasant to hear the Keyboard controller.					
7. Hearing the Keyboard controller gives me a good feeling.					
8. I often think about the fact that I listen to the Keyboard controller.					
9. Hearing the Keyboard controller is an important part of my identity.					
10. Hearing the Keyboard controller is an important part of how I see myself.					
11. I have a lot in common with the average person involved with the Keyboard controller.					
12. I am similar to the average Keyboard controller person.					
13. Keyboard controller people have a lot in common with each other.					
14. Keyboard controller people are very similar to each other.					

Figure D.4: Pre-Test Keyboard Identity Questions

Pre-Test Keyboard Questions

15. I would like to play ("have a go") of the Keyboard controller…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree
16. I found the performance on the Keyboard controller engaging…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree
17. I find the Keyboard controller visually appealing…	Strongly Disagree · Disagree · Neutral · Agree · Strongly Agree

Figure D.5: Pre-Test Keyboard Questions

Pre-Test Post Performance Questionnaire

(i) Which do you think was more suited to the types of sound being played?	
(A) the Mimetic controller or (B) the Keyboard controller?	A B
(ii) If you could only play one which would you choose?	
(A) the Mimetic controller or (B) the Keyboard controller?	A B
(iii) What was your favourite/most memorable moment from:	
(a) the Mimetic controller…	
(b) the Keyboard controller…	
(iv) Describe your experience of:	
(a) the Mimetic controller…	
(b) the Keyboard controller…	
(v) How would you describe:	
(a) the Mimetic controller…	
(b) the Keyboard controller…	

Figure D.6: Pre-Test Post Performance Questions - Page 1

(vi) Do you have any further comments?	

Figure D.7: Pre-Test Post Performance Questions - Page 2

Appendix E

Main Test Demographics Questionnaire

This appendix contains the modified demographic questionnaire.

Mimetic DMI Demographic Questionnaire

Page 1: Welcome to the Mimetic Digital Music Instrument Research.

1. Today's date Required

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

2. Please enter your slider number here: Required

Page 2

3. Age

- Under 11 years old
- 11 - 17 years old
- 18 - 24 years old
- 25 - 34 years old
- 35 - 44 years old
- 45 - 54 years old
- 55 - 64 years old
- 65 - 74 years old
- 75 years or older

4. Gender

- Female
- Male
- Other

Page 3

5. Education: What is the highest degree or level of school you have completed? If currently enrolled, highest degree received.

- No qualification
- Primary school
- GCSEs or equivalent
- A Level or equivalent
- Higher education
- Degree or equivalent
- Masters degree or equivalent
- Doctoral degree
- Other qualifications
- Don't know

6. Income: How would you describe your income level?

- For my age group, below average UK income
- For my age group, average UK income
- For my age group, above average UK income
- Not applicable/Unsure

Page 4

7. Employment: What is your employment status?

- [ ] Self-employed part-time
- [ ] Self-employed full-time
- [ ] Part-time employment within organisation/company
- [ ] Full-time employment within organisation/company
- [ ] Retired
- [ ] Volunteer
- [ ] Unemployed

Thank you for completing this questionnaire.

Appendix F

Main Test Performance Questionnaire

This appendix contains the main test questions 1 to 11.

Mimetic Digital Musical Instrument Research

Page 1: Welcome to the Mimetic Digital Music Instrument Research.

1. Today's date Required

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

2. Please enter your slider number here: Required

Page 2: Please answer these questions after seeing the BazerBow performance.

3. After having seen the BazerBow performance please answer the following questions: Required

Please don't select more than 1 answer(s) per row.

Please select at 5 answer(s).

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
I would like to "have a go" of the BazerBow...	⬭	⬭	⬭	⬭	⬭
I found the performance on the BazerBow engaging...	⬭	⬭	⬭	⬭	⬭
I found the BazerBow visually appealing...	⬭	⬭	⬭	⬭	⬭
I can imagine playing the BazerBow...	⬭	⬭	⬭	⬭	⬭
I would like to "join in" with the BazerBow performance (playing another instrument/singing/dancing/"air guitar"/moving etc)...	⬭	⬭	⬭	⬭	⬭

Page 3: Please answer these questions after seeing the Keyboard performance.

4. After having seen the Keyboard performance please answer the following questions: Required

Please don't select more than 1 answer(s) per row.

Please select 5 answer(s).

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
I would like to "have a go" of the Keyboard...					
I found the performance on the Keyboard engaging...					
I find the Keyboard visually appealing...					
I can imagine playing the Keyboard...					
I would like to "join in" with the Keyboard performance (playing another instrument/singing/dancing/"air guitar"/moving etc)...					

Page 4: Please answer these questions after seeing both performances.

5. Have you experienced the BazerBow before? Required

⬭ Yes	⬭ No

6. Have you experienced a MIDI controller keyboard before? Required

⬭ Yes	⬭ No

7. Please answer the following questions: Required

Please don't select more than 1 answer(s) per row.

Please select 2 answer(s).

	Keyboard	Mostly Keyboard	Both	Mostly BazerBow	BazerBow
Which do you think was more suited to playing the types of sound you heard?	⬭	⬭	⬭	⬭	⬭
If you could "have a go" which would you choose?	⬭	⬭	⬭	⬭	⬭

8. What was your favourite/most memorable moment from:

	Required
the BazerBow	
the Keyboard	

9. What do you find most interesting about:

	Required
the BazerBow	
the Keyboard	

10. How would you describe the:

	Required
the BazerBow	
the Keyboard	

11. Please add any further comments here:

Thank you for taking part in this research.

Appendix G

MUSE Questionnaire

This appendix contains the MUSE questionnaire developed by Chin and Rickard (2012).

Medicine, Nursing and Health Sciences

MUSE Questionnaire

MONASH University

M8Alliance

Australia ▪ Malaysia ▪ South Africa ▪ Italy ▪ India ▪ China

SECTION A

You and Music

Please tell us about how you use music.

Instructions

- Read each statement carefully; and
- Tick the box that describes you best.

1. On average, how often do you listen to music in a week?	☐ Less than once a week ☐ 1 – 2 times a week ☐ 3 – 4 times a week ☐ 5 – 6 times a week ☐ More than 6 times a week
2. On average, how many hours do you **purposely** listen to music a day (as opposed to music in the environment that you have no control over (e.g., music in cafes, stores)?	☐ Less than 1 hour per day ☐ 1 – 2 hours per day ☐ 3 – 4 hours per day ☐ 5 – 6 hours per day ☐ More than 6 hours per day
3. Have you played / do you play a music instrument (includes singing, practice, and performance)?	☐ No (please proceed to question 6) ☐ Yes, I've played a music instrument for ☐ years (please continue on to question 4)
4. At the peak of your interest, how many hours per day did you play/practise the music instrument (includes singing)?	I played/practised ☐ hours per day (please fill in the hours of practice)
5. How long since you last regularly played a music instrument (includes singing, practice, and performance)?	☐ Less than a week ago ☐ Less than a month ago ☐ Less than 1 year ago ☐ Between 1 and 5 years ago ☐ Between 5 and 10 years ago ☐ More than 10 years ago
6. What is the highest level of **formal** music training you have received?	☐ None ☐ Primary (Elementary) school music classes ☐ Secondary (High) school lessons ☐ Tertiary (University) undergraduate training, Conservatory of music or master classes ☐ Postgraduate training, or advanced overseas training

SECTION A

7. What other type of music training did you receive?	☐ None ☐ Self-taught (no formal training) ☐ Private (Individual) music classes/tuition ☐ Group music classes/tuition
8. Have you completed AMEB (or equivalent such as ABRSM) music examinations?	☐ No ☐ Yes, I have completed up to Grade ☐ for both Theory and Performance/Practical (please fill in the highest Grade you have completed)

Thank you. Please turn page over for the next section.

SECTION B

Please tell us about your level of participation with music activities by circling the number that describes you best

Instructions

Please respond to all the statements. It is important to us that you consider each question carefully. If unsure about which response to give, please choose the one that appears most appropriate. This can often be your first response.

Example

	Not applicable to me	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I often listen to new compositions	0	1	2	3	4	5

If you agree with the above statement, you would circle the number 4. If you strongly disagree with the above statement, you would circle the number 1. If the above statement does not apply to you, you would circle 0.

SECTION B

Please read each statement and circle the number that best describes you

	Not applicable to me	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
9. Music is often a source of inspiration for me	0	1	2	3	4	5
10. I often play challenging pieces	0	1	2	3	4	5
11. There is a greater connection with my friends when we like the same music	0	1	2	3	4	5
12. Music provides me with a good pace for exercising	0	1	2	3	4	5
13. Music often takes away tension at the end of the day	0	1	2	3	4	5
14. Performing music is emotionally rewarding for me	0	1	2	3	4	5
15. I often listen to new compositions	0	1	2	3	4	5
16. I often look forward to attending music practices with my friends	0	1	2	3	4	5
17. Certain type of music helps me think	0	1	2	3	4	5
18. Mastering this piece of music gives me greater recognition as a performer	0	1	2	3	4	5
19. Having similar taste in music often helps me relate better to my peers	0	1	2	3	4	5
20. Dance is an expression of my feelings	0	1	2	3	4	5
21. I often listen to music when I'm feeling down	0	1	2	3	4	5
22. I often get recognition from my friends for playing in the band	0	1	2	3	4	5
23. I am able to make more friends when we like the same type of music	0	1	2	3	4	5
24. Listening to music whilst exercising often helps me exercise for longer	0	1	2	3	4	5

Appendix H

Video Transcriptions

This appendix contains all the raw video transcripts (using Otter.ai), for all the test sessions.

TEST-1a-MP3 @ 128kps_otter.ai (1)

Speaker 1	0:00	Have you got any further comments?
Speaker 2	0:07	On the Bazerbow, there's obviously something completely different that keyboard you can ? a thousand times with it That share with people who might more interesting...
Speaker 3	0:20	that interests me in terms of what if you could add that to guitar to have a controllable effect with guitar
Speaker 1	0:29	That may be something that might be coming in the future, is that right for you Phil, well, obviously, part of the research is looking at air guitar, because people predominantly if they're going to imitate an instrument imitating guitar, not a keyboard, you occasionally get them imitating drums and things, but it's usually guitar so there's something in the gestures that are quite big and draw people in, which is why I started with a guitar shape. But for further research I could explore other shapes as well. Because you are not, actually, because of the technology, you're not really restricted to the shape, you can have any shape you want. I mean, there are instruments out there in research where you've got like a ball or you know, different shapes. But it it then is how does that relate to the sound? So because it's guitar shaped, you've at least got a starting point. You think well, it's a bit like a guitar.
Unknown	1:27	feel better
Speaker 3	1:27	is using his hands as opposed...The Theremin...
Speaker 2	1:33	Are the two linked in anyway,
Speaker 1	1:35	the two, this one and this?
Speaker 2	1:36	No the Theramin and that?
Speaker 1	1:40	The Theramin actually produces the sound. It's not a MIDI controller it produces an electric sound, and that's put into an amplifier. And it detects through magnetic forces where your hand is electromagnetic force. That's what you call electric instrument I guess rather than being electronic.
Speaker 2	2:01	At the bottom there Phil that says specifically digital
Speaker 4	2:04	Do you want to push these down to the bottom now. No that's all right. See the two holes at the bottom,
Speaker 3	2:11	You can recognising how far your hand is from it.
Speaker 1	2:14	Yeah, it's got a sensor inside Like your phone. Same one in your phone. So you see Yeah, it's on your phone, its got the same sensor inside. Now the other question is what do you want to have ago?
Speaker 4	2:26	Yeah..you go first cause I'm intrigued.
Speaker 1	2:32	Let me u'm
Speaker 2	2:34	do you want to test group two before you have a ago.
Speaker 1	2:36	No. We might as well do it now while you're here, do you know what I mean, because I've got to reset everything on the computer anyway. So I've got a demo set of sounds that might....
Speaker 4	2:48	be up your street
Speaker 1	2:50	well probably not because they are all synthetic obviously with the computer you can produce a piano sound a guitar sound whatever you want I was specifically looking at digital sound
Speaker 3	3:06	This is more my favourite instrument
Speaker 4	3:09	I love that you're resting it on your knee like its a guitar
Speaker 3	3:14	You've got no fret markings.
Speaker 1	3:15	That's for me because he keeps me some of them do this pressure sensitive. Distance sensitive But I don't ??????? distance I can do you find the distance will...position will.. the left hands the pressure switch. pitch bend with the left hand. Press it..pressure The reason its making a funny noise is because your fingers on as it were the middle of the note Okay.
Speaker 3	4:12	because on a guitar you're in the middle of the fret. Okay.
Speaker 4	4:12	I feel like its not going to happen.
Speaker 1	4:24	This is where the other sounds come in though.....like that sound? got some interesting effects for that because it's got motion sensor
Speaker 3	4:46	I saw the thing is yeah
Speaker 2	5:12	it's surprisingly hard It's playing.
Speaker 1	5:14	Yeah, that was one of the design features actually is if you get say Guitar Hero is a very simple thing to use and after a few months but with something that's more complicated difficult to play you have to spend a long time practising.
Speaker 4	5:31	I don't ?????? Guitar Hero - I love Guitar Hero
Speaker 1	5:37	try with a melodic sound first.
Speaker 4	5:40	Suggest ????????
Speaker 1	5:43	Yeah, you don't press the left side, just the right side to trigger the sound like as if you're plucking a string
Speaker 4	5:49	I was working out my left from right - O look I'm playing bass.
Speaker 1	5:52	BaserBow. The Baser bit of it is because it's a base.
Speaker 4	5:57	It doesn't matter where you press it on this slide. No, but it does sense where you're hand is. It's changing different ??? Sometimes you can hear what it is, sometimes its too subtle to hear what its doing. No I still can't, I can't make out. How did you hold it..
Speaker 1	6:44	You can hold it however you want.
Speaker 4	6:48	I want to hold it like this.
Speaker 1	6:50	You can do That's the question for DJ's and that kind of thing, they press buttons on a computer but is it performing? ???????????

Speaker 4	7:19	O I think you could pick it up. I think it'd be easier than you think to pick it up. have you got used to how it works. I don't sense sorting it like this.
Speaker 2	7:26	Im playing it between the notes all the time because I probably do on the guitar
Speaker 4	7:29	So I'm saying that but if you look at the way the frets are marked it goes in a line, yeah,
Speaker 2	7:34	yeah. But then you ???frets on a guitar
Speaker 4	7:36	know, I know that's why I'm saying but because when I think about if you do the same with the base, but in the grand scheme of things,
Speaker 2	7:42	you're playing on the line, I'm naturally drawn to here in the middle and I know
Speaker 1	7:46	it works in the middle
Speaker 2	7:47	does it oh not on the line yeah.
Speaker 1	7:49	but I'm not sure I'm accurate and pencil marks were because it was a kind of wait a minute, stick. Yeah.
Speaker 4	7:56	Do you want a go?
Speaker 3	7:58	No I think You've destroyed our eardrums already.
Speaker 1	8:05	Some people do, some people don’t.
Speaker 4	8:07	I enjoyed it.
Speaker 1	8:09	I took it to a retirement party and this, the mother was in her eighties had never played an instrument in her life and she had a go and she was like this over her head. But a guitarist will generally pick it up like a guitar but this ladywho had never played a guitar thought O this is good..
Speaker 3	8:26	and drummers will (swish, swish)
Speaker 1	8:29	You can get it to trigger sounds by a hitting motion because it's digital. You can do almost anything you want with it.
Speaker 3	8:39	Are you getting it into drumsticks.
Speaker 1	8:39	You can kind of get air drumsticks
Speaker 4	8:46	there are already electric drum kits out there they can do, the work with motion, whereas If you wham it hard you really don’t push it
Speaker 1	8:55	Well that’s the thing isn’t it that’s the perception for performance. What is cheating, what's not everything I played that was actually played. But when I've used it before, I have used layers and loops, which isn't really that completely perception of what's happening,
Speaker 4	9:09	I think as well, something like that. And it sounds silly, but it's all relative to what space you’ve got I've got a friend that practices on an electric drum kit because he’s got nowhere to put his drumkit so he just plays electric to practice.
Speaker 3	9:20	My point is from someone looking from outside, who doesn't understand music and potentially I can look at someone playing the electric drums and go He could have done that before hand then just be doing that.
Speaker 1	9:30	Exactly. Yeah, yeah. When I first performed with electronic drums in 99 1999. And because they were relatively unheard of, the performance, everybody said You sound great. But we thought you were miming saying because the sound was coming out of the PA Yeah, and from me there was just this little tippy top and it just didn't sound right it sounded wrong but now people..I have got,had a student I used to teach and he's using his electronic kit all the time. People don't, they’ve got used to it. Some things you can...
Speaker 3	10:04	The Ed Shearan thing with doing loop pedals, I haven’t used my pedal for years, and then he does it and he has some complaints because he's miming to a backing track but he’s not miming he’s recording it live looping it which is which is a talent in itself and he only has to make one mistake I know you can do it on on his setup or delay your music and make it sound while you are massive band behind you. And it's just you doing all the parts. And then people going its all a mime.
Speaker 1	10:36	But again, it's all about perception, isn't it? If someone perceives it as being a mime, the that’s what theyll believe it is.
Speaker 3	10:38	I saw Bill Bailey looped... people laughed when he looped. Yeah, they thought he was miming. Yeah, that was my interpretation of it. But as soon as he stopped playing, and he looped it, and nobody knows he looped it, and then he stopped playing and people thought it was a joke. Because he was because he because the music carried on playing and he didn’t and people laughed and it was not a bit where you're supposed to laugh. It was a bit he was just about to start doing something else from playing over the backing track. But people laughed because they thought it was part of the bit that was him faking.
Speaker 1	11:13	This is the interesting thing for me with the research isn't which is better. It's just different things and the perception of it and use that for one particular situation. Maybe use the Baserbow for something else. One of the things the other thing is though, if you are playing this you might have found I was stretching. Yeah, and it was difficult, because I've only got two hands and I've had actually had to add a foot pedal. Well, that does the whole control in one go. Which makes it more complicated to play but you can access more control the setup, you can see there the eight knobs on the synthesiser and there’s eight knobs, generally how they build them. But there's no way you can do all eight of those.
Speaker 4	11:56	Yeah,
Speaker 1	11:57	I've got an updated version of that, that will do all eight of those at the same time. And it's got four strings. But that's much more complicated to play. Hence the base is it was it was meant to have four strings but with this being the first one I kept it simpler.
Speaker 4	12:18	I assume essentially although you've pencilled on could you if you want to reprogram that could you?

Speaker 1	12:23	You can have the notes anywhere you want not even in order. You can have it chromatic as well because that sensor isn't segmented. Which is interesting for some research because I don't know if you watched Red Dwarf where the computer guy wants to write music it with a scale of 10 notes instead of eight. And it's supposed to be funny, which it is until you realise people are actually writing in those scales. So I met a gentleman who writes 19 notes so where these go up in semitones his goes up in slightly differing and that kind of thing can play that but obviously this couldn't because its a bit.... singings a nightmare, he has to get get people from the Middle East apparently they were indigenous music. They can pitch between the notes, but we can't. We're so used to semitones so you know. I'm very grateful. Thank you very very much I have brought Beer and chocolate and stuff - it's not much. Was it? Was it all straight forward in the end?
Speaker 4	13:46	Yeah. It starts to make more sense - the second bit I mean.
Speaker 1	13:52	Yeah. It looks complicated.
Transcribed by https://otter.ai		

TEST-1b-MP3 @ 128kps_otter.ai (1)

Speaker 2	0:01	Yeah, so it's interesting. I've not actually thought about it before, when you just got two things and two different shapes or whatever. And then you get a different perception of the day to live. I'm saying it's a good point.
Speaker 1	0:14	They are becoming more and more prolific, I think, because the speed in which the data is transfered is usable now, where when they first came out there was obviously latency, and it's no good when you're trying to play as a musician, the latency is relatively low. Now. You can cope with that.
Speaker 2	0:35	I'm trying to remember the one in the 30's, the Germans invented I'm sure wasn't Hitler into like, it was like electronic one that I can't remember what it was called now (there's a Theremin) it's s not the Theremin I'm trying to think what it's called but he quite liked it in terms of ??????? And forget is it similar as.....
Speaker 1	1:03	Germans were and still are into experimental electronic with a Kraftwerk and they've done deliberately shows where they have had the laptop set up, being playing and then walked off to the bar. And they still are playing. Because this kind of suggesting what is a performance, is it us stood here with a laptop, because we don't need to be there. I don't know how that was taken. Some people would like that..
Speaker 3	1:35	really looking for what have I payed for, I could do this at home..
Speaker 1	1:39	this, this is quite unique in the sense that for most people, it's unique. In the area of research, it's not unique. There's lots of stuff out there and universities that are experimenting with the sensors are relatively old now, the eighties, at the technology
Speaker 2	1:55	Is there sensors all over that though 'cause When you sort of vibrated it at the end that way.
Speaker 1	2:03	Well, that's the question then do you want to have a go of either or both? Oh, yeah.
Speaker 4	2:08	I would like to have a go of the BaserBow but I don't know how to play like a guitar or anything..
Speaker 1	2:14	people approach it differently and there isn't a particular right way guitarist will treated like a guitar, you have to press this to get a note out (sound) Then this changes the pitch. And they are pressure sensitive, so dependent on the synthesiser to do different things on the left hand its usually pitch bend. the harder you press it bends. Here you've got a distance sensor, and also of course a ??? sensor
Speaker 4	3:09	I can't do that..now you've really put me under pressure..
Speaker 1	3:14	Well I can put it on a weird sound if you want it to go weird
Speaker 4	3:17	So you have to..so how do you know what happens?
Speaker 1	3:22	There isn't a right way to hold it either..
Speaker 4	3:25	I like Japanese instruments Okay, cool.
Speaker 1	3:36	For me, yeah.
Speaker 4	3:36	Cool.
Speaker 2	3:36	It's really cool.
Speaker 4	3:49	So if you wanted to you could put the sound of a string if you wanted to?
Speaker 1	3:55	yes because the computer can play any type of sound. So.. I was just using sounds that traditionally use the effects that that moves, with two of the instruments. Doesn't have to follow with it being digital as well. It doesn't have to follow frets, it can be like a violin can be continuous. But there's noway I could play it if it was continuous.
Speaker 2	4:49	It's pretty cool, thank you.
Speaker 5	4:54	It's very cool. Thank you.
Speaker 2	4:54	I can't play it ...
Speaker 1	4:59	Or you can just go with some weird sounds which is potentially more fun I guess. Say that, I guess it's looking at where this might be used. But then it doesn't replace that there's different uses for them. But one thing you may have noticed or may not actually is one of the parts where I was struggling. Yeah. But with this, you can do that. And that was one of the reasons to design something like this is most I don't know if you can see that. But the synthesiser on here has eight knobs traditionally, I don't know why they've started designing synthersiseres in groups of eight controls. So that's why I kept groups of eight here. But there's no way I can play something to move them all at the same time. We can protect with this you can do four with the second one I built you can do eight. But it makes it quite complicated to play. Yeah. Which is why I started using this one for demonstration purposes.
Speaker 3	6:14	You could put something on your head..
Speaker 2	6:18	I can imagine it in some kind of art piece kind of thing, that no mysterious thing that plays into someone's movement can affect their, the music. And you can kind of see that we've got lights to it and all that sort of stuff.
Speaker 1	6:32	its funny now, you mentioned that because it didn't start as a project a university project. I was writing music with a dancer, she was singing. And we were writing songs together was that were electronic. I didn't want to be Pet Shop Boys you know, just stood by the keyboard. Because we were going to use the dancin to control stuff control sound and control the light. Exactly like you are saying. Yeah, I wanted something that would sort of mirror mirror that kind of movement rather than just ???
Speaker 5	7:00	Yeah, that's interesting I can see it like taxi mad from the people different perspective from a data thing of just enlightening. Okay, breaking, breaking a light or something ?of life?. So something else, you know, to mean, and beaming something and that changes. It's not that. And if you add that into the performance, you just,

Speaker 1	7:18	but then it's like mimed. So Is it a dance? Because you could mime it as well. That's always the question, do people perceive it as a mime even if it's not? So people will watch something and think you've mimed it and recorded it even if you haven't? So it's trying to get people to enjoy the performance and perceive it in a particular way that you want? Because I've done stuff with this and looped it, and people don't know I've looped it Yeah. And I've fixed the scale. This I've actually now played in a traditional guitar fret scale. But when I first built it, I fixed it in a major scale, because I just couldn't. I was still hitting the wrong notes today. But I couldn't play it. So I
Speaker 2	7:57	but I did wonder if you're going to do that because you said it was about perception. So I just wonder if you were just going to go so you could talk to any of those kids. If you're doing anything anyway. Because it's not it's not it's not Beethoven. so O you went out of tune there so you can press anything —like this and I have'nt Got a clue what its all about, you no, because it doesn't matter does it?
Speaker 1	8:21	That's the question. How did you perceive the performance? If I? Well, I can tell you, I did play it, but you might not believe that. And it doesn't matter what you believe other than that. It's interesting. Because you could do it all from the keyboard.
Speaker 4	8:38	Kraftwerk shouldn't you..you should have walked out. Yeah.
Speaker 1	8:44	But yeah, so that's the BaserBow
Speaker 3	8:48	very interesting.
Speaker 2	8:49	Very cool.
Speaker 1	8:50	So thank you very much. very appreciated. You are the first two groups to do this, because the other ones at UNi have been delayed. Good. So thank you I have brought chocolate and cake and beer. I couldn't let you have the beer first because that would have affected my write up ?? Describe how that would affect you.
Unknown	9:15	Yeah.
Speaker 4	9:17	I'm really really enjoying this. Otherwise.
Speaker 2	9:23	?????matches grass may continue you know?????
Speaker 1	9:30	Any Any other questions?
Speaker 2	9:33	No. No it was very interesting. project? Yeah.
Speaker 1	9:40	Once I've got this done, it's a case of looking at all the data and analysing it and writing. Yeah. Well, thanks. I'm used to hitting things so the writing ??????, either. Like, I like the drums. So I don't know why I'm doing that. I should have done the drum but this has the gestures you see..
Speaker 4	10:06	Could you have like a drum version of that?
Speaker 1	10:08	You can people made them but of course, it's already a very gestural instrument. Yeah. My I think my
Speaker 4	10:14	because could you like where you could put your hand. Over it.
Speaker 1	10:15	Yeah, yeah, my starting position is that these are used predominantly in the industry. Probably 99% of people use these types of controllers, but they use them to play all sorts of sounds.. Yeah, and to me like I say, just from a practical point of view, they don't give you access to all the control you could have an expressive control it's usually then recorded and so you're playing some of it and some of it in programmed and played. So that was one thing. And the other thing is just that visual aspect of I mean, the instrument that's that's imitated the most probably the guitar with air guitar you don't air keyboard so much it's that interesting Why do people ??????????? depends on the riff, doesn't it, if you get iconic keyboard riffs On air drums it does happen occasionally, especially that Phil Collins thing but it's all hugely the guitar which is where I've used that as a base but wilt it being digital you can have any shape you want.
Speaker 3	11:18	???? because you do more movement and keyboard you're kind of locked into that area unless obviously
Speaker 1	11:28	You can have a Keytar but you still restricted to playIng the notes with this hand and only having one hand to....
Speaker 3	11:35	many different
Speaker 1	11:35	Yeah, there is one Keytar come out now where there is a sensor, it doesn't work like that. It's just one kind of trigger where that actually detects, like your phone detects your position.
Speaker 2	11:49	disappoint you're not like a one man band gonna be like all synthesises you put them on your back
Speaker 1	11:55	thats fast to build up. I've realised when you start the research. You have all these ideas and wants to do everything and then you choose this way.
Speaker 2	12:03	then you need secret. So why is not going to get the data you need?
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TEST-2-MP3 @ 128kps_otter.ai

Speaker 1	0:00	You know, It's the end because we
Speaker 2	0:04	didn't sound the same.
Speaker 1	0:07	Very, very difficult. Yeah, it's very difficult to make it identical And also what you see actually the research underlying it, what you see if affects what you hear, even if what you hear is identical. It's called the McGurk effects.
Speaker 2	0:25	I can imagine that because, yeah.
Speaker 1	0:28	Like, if you've got white wine and they put red colour in it, you'll be convinced it's red wine.
Speaker 2	0:34	Really,
Speaker 1	0:35	even experts with contests on it.
Speaker 2	0:40	The only thing is you're saying this isn't a synthesiser. So yeah, yeah. So you've already pre programmed this sounds dimension. Okay. So if somebody was playing with you, they would also have the Bazerbow through this computer as well,
Speaker 1	1:04	they can plug it in to anything that's midi compatible that has sounds and so plug it into another synthesises natural midi synthesiser doesn't have to be a computer for the actually outcomes. I can show you the synthesiser, on here if you want. So if you fill in the page two which is relating directly to the Bazerbow and then once you fill that in, please skip to the last page and four and five, which a direct comparison between the two
Speaker 3	1:40	Is this the name you have given to it.
Speaker 1	1:42	Yes, given to us I built it in 2011 2012. So that's the first version of two. I've made two full versions. And I've made lots of little since then lots of little baby versions.
Speaker 4	2:00	Now it's like one of those Indian instruments, isn't it
Speaker 1	2:03	It's obviously based on a guitar, bass. But not a guitar. It's more like a society that you find. Someone said it's like, the Japanese ones with the triangle. Well, India has similar Yeah, single string instruments. It's not meant to be anything in particular, what you would recognise it As a guitar if you're
Unknown	2:28	probably or something similar to a guitar.
Speaker 5	2:30	What does it mean? What was your favourite or most memorable moment?
Speaker 1	2:34	well is there a, particular moment that stands out now, after the event that you particularly could remember. or liked? I mean, if there isn't
Speaker 5	2:48	just one minute, I just don't know to desscribe this, five minute segment or something,
Speaker 1	2:52	or just describing in the language that you want to use the actual moment. So if I was doing something on the Bazerbow and was wafting it around i in a particular way, just try and describe that are from the keyboard if it was I was waddling the pedal that's the the kind of thing.
Speaker 2	3:10	you should have Told me not to close my eyes when you play the keyboard.
Speaker 1	3:19	Interesting because people do experience music in different ways. So it's but did you have your eyes open? When I play the Bazerbow you chose tell us
Speaker 2	3:30	I was fascinated
Speaker 1	3:31	about some interesting difference that you chose to close your eyes? Not with the keyboard? As I say there's no right answer that's just looking at it trying to find insights into what people how people are experiencing.
Speaker 2	3:50	earlier? Fermion?
Speaker 1	3:51	I don't think so.
Speaker 2	3:54	Because that was created
Speaker 1	3:55	O the Theremin.
Speaker 3	3:57	the rod
Speaker 1	3:58	I have played the Theramin Yeah. Yeah.
Speaker 2	4:01	Because in a way that sort of very digitally isnt it
Speaker 1	4:08	Yeah, it's, it's got quite a following now. When people play all sorts of really complicated classical
Speaker 2	4:21	It's using your hands isn't it
Speaker 6	4:27	What do you call. The
Speaker 1	4:31	waft. I don't know what you got, I can't put words in your mouth. Rocks.
Speaker 5	4:39	That's what's I thought it was like
Speaker 1	4:43	That's what that's what it's all about your own opinion that that's why I was kind of aiming for that's why I chose the guitar in the first place is that it sort of has
Speaker 5	4:51	not been unusual. It was yes, if you're playing.
Speaker 6	4:54	I don't know what word to use for the large, the expressive movement
Speaker 1	5:05	There isn't a good or bad either, you would use a keyboard for certain things. And you might use Bazerbow for certain things. So it's not a case of saying one's better necessarily than the other. Just while you're filling in that I'll come around and make the floor safe again,
Speaker 2	5:36	Are you hoping to make these commercially Philip
Speaker 1	7:05	At the moment, I'm focusing on the research side of it. Because rather than the actual instrument, it's the kind of psychology underneath music psychology underneath. The actual dissertation is about that's why I'm collecting data about the perception of musical performance.
Speaker 2	7:27	It would be interesting to hear a recognisable piece of music on both Midi keyboard
Speaker 6	7:37	It might be something to consider......economic....
Speaker 1	7:52	nice also converting the process because it took a long time to hand build. So it's converting it to a process where I can build it in reliable as well as a few tweaks over the years. It's The third version that like make it work with the current equipment. I mean, I do envisage it I wouldn't particularly choose all of those sounds, musically, but it was simply because they make it very obvious if I move this knob, it's changing the sound. I think you'd use it in a more subtle way. Maybe
Speaker 4	8:33	When you say how would you describe it? Do you mean to look at or the sound?
Speaker 1	8:43	Well, as an instrument as an instrument from how it may be how it manipulated the sound? Because it's playing this the both playing the same synthesises? Yeah, Also Simone said the Bazerbow sounded different. Yeah, so it does affect the sound in some way. so that's something interesting. If you found that
Speaker 2	9:11	I think you would need to be a musician, maybe to play the Bazerbow where you could be a technician. You know, it's a different field for this its more like an interest in an instrument. And this is

Speaker 1	9:36	Well these are Usually the smaller versions like this with all knobs which are usually used by DJ, rather than a traditional music player. So you're right these do tend to be used by people who maybe not trained, but they create loops and patterns. and solve the buttons and things. You've probably noticed as well The other thing from a practical element to certain things I found quite tricky with the keyboard, because I've only got two hands. So I'm trying to move the pitch bend here and the joystick while playing. I'm moving the pedal of where that it's built a gesture so that Bazerbow can actually manipulate the sound in a much more complex way than you can with a keyboard.
Speaker 6	10:24	you can actually twirl round with it cant youYeah.
Speaker 1	10:30	thats ??? is probably got similar sensors to the drumsticks inside it, they just don't create the sound and manipulates. So has anyone got any comments? Anything you'd like to ask? Because that's the end of the questionnaires and things? Because the other question is........
Speaker 3	10:55	You can relax now.
Speaker 1	10:57	Does anyone want to go if either of them
Speaker 2	10:59	That one.
Speaker 1	11:05	Do you want different sounds. What kind of sounds do you want?
Speaker 2	11:08	guitar but I don't play electric I play acoustic? You have to stand up. You can play? Like he got not Oh, you have got some marks on it.
Speaker 1	11:21	That was for me. Yeah. Because I'm a drummer to start with and then trying to do fretless...
Speaker 2	11:27	you can you are just pressing are'nt you And then you doing all this business,
Speaker 1	11:33	theres a motion sensor that detects across and up So that's two parameters. And I see the holes in the end, that detects the distance a bit like a mobile phone
Speaker 2	11:49	Do you play under here as well under this.
Speaker 1	11:50	If you press that that would start the sound off. And then this is the pitch when I open the it's time now show me acoustic guitar. So I take a look for I look for the guitar.
Speaker 2	12:28	Does it Slide
Speaker 1	12:35	Creating notes, pressing notes you could actually have it, like violin as the sensor isn't in segments so in theory be like a violin really hard to play
Speaker 2	12:55	have to keep pressing on this
Speaker 1	12:59	pressure of that hand will affect the sound as well as the the left hand the pressure affects the pitch. So you get pitch bend like a guitar
Speaker 2	13:06	Okay, anybody else want to have a go...
Speaker 7	13:09	I've had a go once.
Speaker 1	13:12	Yeah, I was trying to find
Speaker 3	13:16	Ive wanted to play the guitar... its been a lifelong ambition but I've never done so. Am I doing that or is it you?
Speaker 1	13:36	I'm looking for a guitar.
Speaker 3	13:37	our son has it
Speaker 5	13:59	falls off. Nobody
Speaker 2	14:05	you can make smaller ones than this without any electronics And sell them to kids as an air-guitar
Speaker 6	14:25	Anyone want a drink..............
Speaker 3	14:42	that sounds more acoustic cup of tea would be great
Speaker 2	14:49	So the
Unknown	14:51	bottleneck. Time
Speaker 1	14:58	none of the sensors are attached to any of the guitar sounds but You will find it Will play pitch bend It does wobble when you get between the notes
Speaker 4	15:09	if you do play the other one on the guitar, what does that sound?
Speaker 1	15:25	Sounds like the guitar
Speaker 4	15:27	It's not the same.is it
Speaker 1	15:29	If I play that note and I play that not it's exactly the same note.
Speaker 5	15:35	It's just the way you're doing.
Speaker 1	15:36	It goes yeah, there's an element of how hard you hit the note will change the sound. But also there is an element that what you see is changing what you hear. If you've ever seen the McGurk effect, if you haven't looked it up on YouTube, it's brilliant. McGuirk MCGURK 1976, he realised, say that word. And you'll see someone saying far but you'll hear the word bar. But you won't hear the word bar, you'll hear the word far, right? Because that makes you think you're hearing far. When you shut your eyes, you start to hear the bar. When you open your eyes, you think you hear far again, but the audio hasn't changed. So
Speaker 3	16:20	were they were they doing I think that only six months ago the radio asking people what they heard, right? Yes. You know, there were conflict, there was a conflicting opinion on what was...
Speaker 1	16:34	will censored. It's not just you. It's not just you
Speaker 3	16:36	That might also involve listening to it with your eyes shut
Speaker 1	16:39	It works the other way, as well as double flash experiment where you see one flash, and you hear two beats two beats make you think you see two flashes. So it works the other way around? Can you taste and scent all our senses are mixed. We take everything together and then make your perception of it. It's all the information being joined. So you can that's where you get optical illusions. tricky, tricky.
Speaker 3	17:13	So So what was the overall nature of the research?
Speaker 1	17:18	Well, this is obviously an outcome of it in the sense of looking at the reception of musical performance.
Speaker 3	17:26	So it is perception as a performance.
Speaker 1	17:27	Performance quite is to do with how you would in a nutshell Well, the main research is called mimesis actually
Speaker 3	17:38	So that's imitating saying..

Speaker 1	17:40	Kind of, when you born The only instinct You're born with is to get your own food, you can't get your own water you can't do anything for yourself initially. So on the baby will do naturally as imitate the mother, because they know that that's the way to create the bond with the mother for secure safety in the food etc. And then Colin Trevarthan a child psychologist did studies has done lots of studies with newborn baby sub 30 minute old babies with the mother. And he gave the googoo Gaga kind of conversation they call it proto conversation on motherese. And that motherese he studied And he's given the recordings to an audiologist, who's found music and music, very strong musical content. So the pitching is very precise the timing between the mother and babies really, really precise. If you remove that, it's not deliberately but he's done it when the mother has postnatal depression or something like that. He's found that the baby suffer cognitively and socially. And so this is why if you ask music therapist Colin Trevarthan kind of underpins music therapy, because you kind of put you back on what wasn't there, potentially in the first place. And so it kind of comes from the fact that you were born to imitate and born to learn by imitating by if you go to a concert, even if it's a classical and you want to sing along, if you know the tune you know you wants to tap you foot before want to involve yourself, but you're not allowed in the modern format. And it's about that what kind of instruments what kind of performances draw you in and make sort of trigger this mimetic effect this natural mimetic effect. Mallock was saying about guitar is probably the most imitated instrument in the world in terms of air-guitar, we see people to air drums and air keyboard and the guitar is the most popular, which is the reason why I started with the guitar, but further on our probably, change the shape and change the design to experiment.
Speaker 2	19:52	Barometer!
Speaker 1	19:56	You could have any shape I've seen spheres, you know, just weird shapes. But for me, it doesn't give you. The other research I'm looking at is Arny Cox Mimetic participation, which is as I've just described the mechanism behind us wanting to tap off what I wanted to do air-guitar. And if you had a sphere and you're playing sounds from it, it probably just look like youre dancing more than performing. Because we haven't got a mechanism that we understand to translate to the instrument. So that's why I've used the guitar shape because you go, I know that's a guitar, I know how to play that, even if I've never played it. So you can imagine I've never touched a violin. But I know if I pick one off, I could put the string and understand what it's probably going to sound like. Even though be you know, I'll have to learn how to play it. So it's that anticipation that your brain goes through. And the sports psychologists do a lot into it as well, which is why they actually go and talk to those sports psychologist because part of the message mechanism they believe it's called mirror neurons, which you may have heard the term on telly, it's a bit of a key term. Basically, they did an experiment with the monkey, where they measured this brain activity neurons and certain neurons fire when you grab the and grab the banana. But they realised that when they were watching the the activity, the same neurons fire when you watch someone else grab a banana. So they call them mirror neurons. So every time you watch something, you potentially preparing yourself to do what they've just done. It's it's that kind of preparation stage that we do to learn something before we've even tried it. And, and that's part of you know, what I'm trying to tap into the performance instrument
Speaker 2	21:49	We've got 6 grandchildren In Sweden are all bilingual. Except the baby hasn't started back yet. But grandson Ethan, who was six is the only one of them that speaks English with the sing- song Swedish. All of the others speak Swedish, more like an English tone. That's totally understandable. But he has this this wonderful little rolling rhythm which he talks to us in and Swedish and the rest of the family, they don't have that
Speaker 1	22:39	the demographic the music questionnaire Because when I come to analyse it I score it. And the score gives you the type of way that you engage with music in terms of a more physically engaged How do you engage more emotionally or more mentally, which is similar thing in people. Although everybody asked this mechanism.??????? I think the other element is empathy as well. There are three areas I'm looking at an empathy, of course,
Unknown	23:16	mirror neurons, but supposedly involving empathy as well
Speaker 1	23:20	we can't measure them in a human Because the ???????
Unknown	23:23	construct appropriate ??????????
Speaker 2	23:28	That thing the brainwave thing I saw that in a ????exercise they fitted this lady up with this thing, and took her shopping, the thing she was excited about her brain activity in certain areas went really, really red. And if she wasnt very interested it went blue-green She had this great big hat on...
Speaker 1	23:56	its amazing when they do scans of people listening or engaging in music are to the brain when you listening to music, most of the whole areas of the brain lit up and are active. And I was talking to one of the one of the students at UNI need going on to be music therapist, and he's working Alderhaye the research. And he's saying one reason to think it works is awesome work is because if a particular area of the brain is damaged, because music engages the whole of the brain, it can help encourage regrowth and repair quicker than if you didn't. So it's the starting to use in stroke. If I
Speaker 2	24:42	Youve got two extreme so you've got all this using music in therapy and revitalising people with a young friend who is a music teacher at local comprehensive school. And he's telling me that kids don't get instruments from school anymore. If they have lessons at school, they've got to pay for them. You know, when I was I went to comprehensive school in London with 1200 girls, and we play whatever musical instruments we want to they want provided for us. We have two orchestras in school. Less you know, music rooms, you could go into every lunchtime. And then you've got this stupid thing now that kids have got to pay.
Speaker 1	25:38	And it's expensive as well.
Speaker 2	25:40	He said, six pound for,no, 16 pounds for 20 minutes, which can be two of them have a lesson then obviously its eight quid each
Unknown	25:54	substantial amount of money
Speaker 2	25:58	to buy the instruments.
Speaker 4	26:01	And like I say, you know, when I was at school, he used to have singing. It was called music. And you'd all sing, you know each class would sing them
Speaker 5	26:11	And then to try to make up a choir before each one had to sit at the front.
Speaker 2	26:19	Because we had ??????????? we were an all girls comprehensive school. We had a fathers choir and the dads and granddad used to come and rehearse. We did three concerts a year. We did a Christmas service at St. Martin's in the field in Trafalgar Square, because the school was Dick Sheppard and he'd been Dick Shepherd had been a minister of this church. And we put on Cavalier, rustic counsellor and Carmen. And we had these wonderful dads and grandparents in their tuxedos, you know, and bow ties, and it in the summer concert, they'd always got some sort of novelty thing that they practice together. And it was just glorious. When I was 10, at school, in my primary school, we put on the Mikado
Speaker 3	27:20	I should think that was pretty exceptional.
Speaker 1	27:28	There is a reduction in music activity in schools.

Speaker 2	27:33	The headmaster, the music teacher, Mr. Rodney, this is a primary school would have the whole school sat down in the hall listening to classical pieces. I went to a Jewish primary school there were only three non Jews in school. And one of them a guy named Sam was in the year above me. He was the only kid came in long trousers, all the boys came in short trousers. And every week, Mr. Rodney would say and what is this piece of music and Sam know, and I was listening to this piece of music, and I was thinking this is very dramatic. What the heck's this. And Sam stood up at the end Massorgsky's Night on a Bare Mountain only way we used to have to sit and listen to classical music.
Speaker 1	28:28	I remember I pass the test, my driving test and I got given a DVLA magazine, and from the examiner. And one of the articles was studying people's concentration, driving and music. And they put them in a simulator and everything including really loud, heavy metal and tended to make you drive better and concentrate better but they found one piece and that was Night on a Bare Moutain and it made people drive into hedges and things. Yeah.
Speaker 4	29:02	Really?
Speaker 1	29:04	I don't know. I did try it.....
Speaker 2	29:07	Trips to London, Jazz singers. Mostly, it's trying to remember who we think the singer is
Speaker 1	29:18	about. Spotify has been an interesting development. When I taught a lot of drums a few years ago, and then I found that the students were listening to a much broader range of music than I ever did because they've got access to it. And I think that's probably a good thing.
Speaker 5	29:36	Because when you have to buy it, careful, yeah.
Speaker 1	29:42	Yeah, you only buy an album if you like,
Speaker 5	29:44	but I mean, he is just saying to Susan listen to inheriance tracks on yourself. You know, Otis Redding, download this album. 12 ????????? listening to it.
Speaker 1	30:00	When I when I was at uni, we were told we had to buy certain songs I had to buy the CD now
Speaker 4	30:11	sorry, I was gonna have a scone Thank you. Pleasure. No, that's, that's fine. Yeah.
Speaker 2	30:24	We put the CD out kids come over we are to the show to California. And they were listening to A 1960's and each one of the children chose three songs that they had to have on every journey, one was Puppet on a String that was one of them. And then I can't remember what the other two but it was driving Steff and Matthias. That's because as soon as they got in the car they were arguing I gotta play my song first. Yeah. You're right. I mean, I think we have got we must have more than two or 300 LPs from the days when we use our stacking Hi, fi. We must have pretty much the same in CDs. And really, you could you could download absolutely everything onto an mp3 player get shot to get into records are coming back.
Speaker 1	31:30	Yeah, briefly, I think. I think there's something really nice about if you listen to a record you deliberately want to listen to the music and there's something very nice placing the record and sitting back and listening. It's a bit like I compare it with modern music its like having to drink coffee, everybody seems to do it on the go. Where you record is like having in a cup of tea in the at the Tea Pot. You have to sit down and it's kinda there's something more than the actual music is an experience when you have a vinyl
Speaker 2	32:01	you've inspired me having spent a fortune on something called a living song deck deck and needing to spend about 60 pounds just for the stylus. I think we need to think even a replacement lid for the thing is going to cost about 150 quid I should talk to my husband about getting this back.
Speaker 1	32:31	You can't jump around too much. So can you they tend to skip
Speaker 4	32:34	the sad thing is the side finishes all too soon on an LP. It goes on much longer on a CD and you just enjoying the music on your LP and it finished? Yeah. Yeah,
Speaker 2	32:51	we just got we sold our little KA and that a tape cassette thing in so it might mean i get shot of my tape cassettes.
Speaker 1	33:02	I don't think they tried to bring back the cassettes in the last year or the year before but it was too much wrong with them I think for them to come back.
Speaker 5	33:12	And the great thing is about Spotify they were saying on the wireless this morning dr. john Stein, ??Dr John stop talking about Alexa, play Dr. John and up it comes
Speaker 1	33:33	again there's a debate about the quality and the sound of vinyl but you put experts in a room they can't really get the difference and with the modern way audio
Speaker 2	33:45	when you've trawled round any number of shops to get your Hifii system. And then I mean at one point Phil was gonna knock out the side of the house two alcoves so that he could fit his own handmade speakers in that look like Daleks. We ended up with a quad system which we've got a valve amplifier It's Quad electrostatic the quad amp, which goes into the deck so it can play anything. The speakers we did get in the end, not mega big ones. Thank goodness. Speakers make a big difference. In listening,
Speaker 6	34:34	you'r dad got rid of his Goodmans
Speaker 1	34:37	Yeah. Still got the record deck, the cassette deck
Speaker 2	34:42	We've got a B&O one that we picked up at the church car boot sale some eight years, and that's still in the box.
Speaker 1	34:54	Me erm, one of the bosses he's in his research is calling ??????mantic its a term used by Pythagoras when he taught he used to teach behind a screen, because he believed that people should be focused on just the work rather than him so when he's presenting. So the music acusmatic music is music. So without any visual performance so when you go to see Additionally, surround sound. Very nice.
Unknown	35:30	So yeah, for sure. Yep.
Speaker 2	35:33	I'm sorry Phil was working today I think he would have Enjoyed it?
Speaker 1	35:42	I'm doing it. I'm doing it again. Hopefully next Saturday. You know? Yeah, I'm going to try and get through it depends on numbers. it should have All been at MMU, you put it's been a bit tricky was security in the fact ???? is
Speaker 4	36:01	Does the way to do it make a difference? I mean, bearing in mind, this is a relatively relatively small group when you think you're going to do it in a hall?
Speaker 1	36:11	I think the answer to that is yes, definitely. And interestingly, when I suggested to one of my tutors, he immediately said, Oh, that's gonna be an interesting rather than rather than doing it at Uni and more sort of kind of like a laboratory. And most people come in and sit in front of a performance and it's a test and you're doing the questionnaires, going to people's houses, and doing it is a lot more informal
Speaker 3	36:43	that we didn't
Unknown	36:47	want to buy issues. Yeah.
Speaker 1	36:50	It does change the environment, I guess. But I think in terms of the research I'm doing, part of it is wanting trying to draw people in and wanting them to have a ago when you're part of a performance been part of the music.
Speaker 2	37:04	I think it's just very difficult using this without any instruments, because and then I think it must have been the 80s or the 90s. There were a lot of groups that were using this device, I think I caught a Pet Shop Boys. There was these guys like blue mask so because they knew that they couldn't engage people in performance by just standing there. In a

Speaker 1	37:39	blue man group thing called book Kraftwerk were the ones who took it to the extreme And they had four laptops, and they're all playing around the laptop, man, they just leave and go to the bar, but it's still playing. The assumption was the doing something they weren't doing anything, trying to push the boundary of what people are expecting from performers. Going back to the electric drums The first time I heard about them in 99. And I use them for a gig. Everybody said, You sound fine. But we look like you were miming, because there was no sound emanating For me it was all coming out the PA. And we just weren't used to seeing electronic drums. Well, now I've got students who actually use electronic drums all the time, no uncommon comments about many more
Speaker 2	38:25	That’s cause they don’t know about real
Speaker 1	38:27	Yes its a learning experience
Speaker 7	38:29	just don't know what real Drums are among men,
Speaker 2	38:46	We have a tea and chat group at the church once a month and quite a few have different stages of dementia. And we bought loads of different games specifically. And one of them is like memory cards. And I was sitting on the table the last time and there were six residents from the care home and two very two young carers who'd come with them and then you know, show them the record player, which just because more recent interests they have, the younger ones were able to identify, but the tape deck, reel to reel, now the younger people have no idea what that was at all and going into schools with the Gideons if you talk about video they have no idea what video is it's all DVDs and MP3
Speaker 1	39:47	I was told one and as you say none of the one of our tutors who taught us music business was a consultant to the government that and he said to us one day you're listening to your own radio station and that was when the Matthews with the taxi and where are the new
Speaker 2	40:30	Well my ?? had the first type of mobile phone, you had to have the battery over one shoulder and a normal size
Speaker 1	40:49	I’ts amazing how things change .....the truth
Speaker 3	40:54	one thing that stuck in my mind I was watching a anniversary programme on the TV about ??????
Speaker 2	40:59	Can I have the strawberry on the top of the scone?
Speaker 3	41:05	and they made the comment that probably most of the technology they they had in this huge studio you could get on a phone now
Speaker 1	41:18	I had a go we have the my course we were still analogue it was still tape to tape so it was the two inch one inch to inch tapes the ways that you copy and paste was that you cut with a razor blade and then you splice it....
Speaker 2	41:34	We.ve got a cutter at home....
Speaker 1	41:36	And I had a go which ???????????? Moving it backward and forward trying to find the Start...
Speaker 3	41:54	people did that and the
Speaker 1	41:57	Beatles The Beatles tracks were done like that
Speaker 4	42:00	how do you go about making your Bazerbow
Speaker 1	42:07	it which which part of it
Speaker 4	42:09	here your bit in the middle, the electronic bit that's where you that makes you then yes the string
Speaker 1	42:17	and there's several sensors and they're connected to a little PCB inside the PCB The sends
Speaker 4	42:25	PCB being?
Speaker 1	42:27	printed circuit board and anything that's the electronic electronic you'll see usually a green hard board with lots of bits of electronic components on this little computer This is called an MPU and it's a mini computer does what that does but it's just not powerful. Then you can programme it and tell it what to do.
Speaker 2	42:54	We’ve got a lovely computer man that's taken the hard drive out of our computer put in a like yeah, and suddenly the thing is working fast
Speaker 1	43:14	and the one thats built in here I have been able to buy it off the shelf. And it's made for hobbyists for doing exactly what I've done which is plugging in sensors various things and we can go on and design because the second one I made is much much bigger and it's too big and that's because the the PCB stuff inside was too big and I had to make a compromise the shape to fit the stuff inside and it is not I've not used it because it's just too heavy and too big and it's got four strings which is why it's bigger but I'm having to design the custom made PCB to do the same thing will shrink it all
Speaker 3	43:56	or you put put a strap on it
Speaker 2	44:00	brackets
Speaker 6	44:12	we haven't seen it demonstrated much but when he did it at UNI He had a lot more freedom of the big hall and he did a lot more moving about
Speaker 1	44:24	was more like a single stap like a saxophone that's what I was thinking about I know people who play heavy guitars really strange but it was the width of it as I was just too big but it's the wood bit as well I've had to learn because I've not done any woodwork so I
Speaker 6	44:53	He’s had to buy a lot of tools cluttering up the garage.....
Speaker 2	44:56	become Sam works in the wood shop at Bentley and so he's made two electric guitar blanks
Speaker 1	45:11	and I know I forget first name but Alex is the second name he works At the Bentley wood shop he works on the veneer dashboards..
Speaker 2	45:22	okay ask him if he knows Jeff barrows
Speaker 1	45:27	I work with his wife in a school as I say this could be any shape Yeah, but the original design so now it's all goes back to me it wasn't part of research it was part of working with a dancer and the dancer and we were writing songs together and she was singing and dancing and I was playing and and we decided that it'd be fun if she could control sounds with dance gestures, which is where some of the sensors came from. So then I thought well i'm going to be very static doing so I need something that complements the visual visual well that's still after essentially dancing isn't it? Yeah drums on as well but that was the idea of having something that you move rather than something thats quite static... up the idea came from an initially..
Speaker 6	46:29	Unfortunately she’s gone to live in South Wales...
Speaker 4	46:33	what going back to say so she could control the music?
Speaker 1	46:37	she Could have done yeah. got it with the same sensors strapped to various ??? yes
Speaker 4	46:44	that's why I was saying you could learn to try to dances laughs so that you both got Sensors attached
Speaker 1	46:50	Yeah. Maybe a bit more difficult to control pitch in a complicated way easy play melodies without But there are people like Imogen ??? as a singer from this country and she uses gloves. Gloves help her when she's singing that she can mke gestures with the hands that affect The voice.
Speaker 4	47:16	So this is really sort of

Speaker 2	47:21	really futuristic isn't it? Like me as untechnical as you could ever come across and I just find it quite amazing that you know sort of by waving that around in the air Yeah, you controlling sound and you could strap something on somebodies body and control sound that is absolutely staggering.
Speaker 1	47:46	I thought it was really cool and unique. So I started doing the research and then realised people have been doing these things for decades. But he probably any research is like that and there is lots and lots of different types of crazy instruments, out there that people are built. And this technology is that sense. It was patented in the 70s and you know some of the gyro sensors inside it from mobile phones so that's that's quite a new one actually changed and probably 20 years old at least
Speaker 5	48:27	just imagine Jake if he fitted you with sensors is going
Speaker 4	48:33	I tell you what my daughter would be more scared than my grandson
Speaker 1	48:37	the technology is used in lots of places. So the motion sensor technology is really for transport like helicopters and things obviously a lot of development comes from the Defence Ministry defence and initially
Speaker 2	49:01	grandkids we were in Copenhagen and we went to this sort of weird and wonderful museum and they had a flight of stairs and you feel they can use it because you climbed up and down the stairs ran up and down yeah we we've actually never got far yeah that was some really Peculiar things it should have come with a warning
Speaker 1	49:33	it was an invention because this is the idea of synthesis and combining synthesis and performance is really really old. I think is in 1700s he invented and a keyboard type machine that for every note and different flame would light Different coloured flame because he believed then the sound and light with very linked scientifically so the show room to chat so the top different things that would burn different colours
Speaker 2	50:04	When was the Theramin done?
Speaker 1	50:06	that was the late 1800's
Speaker 2	50:10	that was quite a long time ago
Speaker 1	50:12	the Theramin squad
Speaker 7	50:20	sticks it on the end of his keyboard
Speaker 1	50:23	it's come back actually the one of the companies that made the first commercial slightly different and it's not digital in anyway. So the sound that you make it creates an actual electronic signal electric signal that goes into an amp a bit like an electric guitar. This is not someone digital it has to go through a computer of some kind just as I said a synthesisers are quite old, digital is is probably the newest part of it okay
Speaker 3	51:09	picking up the children unfortunately the rain spoil the sports and the Hawkins with a small a
Speaker 2	51:27	If Philip had come with me I'd err..... I'll be quiet well I mean Bye. Coming a long
Speaker 7	54:30	time integrated circuits today
Speaker 4	54:55	My questionnaire will not seriously reflect what I'm feeling about, about it now. Yeah. Okay.
Speaker 1	55:16	The keywords that are interesting.
Speaker 4	55:21	Stop recording is now okay. I think seriously, I think absolutely brilliant and I'm absolutely amazed by it because it just seriously goes over my head and so I'm amazed when somebody understands it can do something with it.
Speaker 1	55:43	bits of it, not all of it I shout a lot when I'm building I use my electronic kit now
Speaker 4	56:21	Yeah, yeah. Yeah.
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Speaker 1	0:00	Free now, it wasn't on the question as
Speaker 2	0:03	Can you. Are you free to tell us about your interface? Yes. So
Speaker 1	0:13	Well, I think
Speaker 2	0:16	you must have, you must have at least three mechanisms that you've adapted in a tilt mechanism
Speaker 1	0:20	There is a gyro inside and there's , obviously touch sensors and there's an infra-red sensor a bit like your mobile phone, okay, since that's the phone,
Speaker 2	0:32	that's giving you a proximity distance, so you're able to snap that says one there, then the tilt, and then to
Speaker 3	0:42	two sets of positions. impression.
Speaker 2	0:45	Okay, so is there any more than that? Now, it says four sets of controllers,
Speaker 1	0:50	The other one has,
Unknown	0:52	this one's easier to play and I'm a drummer, right by background. So that's why I've got the notes.
Speaker 2	0:58	Oh, right. Okay. quite like to have a look at that one
Speaker 1	1:05	that. Okay. Because it's just continuous continuous control. This one took me about a year to make a while ago, on an MA be the second one at the second year. So the two projects, I've used this, there are reasons why we use this one for testing now with the research, but it's the
Speaker 2	1:27	is the ribbon clinic, velocity sensitive. pressure, pressure, pressure sensitive.
Speaker 1	1:34	I mean, you could convert that to velocity is right. So same kind of things. Yeah. Keys.
Speaker 2	1:39	So I'm just I'm trying to understand what your mapping is. So on the notes,
Speaker 1	1:44	well, for me, personally..
Speaker 2	1:45	Are you using velocity there,
Speaker 1	1:48	no right handed.
Speaker 2	1:49	but you're using the equivalent of volume or something here, proximity,
Speaker 1	1:54	that's Reverb basically
Speaker 2	1:56	right, okay. As you tilt then that's going to..
Speaker 1	2:00	Hopefully content or whatever else you write is similar to that.
Speaker 2	2:08	But that's a that's a vector, isn't it? So you go, you can go in,
Speaker 1	2:11	which is the same as this.
Speaker 2	2:14	Right? Okay. So okay, it's great.
Speaker 1	2:18	And the pressure on his mouth to pitch and okay, right, and the pressure on his massive modulation right? So this is the sensors on here are our all mapped to the ones on here
Speaker 3	2:34	But you can be with us to do, what he wants it could be a pitcher inside the pitch.
Speaker 1	2:38	And what's the thing with this get out? You can it doesn't have to be 12 Tone, it can be some weird, nineteen something. When there was a specific effort to make out of wood, because I don't like part of the research is out how an instrument looks and feels and obviously that doesn't feel like an instrument, feels more like a computer or an extension of a computer.
Speaker 2	3:09	Are you studying it from a perspective of performer as well or
Speaker 1	3:14	Yes. Well, yes, um, but mainly audience when the way that we perceive performance. So what three areas of research The first is empathy, right, because that's involved with imitation and imitation learning. Which then links with communicative musicality, basically Colin Trevarthan and is a child psychologist forefront of child child psychology. And he has studied newborn babies for a long time. And he does experiments with them and the mother when 30 minutes old, so very newborn. And what he's discovered is that all babies have an innate ability to imitate. The reason being is that how it creates the bond with the mother that bond, the GooGoo Gaga the proto conversation on motherese they call it, and he gave a lot this taped, videotaped and recorded motherese to an audiologist, who discovered it is very, very musical inate musical and in pitch in intonation, in turn, taken to invade. And if you remove that, which they didn't deliberately do but they could study it when the mother main was suffering from postnatal depression or something like that. The baby quite often suffered. And cognitively socially later on, that's why, that's one of the main areas of research for music therapy was something there should be there in this musical musical. And the reason I'm interested in this, because it links in with mimetic participation, which is a term so coined to explain the process of air guitar and other phenomena. Why do we respond to music in a certain way? Why does it make us want to sing along, and that kind of thing. And that's why it's guitar shaped, simply because the theory comes out of that. I mean, guitar at the moment is probably the most demonstrative in terms of the air instruments. People copy the guitar. But then this all links with the way that we learn and tend to learn through imitation, through looking online prepares us to do something before so I don't know if, maybe heard of the term on telly mirror neutron. And in the 70s, they were experimenting, typically, the monkeys, they realised that when a monkey grabs a piece of fruit, certain neurons fire, but when they saw someone, grab a piece of fruit, the same neurons fire. So it was because the monkey was looking at that action, the neurons that are involved in the actual motor process, we're firing to prepare them to do the action and copy of the action, and they haven't found it in humans, because they're not found anyone who happened to stick a probe deep into the brain. So they believe it's there but having to look elsewhere. We did see in terms of the way we think about instruments, I've never touched a violin before, I'm absolutely certain of what the sound will be. And on the mechanics of it, because I've touched wood before, and how that would feel in hand. Because I prepared the neurons are prepared when I watch people play violin. So when you watch someone play guitar, you may never play the guitar before what is that connection? Have you seen it You may be connected and understand the properties of. So that's where the research is based, rather than design, the design of the
Speaker 3	7:02	sure research as well as music psychology as
Unknown	7:07	well based around the performer and the audience
Speaker 2	7:14	Can I ask a question about the interface then? Yes. Right. So watching you perform. And I suspect, what you're finding is that the gestures that you're making using that have are more engaging and when you when you say when you say my keyboard, but what I'm most critical of, often, when I'm looking at people, for me experiment, even if they perform on another instrument, several forms come to mind is that they tend to be a lot twiddling with their heads down. And then maybe they stand up and they're playing the flute, which is quite engaging, or the do a bit of singing that they were doing, knob twiddling with their head down, and the difference between what was quite transparent performance in terms of the gestures that we were making. And I know, I know, I knew more what was going on with the keyboard, but I know I, you know, I feel the same thing your head is down, you've engaged them. It's very introverted. It's not outward looking. But nevertheless, when I'm looking at you on the keyboard, and I'm looking at your little movement, okay, so you've got loose foot, you've got one hand on the vector controlling and you've got one hand on keyboard, they are all free. Okay, now when I'm looking on this, there's a slight problem in any movement is possible. So let's supposing you do this, that's it. We want to keep this free. Right? But in order to keep that totally free, you have to be supporting here. Because it's okay. You could put strap on it. Yeah, but if you put strap on how are you going to do all of these gestures?
Speaker 1	8:53	Well, the strap I would use, and the big one needs a strap and is one like a saxophone. Okay,
Unknown	9:00	So its a single.
Speaker 2	9:01	So that solves it.
Speaker 1	9:02	Yeah. Okay, you can move it around completely.

Speaker 2	9:04	Okay, perfect. Right that I think that would solve it?
Speaker 1	9:07	Yes. Well for me because I played in practised it holding it Yeah. On this one I haven't put a strap, but the other one did have a strap.
Speaker 2	9:14	me I mean, you weren't trying to do anything really virtuosity on the keyboard you see what
Speaker 1	9:18	well that's the problem when I came to work out some music for it that if I went full on with this I couldn't reproduce it Yeah, and that's why a lot of it was based down here and not up here because all the controls are here. Notice I had to do two things with one hand..
Speaker 2	9:40	so you think more freedom on that than on the keyboard.
Speaker 1	9:43	In terms of multaneous control right is there's a practical element that design is this can control all those parameters at the same time individually? Yeah, and the bigger one can control eight or more parameters at same time but not so much more complicated and more difficult to play.
Speaker 3	10:01	so to get it on the fly is more interesting in that than on the fly with that isn't it? and we do have you still have to control it is like American Dream fits. They have keyboards where you can be downtown. Okay step by that way you can have a massive three steps but yeah
Speaker 1	10:24	This isn't unique It seems you know, you just watch an average band or whatever but in the research as you know this isn't unique there's lots and lots of people make
Unknown	10:38	Strange ??? in this lifestyle
Speaker 1	10:39	The guitar people have made dogs and pretty shape things up for me to link in with that theory of understanding you have to know how to have a base knowledge of an instrument so I started with guitar which says well it's it's a guitar it must be plugging in somewhere and this must be somekind of Fretboard, so that was the reason.
Speaker 3	11:00	I think there's more to live element possible and then the premises on that on the fly with the note is more accurate isn't it?
Speaker 2	11:12	I don't think I don't know
Speaker 3	11:14	there is more excitement in that in the way that it's like anything the gyro you could go a bit too far just like a violinist could but that excites me matters you can argue that you could turn it to it's maximum it sets the tone with some Islam I find that
Speaker 1	11:29	to be more accurate we need a lot more practice is anyone can do that and the laughingstock just try this one you could get you can be very precise with it but you have to know exactly where it is.
Speaker 3	11:42	Competition I find that very excited and respectful
Speaker 4	11:47	and we want ??? Performance
Unknown	11:49	to do that when you're watching wherever you are makes when I was watching you ???????????????????
Speaker 1	12:00	last one I did someone was very apologetic because they said "I shut my eyes while you were playing the keyboard" so I said did you shut your eyes while Iplayed the Bazerbow they said No, I wanted to watch the extreme difference well I just want you to listen to the keyboard I did'nt want to see it.
Speaker 3	12:17	Is that design and the same as your first design for the instrument
Speaker 1	12:21	the first one there might be a
Speaker 2	12:22	When you first started thinking that of that one was it in your head looking like that or did it change from your original was meant to
Speaker 1	12:29	it was meant to look a little bit like this., but it was meant to have four strings which the second one is four strings but the technology I put inside it was a bit too big so the whole thing became too big. And if you'r used to a guitar this was too wide and
Speaker 3	12:44	See one of the things that attracted me to that one it was that it only had the one string
Speaker 1	12:48	that's the main thing
Speaker 3	12:49	simplicity was the beauty of it.
Speaker 1	12:51	I think the other one was to complicated.. the third one which I haven't finished has this shape and aesthetic and slightly bigger and incorporates the harness.....
Speaker 2	13:06	I'm not sure about why it's monophonic
Speaker 1	13:08	It's just got one string and this is the way its set up so this is the plugging hand And this is the fretboard for the pitch. So you could set it up tp play, well actually you couldn't because the sensor doesn't work like that - this sensor is a linear sensor so you can only put one finger on it time
Speaker 2	13:37	is there no way of changing that?
Speaker 1	13:38	it a good do you build it different ways there is a Guitar by StyleLabs where the frets each have a button
Unknown	13:45	or the Eigenharp the same thing
Unknown	13:47	The Eigenharp is very complicated has as its gesture control so and
Speaker 1	13:52	so in their case they are playing it more like a keyboard where each pad has a note where this is designed to specifically imitate a guitar
Speaker 3	13:59	so it has a real simplicity about it
Speaker 2	14:02	so again be a pitch you've sent you 've done Kees down the side
Speaker 1	14:11	Yeah, I've just draw them on so I can see where to put my fingers, so I've set it like a guitar
Speaker 3	14:23	okay, okay. Okay
Speaker 2	14:28	because I'm quite interested in the alternative tuning applications I've got a PhD student speakers deciding his spaces for alternative tunings and other guys.........
Speaker 1	14:41	Do you know Professor Graeme Hare?
Speaker 2	14:43	That names come up
Speaker 1	14:45	he's a composer for strange tunes right yeah. So he's been interested in anyone who builds instruments that do 19 tones it needs some mastering
Speaker 3	15:02	it is somebody at your place
Speaker 1	15:04	He is a professor emeritus so he's linked with MMU mainly classical actually I've heard some of his compositions really really good But he has to get Middle Eastern singers to sing it is apparently because of their traditional music they can pitch in between so anybody want a go of either?
Speaker 2	15:29	Yes
Unknown	15:35	because anyway ????????????
Speaker 1	15:36	Do you want a go of the keyboard? press that......someone did ask if I could get a guitar sound on it..... that's probably the last musical.... Hear the changes so.... strange things the financial here........do you want to try that again..... I mean that was interesting the first time I showed it quite a few years ago someone said ??????????? while he was dancing It with the sound was changing so he was dancing ???????????
Speaker 2	22:00	Have you done this with Bluetooth....
Speaker 1	22:17	In this instance yes

Speaker 3	22:20	How did you find where all the ???? is a quite a simple thing.
Speaker 1	22:56	It depends on how much background knowledge which is why the design interesting because the stuff I've used inside this is off the shelf all the sensors and the brain microcontroller is off the shelf stuff that thry use in secondary school - I use the Arduino technology ???????? you can use them to create things that are unique and That uses the ???? arduino Have you heard of arduino controls that uses one from Adafruit so it's not an official Arduino in the sense that company has made ?out of reach medical ?is still easily programmable by you know college goers some of the stuff is used in primary schools now like the Raspberry Pi so its just a case of having to stick the sensors in to the Arduino and then programme it from the examples but it doesn't have it????????? things????????? Other things could control it, pyrotechnics ????????
Speaker 3	24:52	some shape to a kid his last five years yeah he said go in case they wouldn't buy in right and say not qualified to play it.. recognise that but he said no.
Speaker 1	25:15	I mean it was a balance act between being based on a guitar from the guitar image but not ????? doesn't do what a guitar does
Speaker 3	25:23	sort of mentioned a very good lady here. Yeah, so they do sound Yeah, that's got more values. So
Speaker 1	25:36	again, anything like that feels more like an extension of the computer.
Speaker 3	25:41	That's right one
Speaker 1	25:43	i'm not saying there isn't a use for those either. I mean to use both. But it tends to be a recording studio because it's just easy. But I don't really like to
Speaker 2	26:03	Can I ask you about the software on the on the Mac. is it a Mac patch you are using here..
Speaker 1	26:12	No it's Massive - It's called Massive By Native Instruments I'm running it in Ableton Live okay, bookmarks he can inside it
Speaker 2	26:24	Yes you can I'm just one I'm still wondering about the alternative tunings...
Speaker 1	26:34	when I first built it this is actually different from when it started in five because the microcontroller I had was the one I had all these plugged into and it produced midi data and that was all it produced and it was the wrong type I had to put it into a software programme called Reactor and manipulate it before you do anything useful, right? This one's programme, I put my own programme on it This plugs straight in an iPhone maybe it doesn't have to be A computer where before it did...
Speaker 2	27:11	so that's compatible with the controller
Speaker 1	27:13	its midi it just produces midi.
Speaker 2	27:15	Okay, so have you worked on anything That's not twelve tone before? Sure,
Speaker 1	27:25	???????????I couldn't ???????professor Graeme Hare??????????
Speaker 2	27:26	sure. But to actually turn that into a controller that would work with a piece of software that we found any other way other than to do that?
Speaker 1	27:35	Well if it if this produced 19 toning and it will produce 19 tones so you wouldn't need software to do it.So I could produce 19 tones with Massive...
Speaker 2	27:52	I am still not clear about how you doing that is it and no stress? Are you doing it through pitch band or how you
Speaker 1	27:57	You can do it several ways, pitch bend is the easiest
Speaker 2	27:59	Right. Okay, so no plus pitch bend. Yeah, that's the way we work. Yeah.
Speaker 1	28:14	Very specific formula. You can follow it and then just type it in the computer likes that............
Unknown	28:33	Any other comments.
Speaker 3	28:38	traffic do you think there are any problems with not having a display output on something like that compared to that...
Speaker 1	28:46	There could be it depends I think in practice you wouldn't need ???????
Speaker 3	28:54	displayed
Speaker 1	28:58	that's what I'm using it so I think there's some initial emotion thats when I first did it, I needed I actually needed the video to see where I was but I've improved the gyro. It's just been inside five years you know the technology is a lot easier using the analogue one . Hey
Speaker 3	29:41	how's it going? Oh yeah.
Speaker 1	29:55	I made this In 2011 ive been progressing but now the research????????
Speaker 2	30:07	is this just your research profile starts.
Speaker 1	30:14	No. It's A post-grad PhD
Speaker 2	30:15	So this is your PhD?. Okay.
Speaker 1	30:19	Following on from a Masters. there was a gap in between where i got some commercial funding from the from the university to Explore the idea further
Speaker 3	30:31	When are you..when are you... Are looking for an external examiner?
Speaker 1	30:35	Yes, possibly.
Speaker 2	30:37	If you want to look at my profile and you will see why i am suited.
Speaker 1	30:45	i might need two because I've classed as staff finish early.
Speaker 2	31:00	I would like you to come and do a masterclass on that. that would be terrific.
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Speaker 1	0:00	Any comments? free to ask questions now? Comment? Yeah,
Speaker 2	0:07	I think just one thing that I noticed, especially with it being with the Bazerbow when you're like, tilting it what is that? What is it about the filter?
Speaker 1	0:18	Yeah, it's comparable to the XY joystick? Yeah, you've got the same motion. But it's actually a physical motion.
Speaker 2	0:25	What does it How does it like detect...
Speaker 1	0:27	It's got a gyroscope like, we control? Yeah, we control the games on your phone, mobile phone has gyroscope to tell you which direction is pointing.
Speaker 3	0:40	So it does require like physical movement to get the different sounds?
Speaker 1	0:44	Well, to change the in that set, in that instance, it's tied to what's called the filter, so you'll hear it change in the frequency that's being resonated. It's got two holes there, you'll notice on your mobile phone, there are two small holes usually at the top of the mobile phone. And it's got the same kind of detector as the mobile phone, which is a distance sensor. So when you put your phone to your ear, it knows it's at your ear so it turns the screen off while you're on the phone. But it's the same kind of sensor. So that's why I didn't need to pedal. Because this was doing what the pedal was doing. That make sense. And then I've got pressure sensors in here, so how hard you press is similar to moving the little wheel there. As I say, it produces the same data that's coming out here, if you saw in just data form. I like a series of numbers. It looks similar, but it's just produced with different sensors.
Speaker 4	1:50	The production of the notes like a violin, you got to be a very skilled musician to get the notes can put your finger on the right place, haven't you unlike...
Speaker 1	2:03	I've got a cheap, cheap masking tape on the side to cheat Yeah, it's it's split into 20 frets. But you still need to know where they are. Which is why I put the masking tape on.
Speaker 2	2:20	Similar to like a normal guitar. neck.
Unknown	2:23	Just imagine you couldn't see the frets. Yeah, see you using the the top to see where the where the frets are. But you could make it continuous like a violin, I just haven't done that. I just wouldn't be able to play it and he will be able to compare with the keyboard easily then, it's gonna be completely different.
Speaker 4	2:40	Yeah. So it can only be found on the note. You can't have a half note.
Speaker 1	2:46	You could do because it's got a microprocessor, you can programme. So you can programme it to do that, as I say in this case, I was specifically basically restricting what I played on here, so that I could play it on here. So a lot of the notes were down here, you could see I was having to stretch with the controllers. And so you can actually do more with this at the same time. But you wouldn't, I wouldn't have been able to reproduce it. And the other one I've made, you can do even more stuff on it. But as you say that it becomes more skilled, because you're essentially controlling anything up to 20 parameters at the same time. But you've got to have that coordination. So it's like having playing drums but having 20 lanes instead of four. So it becomes very, I think people possibly prefer the simple, simpler, it's easy to access the simpler design. It still gives you access to a lot of control simultaneously. But you don't quite get with the keyboard. it as a skill comes in.
Unknown	3:52	Any the other
Unknown	3:56	comments?
Unknown	3:56	You look slightly stunned..having had that detour at the start
Unknown	4:05	that's the only group that's had the detour at the start.
Speaker 1	4:11	Well, I haven't come to play.
Speaker 4	4:38	So that to play chords , you've got a single note instruments as you have at the moment haven't you.
Speaker 1	4:47	Not my you could I suppose with this one, you can programme it to the send chords. Yeah, the other one I've made as four strings rather than to the one string. So yeah, she can
Speaker 4	4:58	play the four strings, your whitelist.
Speaker 1	5:01	Yeah, yeah. That's why it makes it more complicated. And we can get harmonies and different sounds with each string, whatever you fancy doing.And the midi protocol is was developed in the 80s. But only within the last five years of this started to develop it, and, we've got something called MPE, which is something like multi phonic expression, it takes midi to a whole new level because of devices like this are starting to be used. traditional midi is struggling to cope so that now advance in the midi as well to cope with the actual data that's being sent.
Speaker 5	5:46	The difference obviously, with the keyboard, you rely much more than just listening to the sound or the music as being creative was obviously the Bazerbow of the performance is more engaging,
Speaker 3	6:04	outward facing isn't it, you're you're you're looking out your audience rather than like head down and sort of fiddling buttons. And the slope
Speaker 1	6:15	Having both usable in different situations. This is mine. So I do use it, but I tend to use it in a studio context, but I want to put something into the computer. So I am just on my own. And it allows me to do that because of all the controls on there. And I am on a computer you generally only programming one or two things at a time to get the precision but if you are performing that would be wouldn't prefer a person more visual. And the other question is to anyone wants to go with either the both setup. So you can have a go of either. There's only one of these in the world by the way. Iv'e had guitarist play this, and I've had a lady was 80 and never played an instrument in her life. And she was just whizzing around the head and it sounded brilliant. You don't have to think of it as necessarily making a musical sound out but just having that experiment. Do. You want weird sounds, more melodic sounds.
Speaker 5	7:34	totally weird sounds. That sounds good.
Speaker 1	7:38	Oh, that's why it's been awkward. You do actually find it's reproducible, reproducible, so you can be precise for that, but again it takes practice. Someone was saying the other day the knobs have a maximum and a minimum And you can feel it, where that dosen't it's free motion so you have to know where the maximum and mimiums are. takes a while to get used to being able to reproduce an identical sound. That's more of a melodic sound. Feel free to
Speaker 7	9:20	Who was the one who was doing it with like drumming sounds

Speaker 1	9:32	That was me Yeah. Press the right hand side.............each sound the gestures do different things to the sound.... These are just presets that I've used deliberately from a commercial synthesiser that's available. And it's got a traditionally commercial software and synthesises into 8 parameters, which is why I've worked in groups of eight. And you just tell it, what gestures information you want tied to what sound change. I mean, you could make you do anything. But for me, it makes sense that your pressure does pitch with the left hand. So there's certain things that make sense, and then certain things that you could experiment with. But that's part research really. So as part of the research is more psycho psychology based music psychology around looking at how people perceive performance, rather than instrument design. So that won't get submitted the the people's perception of a performance and design relating to this is what I'm looking at. So I've got three areas of research, empathy, which looks at how imitation, learning how we imitate how we understand each other through empathy. And then communicative musicality, which is a phrase coined by Colin Trevarthan, which insisted on now because it's the main guy people point to with child psychology. They use it as a base point for music therapy. He basically has done a lot of studies with newborn babies, 30 minute old babies, where he studied the interaction with the mother. And this is very, you know, the conversation that the mother and baby have the Goo goo gah gags, they call it proto conversation, mother ease, and this music in there inate, baby's born with this ability to imitate the mother and have a very musical response with the mother. And it creates bonding between the baby and the mother, which is why it's really interesting for music therapists. And Colin Trevarthan worked with an audiologist that found these intonations that are incredibly musical and the rhythm. And the turn taking that they do is really, really precise. And that then, that ability to imitate is what helps us to learn things, because we did it when we were born. And we carry on doing that to learn pretty much everything. We do it by looking and imitating, which then leads you into mirror neurons. Have you ever heard of mirror neurons. And it was a phrase on telly that was being used a lot, coined a lot. What happened in the 70s, they found that studying a monkey in the brain and the monkey neurons fired certain neurons when a monkey grabs a piece of fruit. But the same neurons fired when the monkey watched someone grab the fruit. And they call them the mirror neurons. And the idea is, so they believe that the monkey mind is watching is preparing to do the action. So the same neurons are firing as they would if they're actually doing it. So when we're watching something on mirror neurons are firing in preparation to do something we never done before. So that's interesting to me, because if you've seen an instrument, I've seen the violin manytimes, but I've never played them. But I'm certainly myself because I understand what what feels like and what metal feels like in streams, that if I pick one up, I'de understand it mechanically, I'de understand that if you press here, you get a higher pitch. And if you pluck it, you'll get a certain sound, it will be very good because after practice, but without actually having the mechanics on how to get a sound out of an echo, pluck it and now it's gonna make a metallic sound. Which leads you on to my last area of research which is mimetic participation. Arnie Cox's using this theory to describe things like air guitar. So why is it that we imitate and we desire to imitate musical performance air guitar being the most common? Why do we sing along Why do we want to sing along is always someone in a classical concert singing along with them. But it's built into us we want to join in, we don't want to be sat watching wants to join in so mimetic participation looks at that as well. So from my point of view, where digital and electronic music seems quite insular I'm looking at ways of why that might be a way that you can expand into the audience and draw people into an electronic environment. Because it doesn't seem to be like that at the moment. Just to give you a background, about the background, and that's that's the research, but this is kind of a test of those theories. So that's been designed using those ideas. That's why it's very visual. In its gesture, as opposed to little totally know. And that's why it's out of wood as well that was really important. And anything for me that's like this is plastic feels just like an addition to the computer rather than a musical instrument it doesn't feel like an instrument to play even though it's kind of shaped doesn't feel like a piano to play. Where that it's a piece of wood even though it doesn't make any sounds it to me. It feels like you are holding an instrument sounds important. And as much as I could hide the plastic in the electronic so the latest ones is the electronics that hit me even more. I wonder what they'd say if you did it for your dinner exam? Yeah. Yeah. You can do you want a go? traditional sound? Yeah, I can put you a guitar sound
Speaker 4	16:35	Yeah, that's a good idea..
Speaker 1	16:45	see the press with him See some of the gestures do transfer from a guitar, like guitar gestures so that being acoustic doesn't have a filter in it. So you wont hear quite as much happening when you twirl If you are playing a base sound and move it you'l find that motion does a lot more...
Speaker 4	18:03	Super...
Speaker 1	18:19	The last group I had is in the school and some of them were theatre based. And the course because it's data coming out of a digital instrument you don't, you don't have to just limit it to music you can control lighting, anything in the theatre, you conventionally controlled with that technology. They some of them were interested with the light that someone on the stage could manipulate their surroundings, and pyrotechnics. I think that's the advantage of digital is once it's digitised, you can then manipulate it to do anything you want. This digitising it in the first place, and what gestures do you choose? So this this might seem unique. But actually, within the world of research, it's not that unique in the sense of the sense of technology is quite old. People have been making really weird instruments for a long time. And you just don't normally come into the commercial world. But you can get instruments that just don't look like an instrument very strange, like a spear are all sorts of shapes, battons. But they all use a similar sense of technology. I've got more I've got in between so slightly traditional. So people will recognise it as a kind of guitar. But then it's extended. It's does things that guitar doesn't do, I think if you just appear with a knob or something, you wouldn't really know what it's doing. Anyway, I wouldn't have a starting point. So I'm not sure if the intention at some point is to make something other than a guitar. It should have been drums. drums are very gestural anyway, so there's loads of Trump stuff out there as well. digital stuff in the last five years. Guitarists tend to be a bit shy of electronic songs.
Speaker 4	20:30	Why isn't the wooden type of instruments, which you you can imagine, by force and frequency of blowing down a tube that that could be where controlling sounds,
Speaker 1	20:50	Akai make one and Yamaha and they've been out for a long time, but they just never taken up. I think most clarinettist and saxophone players is a very traditional in the mindset because that's how the train that's how they learn. And so they generally don't go down the route of accessing digital same as the violin. electric violin has been around for years but there's not many violinists that will pick up electric violin. So you've got Michael Kennedy he likes his electric, and you've got Vanessa May is not the way that you learn your instrument. I guess. There is another one called the eigenharp, which is it's quite hard to explain is long and thin and it's got lots rather than just a continuous controllers got lots of buttons like frets, there's four of them four rows, and they've got pressure sensitivity in each direction. So inwards, up, down left and right and on the top of it is a reed. So you can activate the sound, you can either touch it and activate the sound that way or you can blow into it. I've not actually ever seen anyone play that commercially. I've only seen it in terms of research context, is commercially available. You don't see many people playing saw the same style labs make digital guitar and Pendulum that black drum bass band. And it's again it's got buttons where the frets should be influenced by StyleLabs. music using StyleLabs one as well it uses an iPad where you touch the iPad as well.. they're out there. I think for me those move away from the idea of it being an instrument because they'r all plastic you know, I can construction which..although the Eigenharp's quite polished. Likes I say there's lots of stuff out there when you start researching I thought oh I've made this and no-one else has and when I started researching I thought not quite so unique as I thought it was. Any other questions? So thank you very much for coming and completing especially since the detail that was exciting. This is the last one I think I'm going to do now. So this case of putting the data together Lots of writing about it. Applause... It would be interesting to see if ??? wants to come for me to come in and play.
Speaker 2	24:06	Yeah, I
Speaker 1	24:08	don't know what the links are with Manchester Met for some of the other Uni's, because the Salford in Manchester that heavily based in music pop music and the Royal Northern College of Music which Manchester Met that ratified the degrees for them...
Speaker 2	24:29	master classes and stuff.
Speaker 1	24:32	I don't know how much music I know they'll be recording
Speaker 2	24:40	production costs for people at first you get into the second and third. But yeah, first is is just eating like your own production costs.
Speaker 6	24:52	Like you can just do
Unknown	24:54	it yet. Notice this. Secondly, you've got that she gave musicianship and I told you about.
Speaker 2	25:01	recording samples and midi all that software. So that being
Speaker 1	25:07	Speak to my boss man..
Speaker 7	25:12	you should really

Speaker 6	25:14	pay for
Speaker 2	25:22	plus one it's more, I think got more portable as
Speaker 1	25:28	well. It's actually wireless even though it's not wireless,I've just deliberately plugged it in because that's plugged in.. to kind of keep it comparative. That was the first thing that someone said to me when I presented it a few years ago, it was a dancer. And he did I wasn't it didn't play an instrument but he got hold of it after everybody had gone home, we were packing up because he had some stuff he was presenting as well. And he started dancing with it and the sound change so he changed and there was just this loop that he just couldn't get out of it and just enjoyed moving around and then finally his movement was changing the sound and then he could move with the sound we were there for about half an hour and just playing it
Speaker 3	26:11	in clubs. And the musical happen
Speaker 1	26:21	probably quite A niche area, well it is a niche area because of course DJ like their lights and some fireworks and things so that maybe not as interested in playing an instrument is still very much like their buttons and grid buttons Launchpad and things like that. Whether they want to be bothered learning an instrument for them musicians don't tend to go so far as the electronic music like DJ's though it is moving on that electronic music really is being used in a lot of areas. You hear it on classic FM now as part of the film night, because Hans Zimmer is being played and game music is being played on Classic FM as well. But they tend to mix electronic with acoustic the thing that's introducing electronic sounds to a new audience who traditionally want to only listen to classical music and suddenly hearing these atmospheric sounds that work well with the acoustic.
Speaker 3	27:21	Kim
Speaker 1	27:31	Yeah, this is focus forms is interesting going over them, I've been enjoying it over the last couple of days.
Transcribed by https://otter.ai		

Appendix I

Screenshots of Slider Data in Ableton Live

This appendix contains all the main test phase Ableton Live recording sessions highlighting the slider data.

Test 1A Mc

Figure I.1: Test 1a Particpants 1 to 4 Mimetic Controller

Test 1A Kc

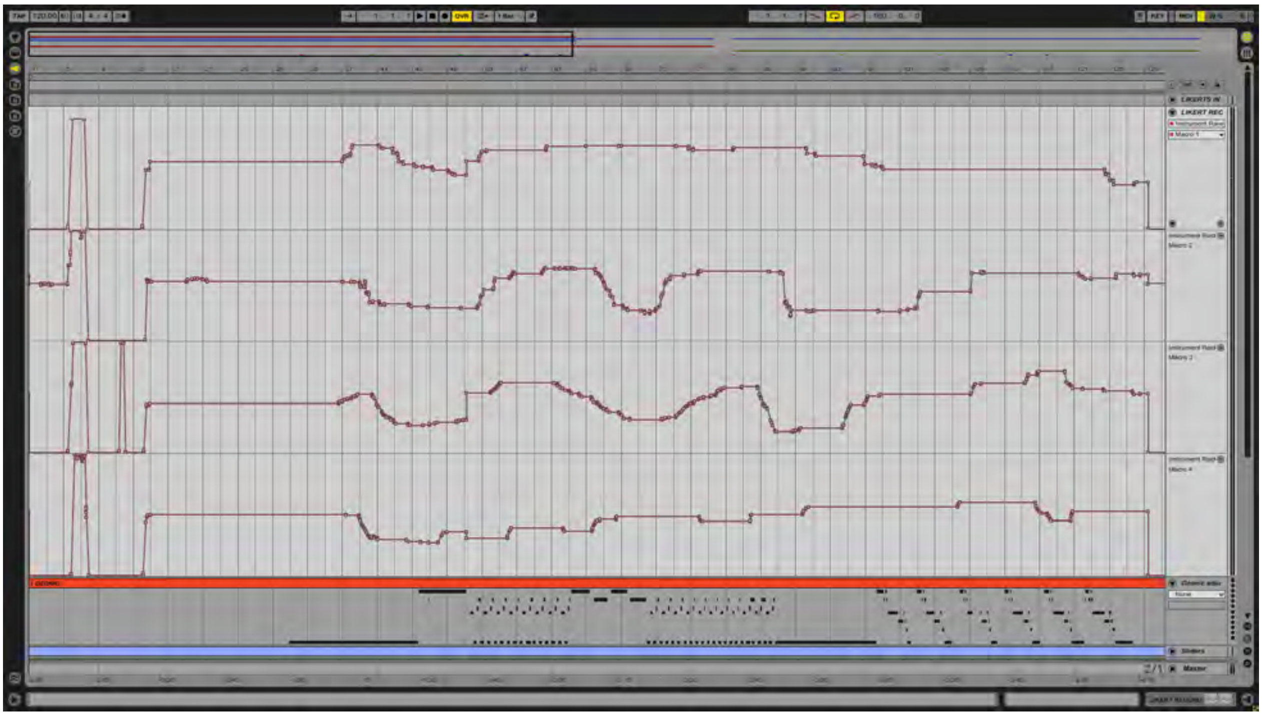

Figure I.2: Test 1a Particpants 1 to 4 Keyboard Controller

Test 1B Mc

Figure I.3: Test 1b Particpants 5 to 7 Mimetic Controller

Test 1B Kc

Figure I.4: Test 1b Particpants 5 to 7 Keyboard Controller

Test 2 Mc

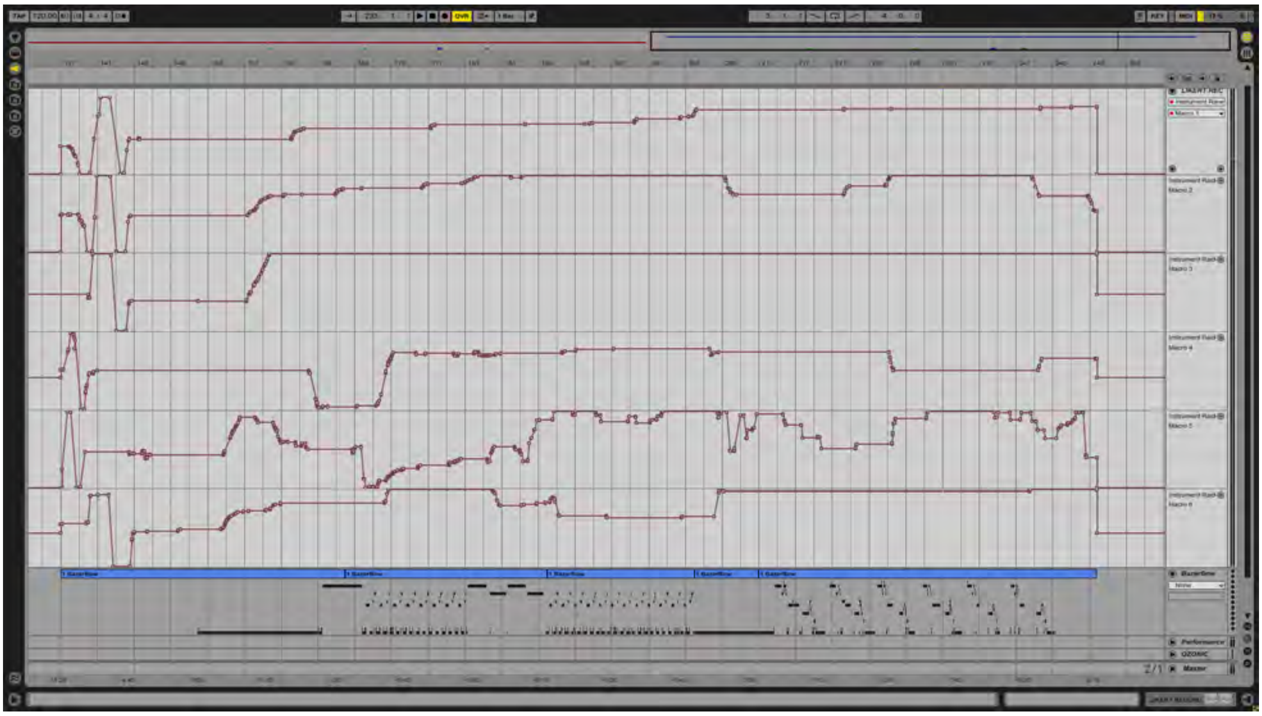

Figure I.5: Test 2 Particpants 8 to 13 Mimetic Controller

Test 2 Kc

Figure I.6: Test 2 Particpants 8 to 13 Keyboard Controller

Test 3 Mc

Figure I.7: Test 2 Particpants 14 to 20 Mimetic Controller

Test 3 Kc

Figure I.8: Test 2 Particpants 14 to 20 Keyboard Controller

Test 4 Mc

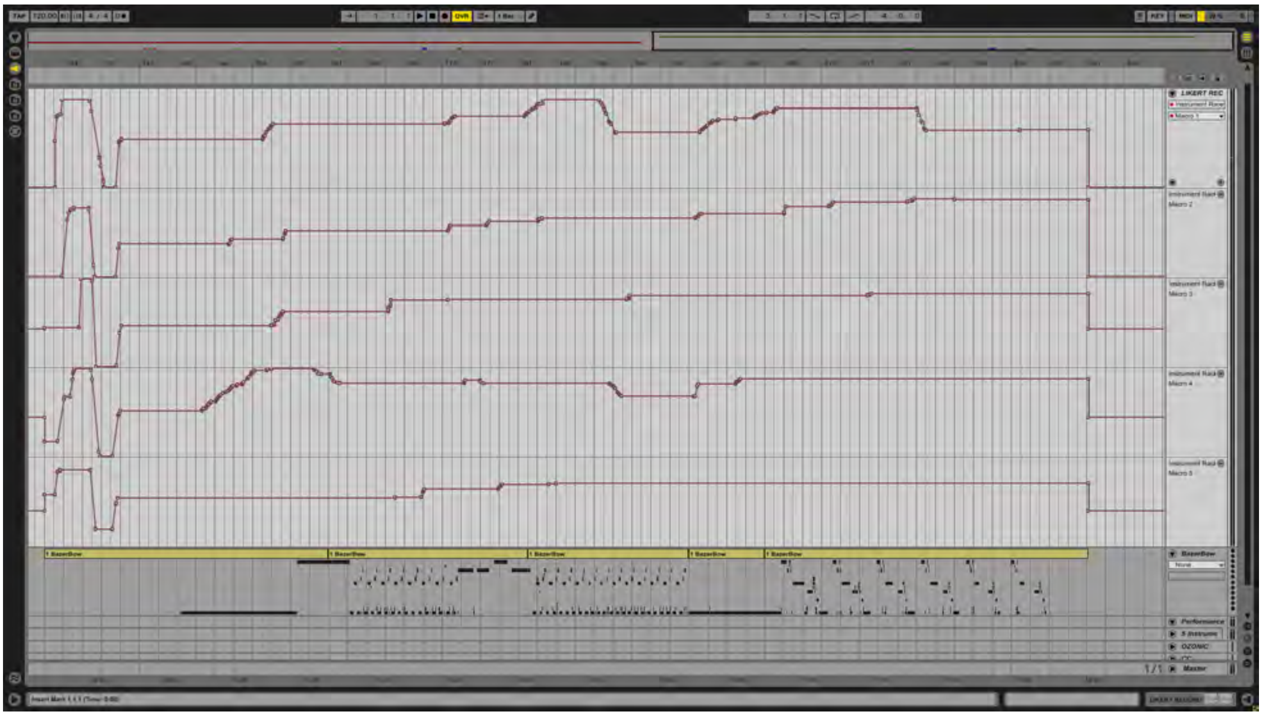

Figure I.9: Test 2 Particpants 21 to 25 Mimetic Controller

Test 4 Kc

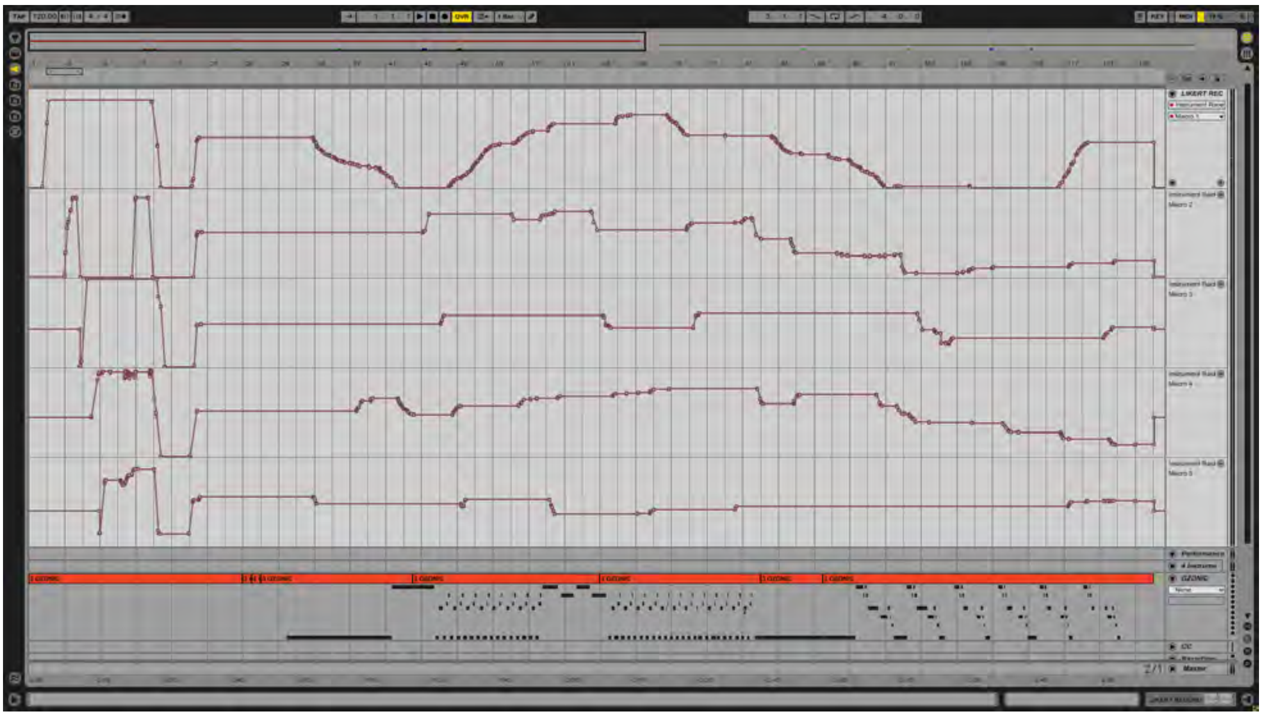

Figure I.10: Test 2 Particpants 21 to 25 Keyboard Controller

Appendix J

Slider Charts

This appendix includes the slider charts of both performances from each session. The charts were generated from the slider and performance MIDI data converted to csv.

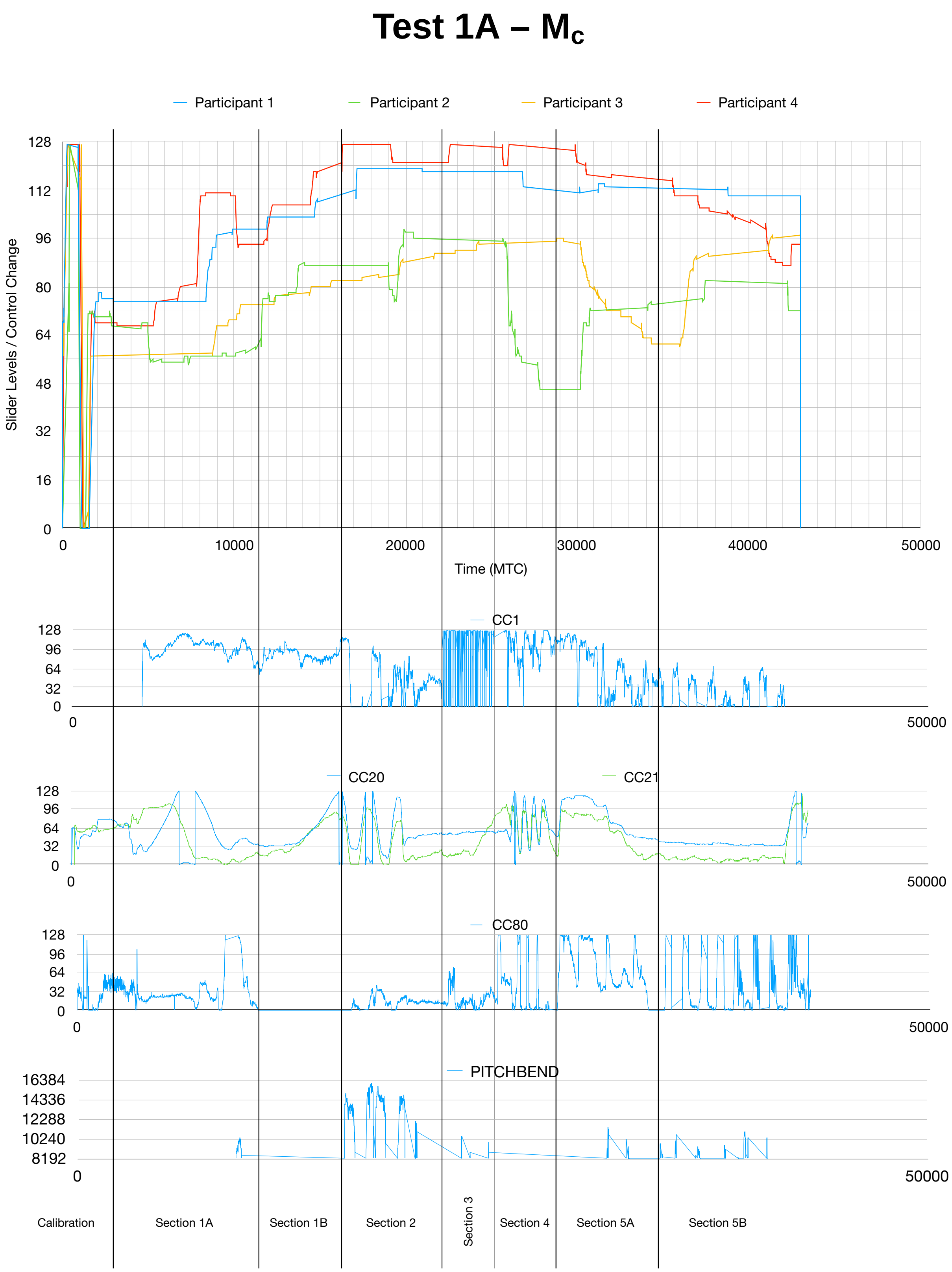

Figure J.1: Particpants 1 to 4 – M_C

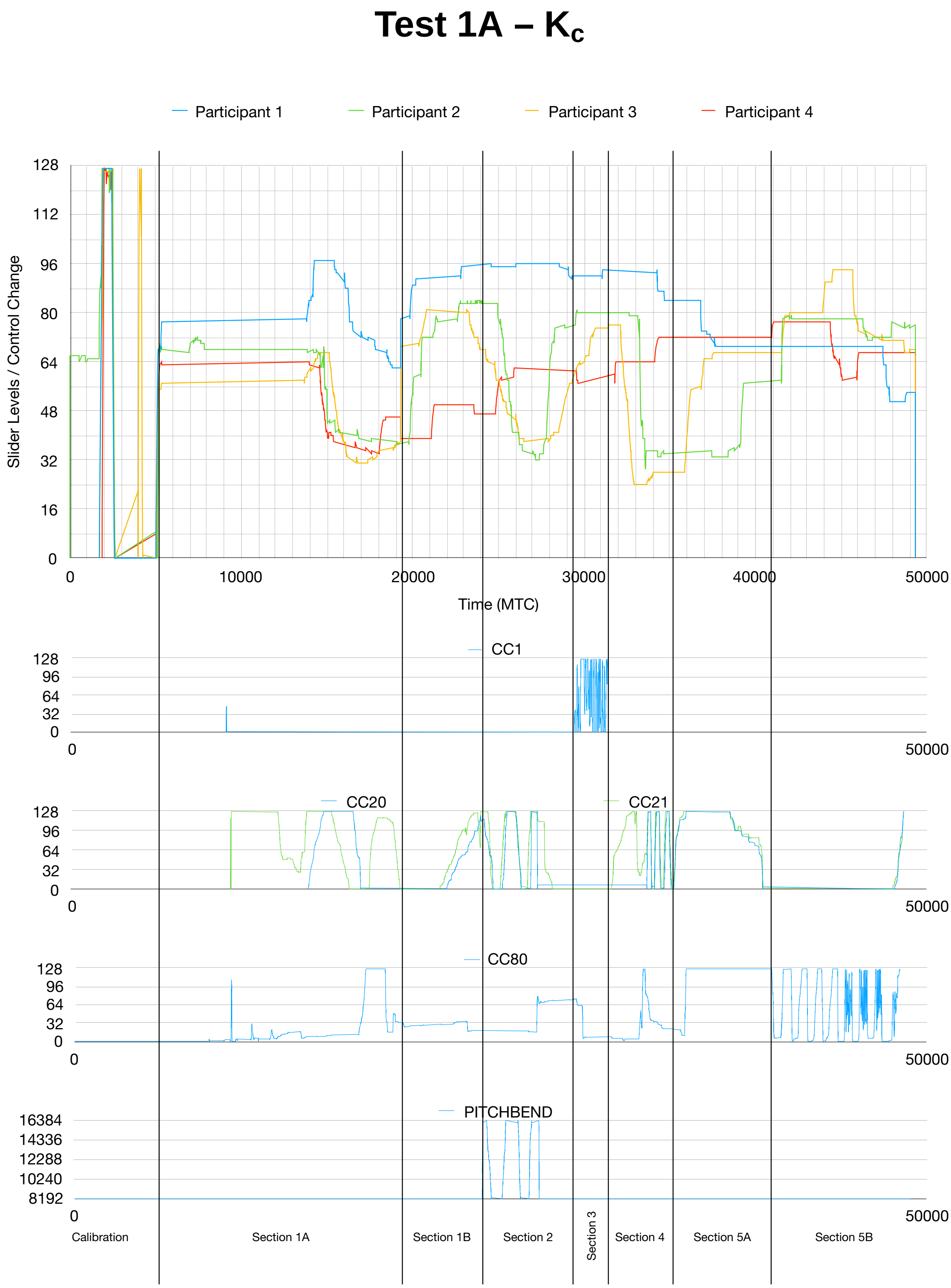

Figure J.2: Particpants 1 to 4 – K_c

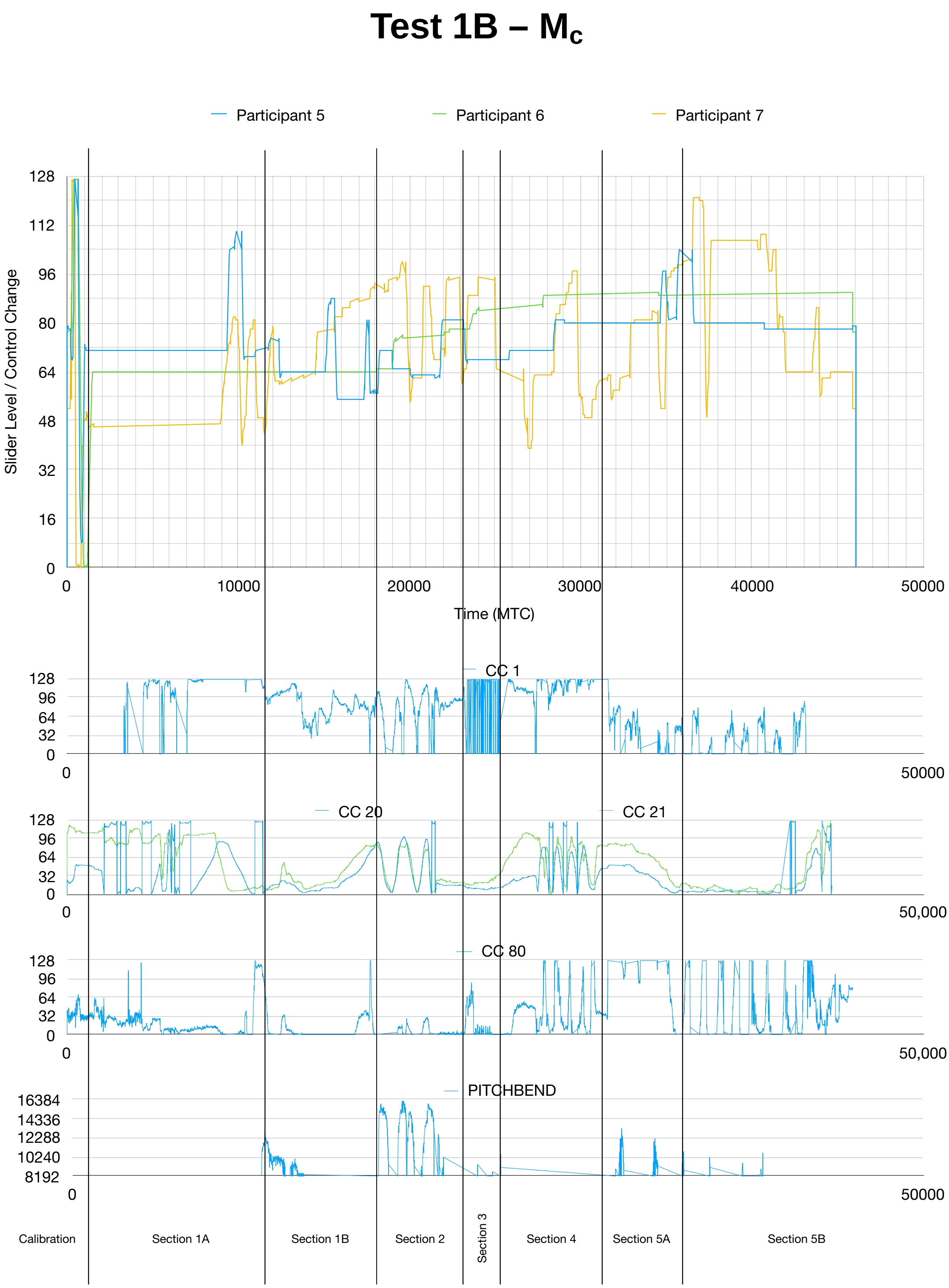

Figure J.3: Particpants 5 to 7 – M_c

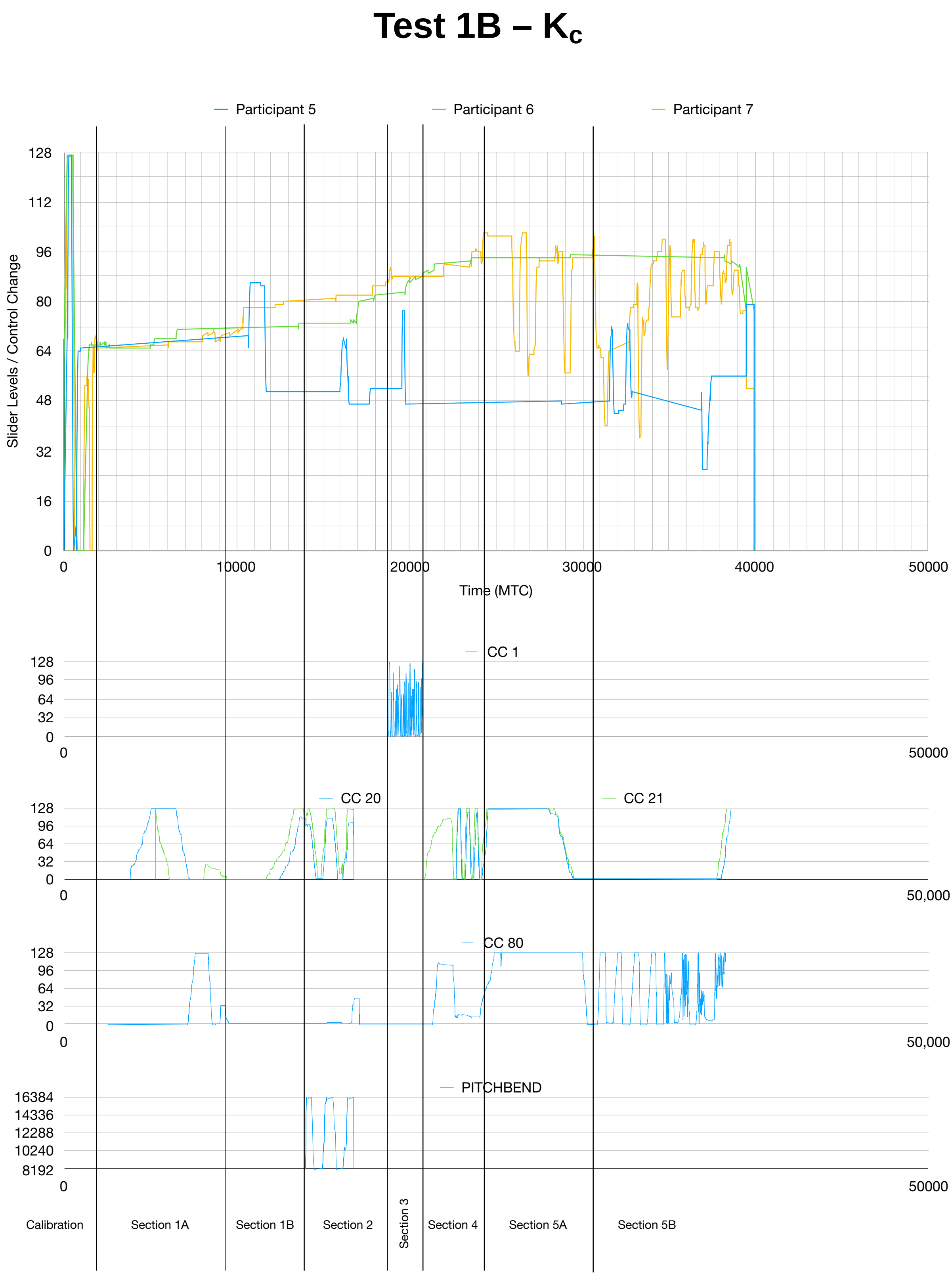

Figure J.4: Particpants 5 to 7 – K_c

Figure J.5: Particpants 8 to 13 – M_C

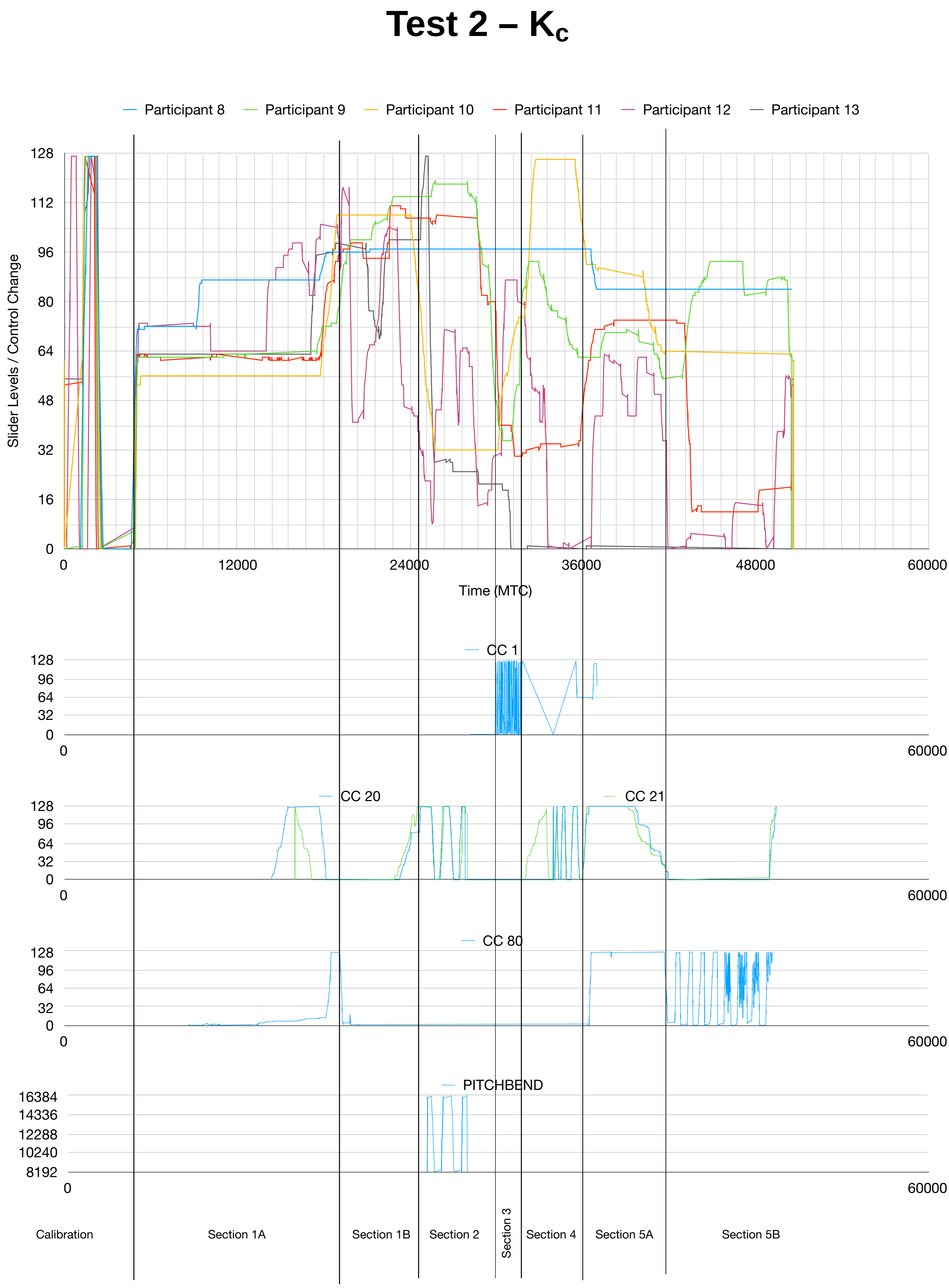

Figure J.6: Particpants 8 to 13 – K_c

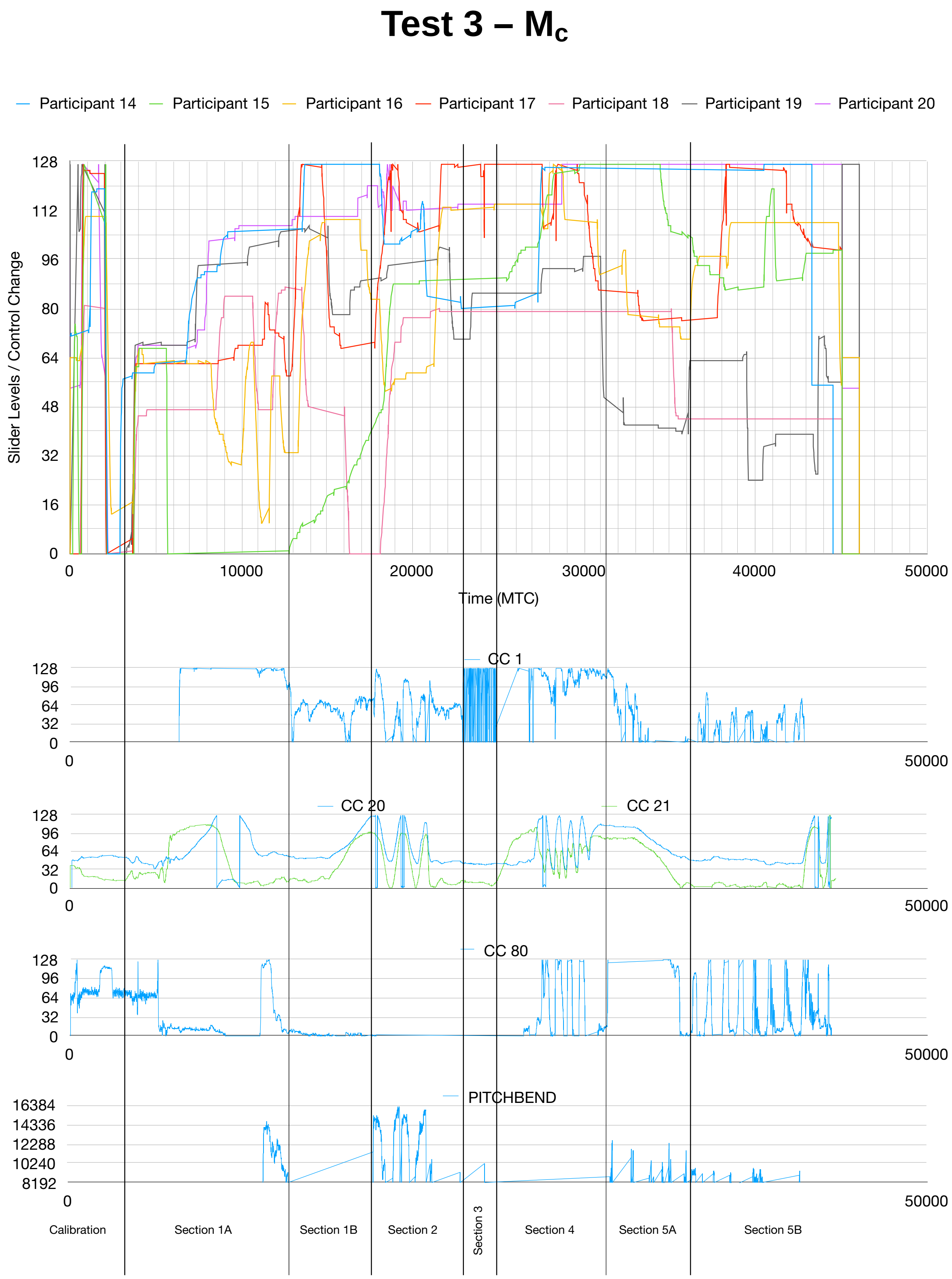

Figure J.7: Particpants 14 to 20 M_c

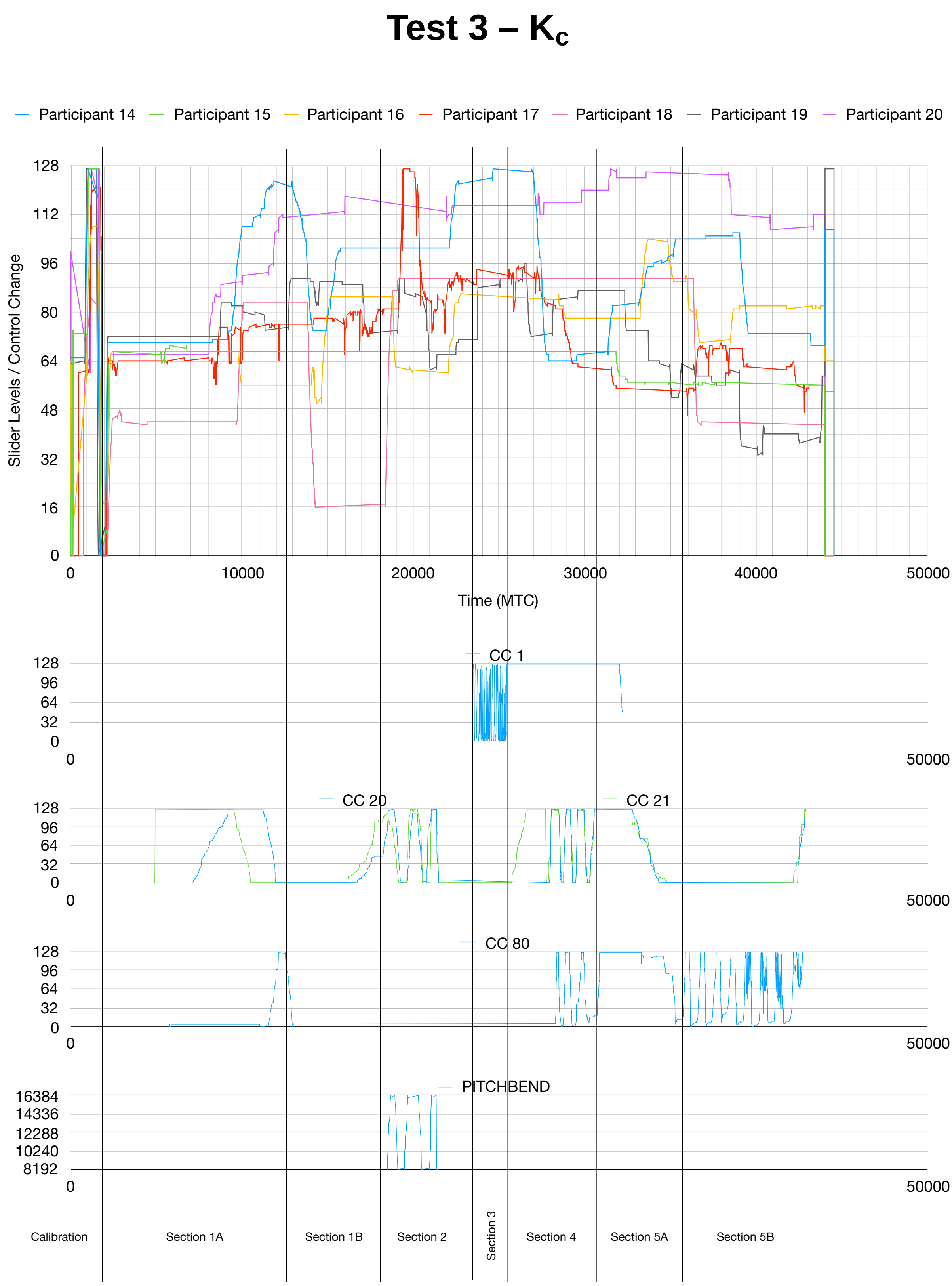

Figure J.8: Particpants 14 to 20 – K_c

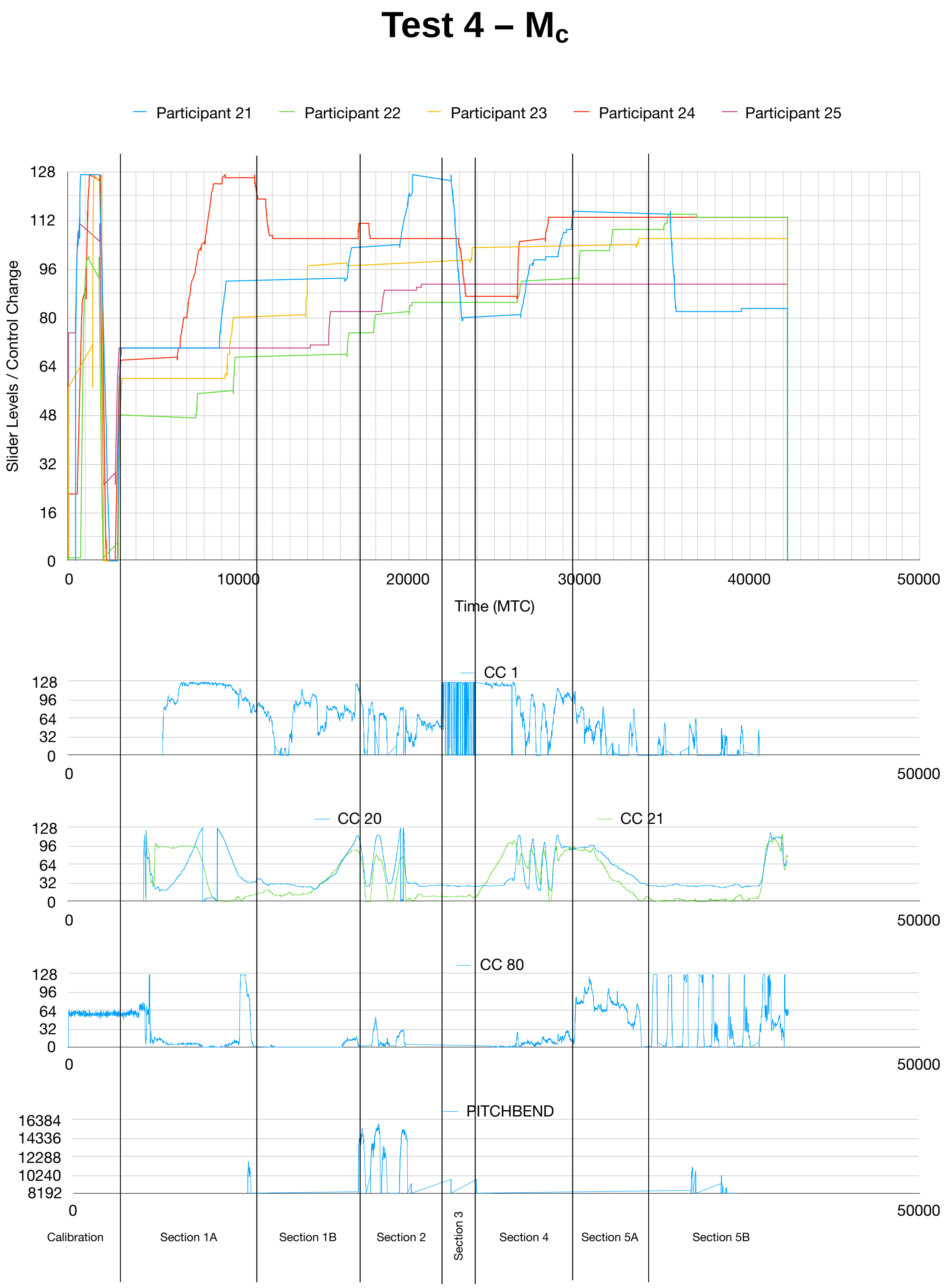

Figure J.9: Particpants 21 to 25 – M_C

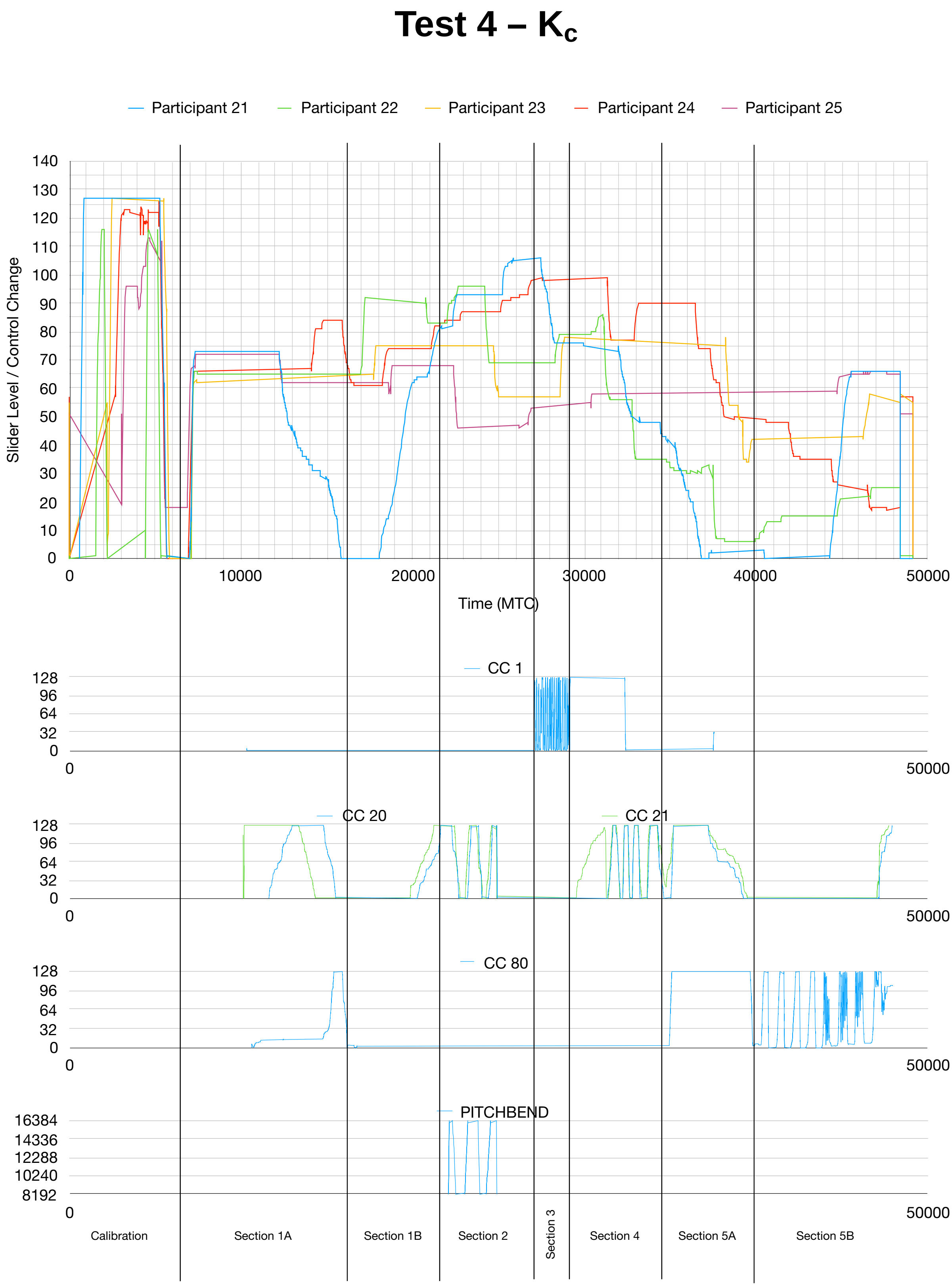

Figure J.10: Particpants 21 to 25 – K_c

Appendix K

Calibrated Percentage Engagement Levels

This appendix contains the CPEL charts derived from slider data focussing on participant minimum and maximum engagement levels.

M_c – CPEL Sections 1 to 5

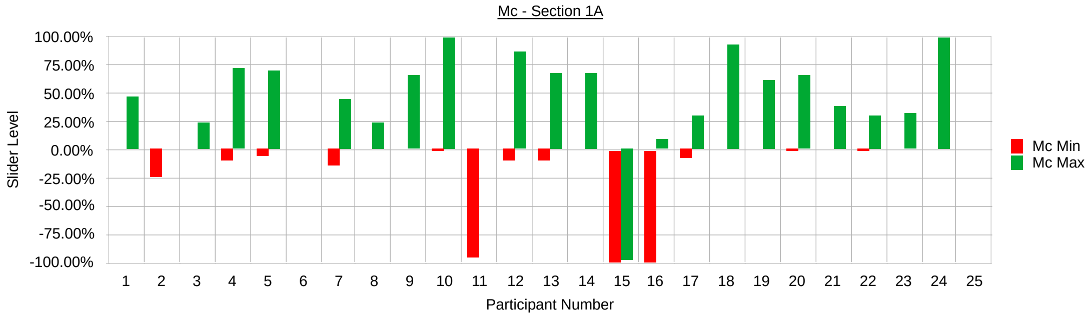

Figure K.1: Min and Max Levels for Section 1A

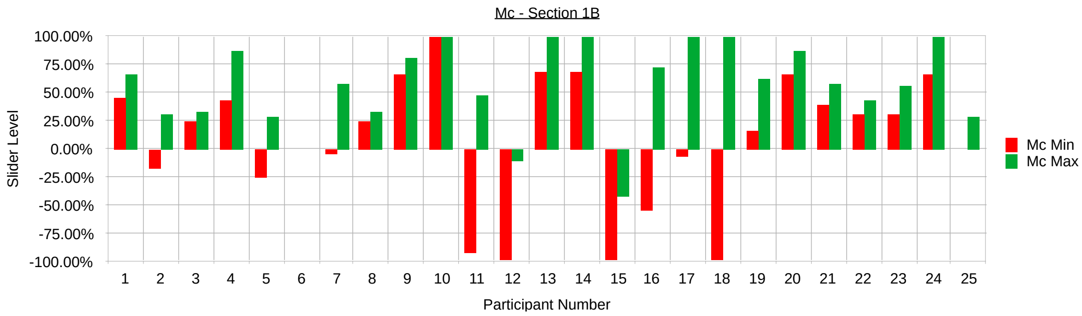

Figure K.2: Min and Max Levels for Section 1B

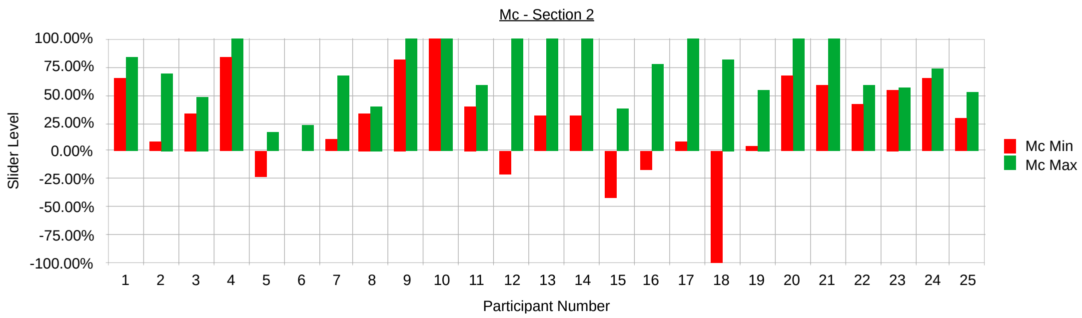

Figure K.3: Min and Max Levels for Section 2

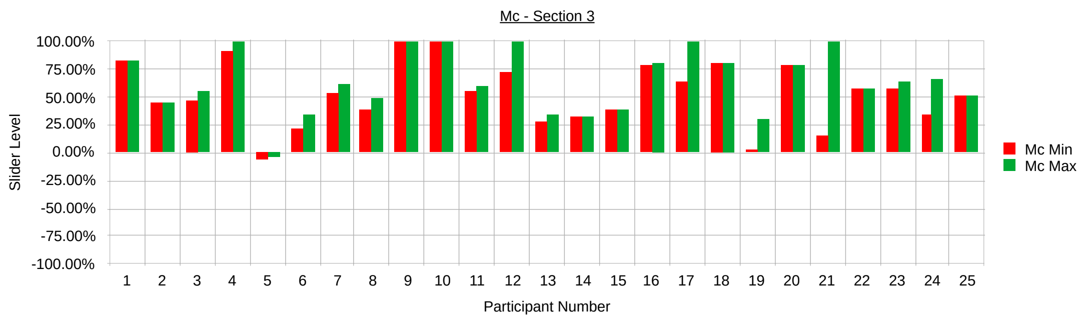

Figure K.4: Min and Max Levels for Section 3

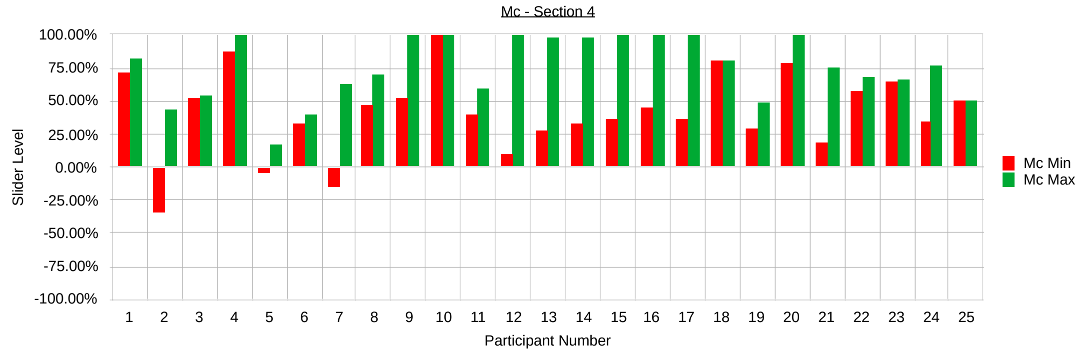

Figure K.5: Min and Max Levels for Section 4

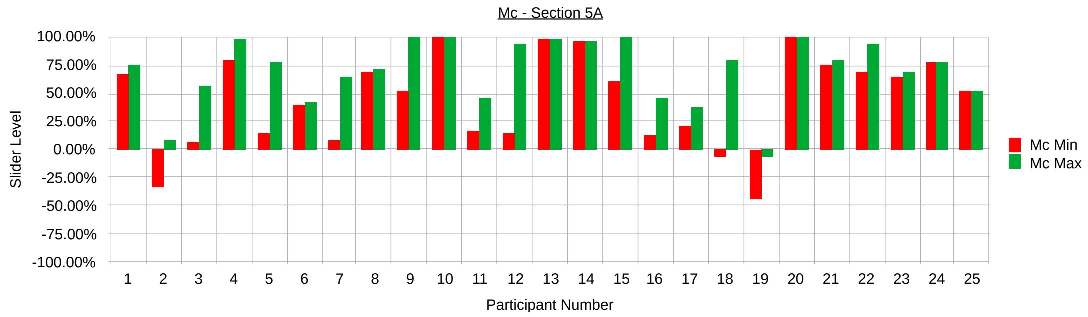

Figure K.6: Min and Max Levels for Section 5A

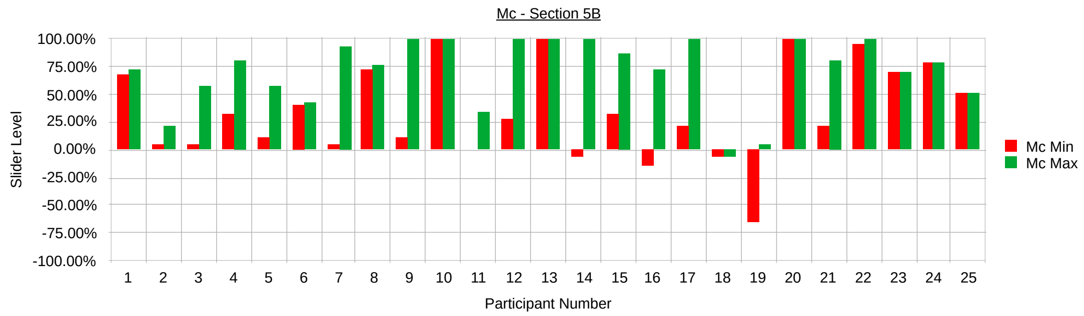

Figure K.7: Min and Max Levels for Section 5B

K_c – CPEL Sections 1 to 5

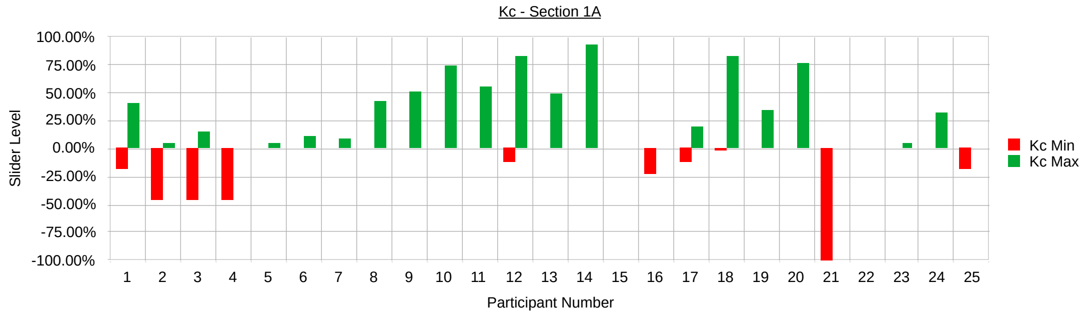

Figure K.8: Min and Max Levels for Section 1A

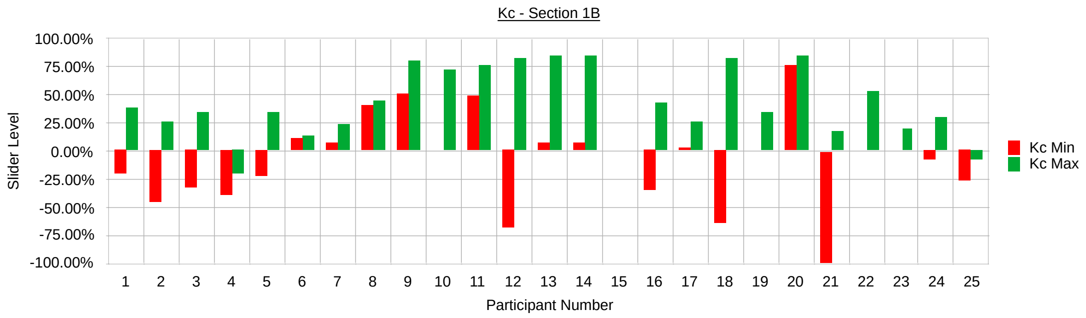

Figure K.9: Minimum and Maximum Levels for Section 1B

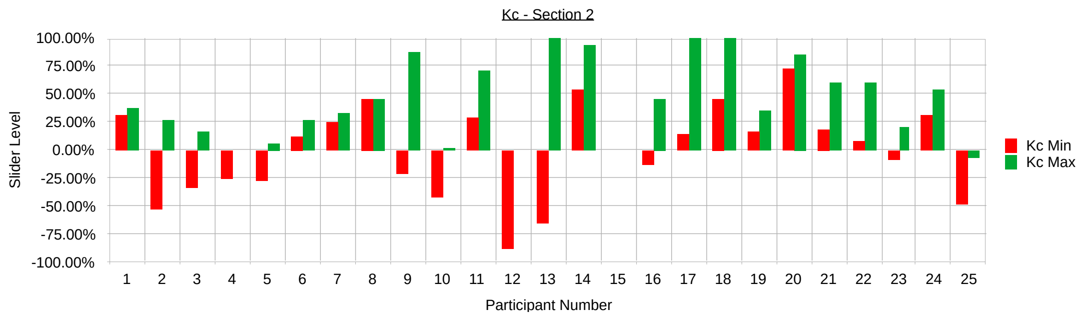

Figure K.10: Minimum and Maximum Levels for Section 2

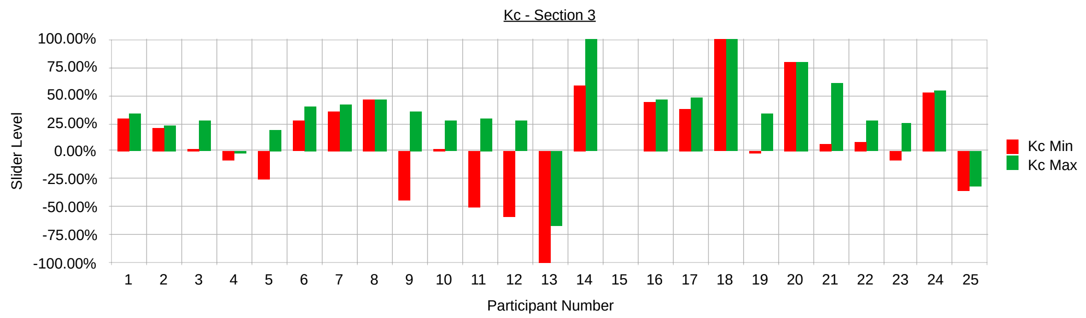

Figure K.11: Minimum and Maximum Levels for Section 3

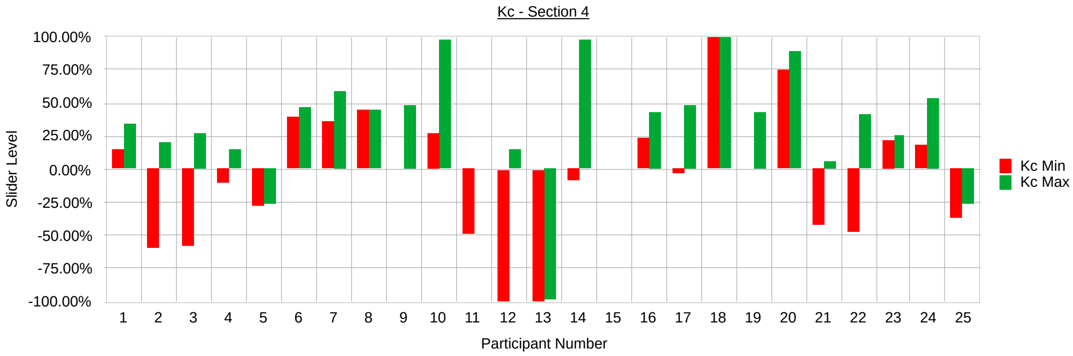

Figure K.12: Minimum and Maximum Levels for Section 4

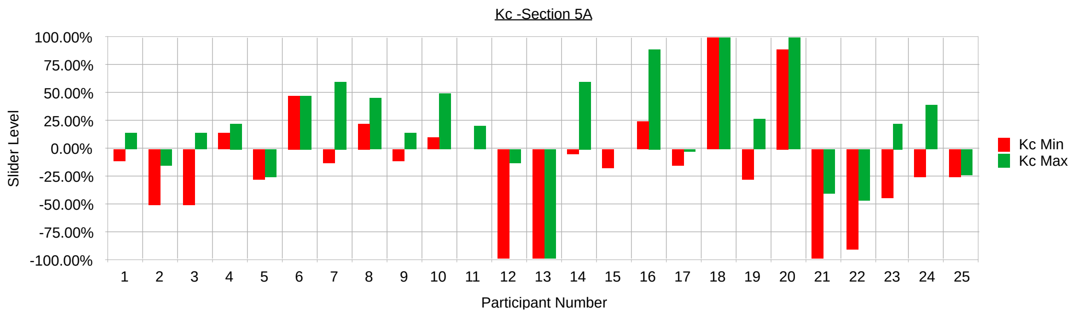

Figure K.13: Minimum and Maximum Levels for Section 5A

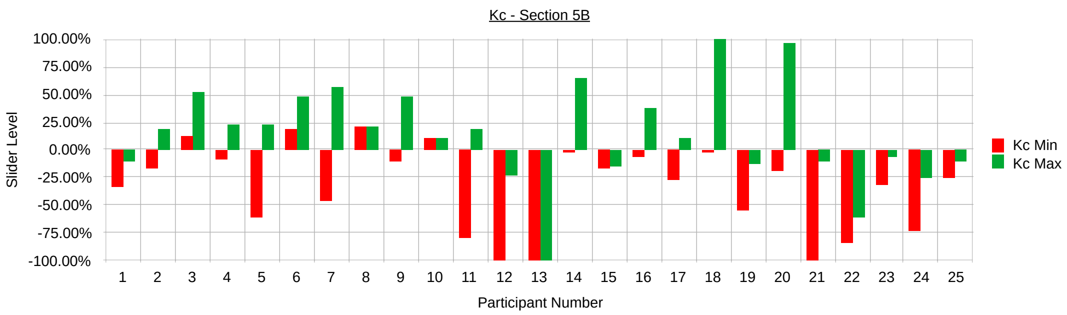

Figure K.14: Minimum and Maximum Levels for Section 5B

Min & Max Levels Across All Sections

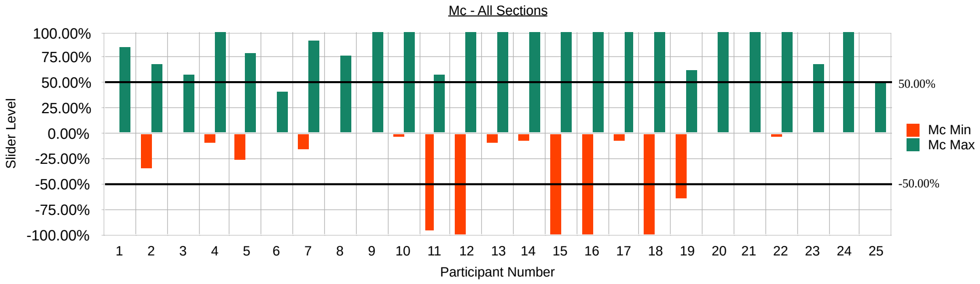

Figure K.15: M_c - Min and Max Levels for All Sections

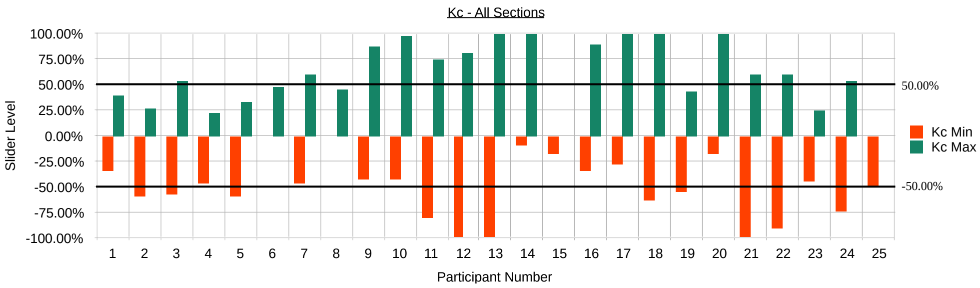

Figure K.16: K_c - Min and Max Levels for All Sections

Min & Max Average Levels for All Sections

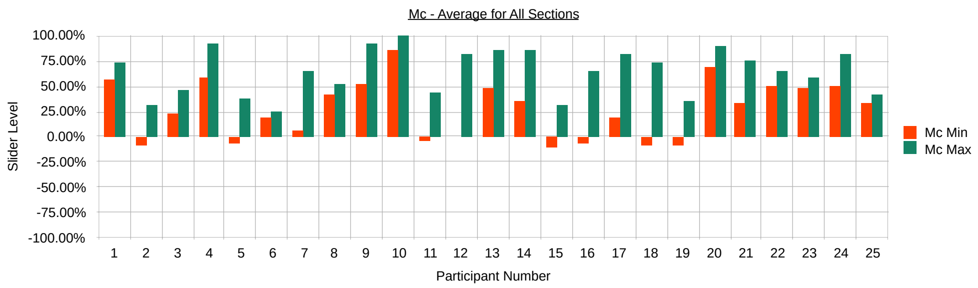

Figure K.17: M_c - Min and Max Average Levels for All Sections

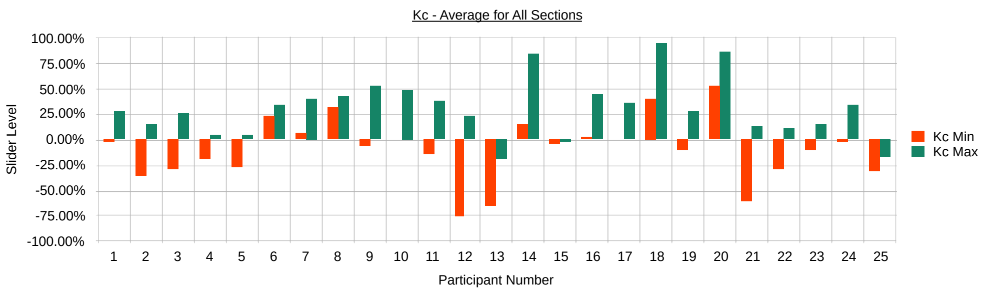

Figure K.18: K_c - Min and Max Average Levels for All Sections

Min and Max Average Levels for All Participants

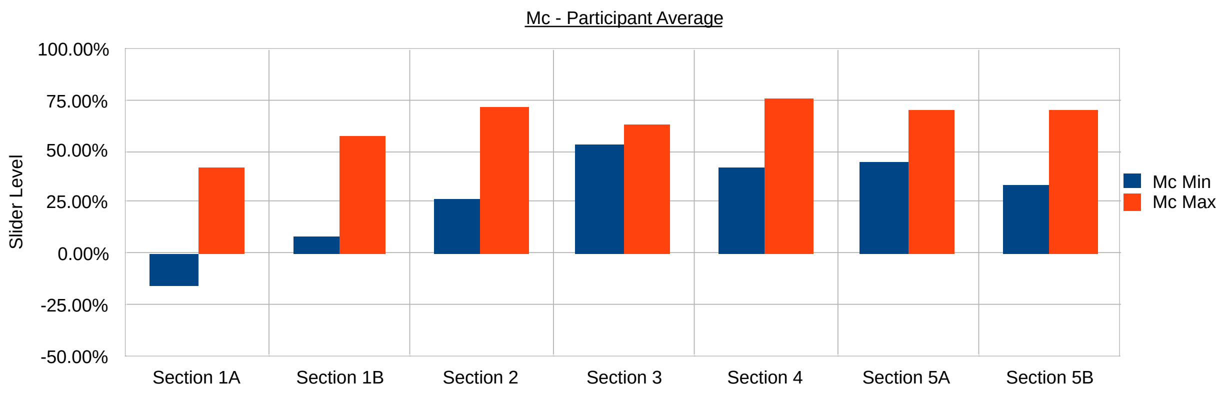

Figure K.19: Mimetic Controller

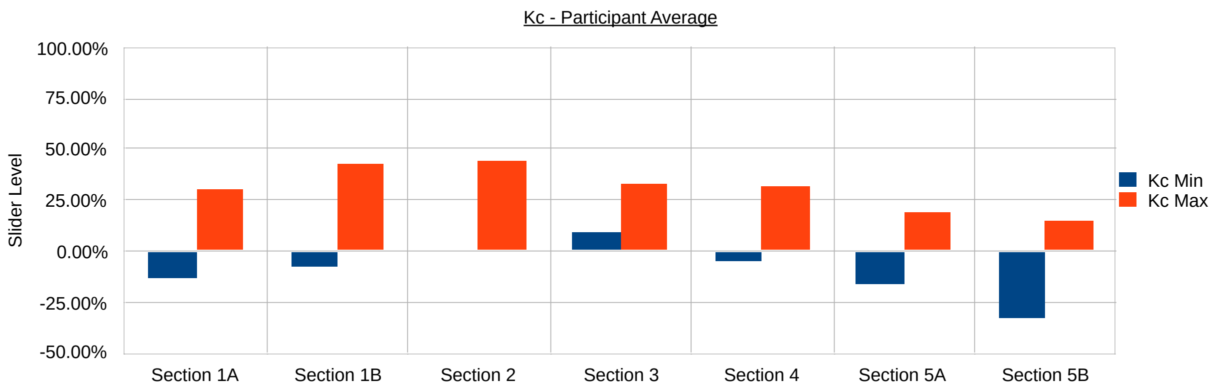

Figure K.20: Keyboard Controller

Min and Max Average Levels for All Sections for All Participants

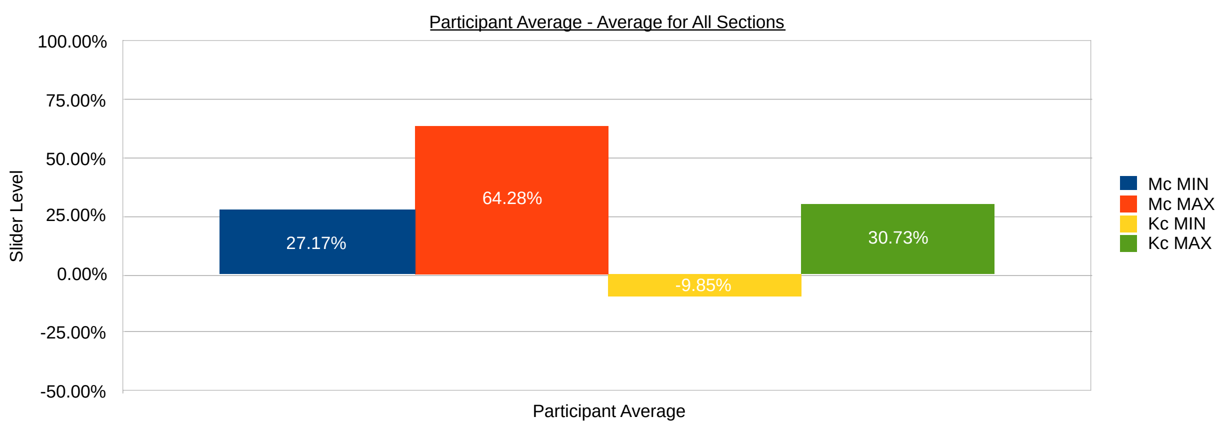

Figure K.21: Likert data

Appendix L

Cross-table of Questionnaire Data

This appendix contains all the questionnaire data that was placed in a cross-table for analysis. This includes demographic data, MUSE scores, Mimetic Response data, post-performance and open-ended question data.

Demographics and MUSE data

Participant Number	4. Age	5. Gender	6. Education: What is the highest degree or level of school you have completed? If currently enrolled, highest degree received.	7. Income: How would you describe your income level?	Index of Music Listening (IML)	Index of Music Instrument Playing (IMIP)	Index of Music Training (IMT)	I (Cognitive and Emotional Regulation)	II (Engaged Production)	III (Social Connection)	IV (Physical Exercise)	V (Dance)
1	25 - 34	Male	Masters degree or equivalent	above average	20	66.5	2	32	38	15	11	5
2	25 - 34	Male	Higher education	average	3	0	1	30	0	8	12	0
3	25 - 34	Female	Degree or equivalent	below average	10	0.78125	6	29	23	11	8	7
4	35 - 44	Male	Degree or equivalent	below average	5	0	0	23	0	11	9	2
5	25 - 34	Male	Degree or equivalent	average	5	0.5	1	27	10	9	11	2
6	25 - 34	Female	Higher education	average	5	10	3	33	26	12	11	8
7	25 - 34	Male	Degree or equivalent	average	12	0	3	32	7	12	12	8
8	65 - 74	Female	Degree or equivalent	above average	5	60	2	23	26	8	10	8
9	65 - 74	Male	Doctoral degree	above average	2	8	0	9	18	8	0	0
10	65 - 74	Female	GCSEs or equivalent	average	5	0	2	19	0	10	0	2
11	65 - 74	Male	A Level or equivalent	above average	10	0	0	25	0	0	3	0
12	75 +	Male	Degree or equivalent	average	3	0.09375	2	23	17	6	2	4
13	65 - 74	Female	Other qualifications	average	3	0.0625	2	31	6	10	13	10
14	35 - 44	Male	Degree or equivalent	above average	10	40	4?	33	40	13	11	5
15	45 - 54	Male	Degree or equivalent	average	10	100	10	33	43	13	9	0
16	35 - 44	Female	Degree or equivalent	average	5	1	3	33	30	10	1	6
17	18 - 24	Male	A Level or equivalent	above average	10	0	2	16?	3?	12?	10?	0?
18	25 - 34	Female	Degree or equivalent	average	15	24	5	32	41	11	13	8
19	45 - 54	Male	Masters degree or equivalent	above average	25	450	9	33	43	9	12	5
20	45 - 54	Male	Doctoral degree	above average	15	441	10	29	40	5	7	4
21	45 - 54	Male	Masters degree or equivalent	above average	15	0.125	3	33	1	11	12	1
22	65 - 74	Male	Higher education	average	4	10	2	22	22	10	9	4
23	18 - 24	Male	A Level or equivalent	below average	15	28	8	30	42	14	11	7
24	45 - 54	Female	GCSEs or equivalent	average	10	0.078125	5	30	3	10	15	3
25	35 - 44	Female	Degree or equivalent	average	2	0.36458333333333	5	17	13	6	5	10
Averages				Average MUSE Values	8.96	49.62	3.58	27.54	20.38	9.67	8.63	4.54

Figure L.1: Demographics and MUSE data

Likert data

Participant Number	4. After having seen the BazerBow performance please answer the following questions: 3.1. I would like to "have a go" of the BazerBow...	3.2. I found the performance on the BazerBow engaging...	3.3. I found the BazerBow visually appealing...	3.4. I can imagine playing the BazerBow...	3.5. I would like to "join in" with the BazerBow performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	4. After having seen the Keyboard performance please answer the following questions: 4.1. I would like to "have a go" of the Keyboard...	4.2. I found the performance on the Keyboard engaging...	4.3. I find the Keyboard visually appealing...	4.4. I can imagine playing the Keyboard...	4.5. I would like to "join in" with the Keyboard performance (playing another instrument, singing, dancing, "air guitar", moving, etc)	5. Have you experienced the BazerBow before?	6. Have you experienced a MIDI controller keyboard before?	BazerBow Average Score (3.1 to 3.5) MI	Ozonic Average Score (4.1 to 4.5) MI	Mimetic Index Differential (MID)	7.1. Which do you think was more suited to playing the types of sound you heard?	7.2. If you could "have a go" which would you choose?
1	Strongly Agree	Strongly Agree	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Agree	Strongly Agree	No	Yes	4.60	3.80	0.80	Mostly Keyboard	Mostly BazerBow
2	Undecided	Strongly Agree	Strongly Agree	Strongly Disagree	Disagree	Strongly Disagree	Undecided	Strongly Disagree	Strongly Disagree	Strongly Disagree	No	No	3.20	1.40	1.80	Mostly BazerBow	BazerBow
3	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.80	0.20	BazerBow	Mostly BazerBow
4	Agree	Agree	Undecided	Agree	Disagree	Disagree	Disagree	Undecided	Agree	Agree	No	Yes	3.40	3.00	0.40	Both	Mostly BazerBow
5	Strongly Agree	Strongly Agree	Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.20	3.80	0.40	Mostly BazerBow	Both
6	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Agree	Agree	No	No	4.60	4.00	0.60	Mostly BazerBow	BazerBow
7	Undecided	Agree	Agree	Disagree	Undecided	Undecided	Agree	Agree	Agree	Undecided	No	No	3.20	3.60	-0.40	Mostly Keyboard	Mostly Keyboard
8	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Undecided	Undecided	Undecided	Disagree	No	No	4.80	3.00	1.80	Both	Mostly BazerBow
9	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Agree	Disagree	Agree	Agree	No	No	4.60	3.60	1.00	Mostly BazerBow	BazerBow
10	Undecided	Strongly Agree	Strongly Agree	Undecided	Agree	Agree	Undecided	Agree	Disagree	Undecided	No	No	4.00	3.20	0.80	Mostly BazerBow	Both
11	Undecided	Agree	Strongly Agree	Undecided	Disagree	Agree	Agree	Agree	Agree	Strongly Agree	No	No	3.40	4.20	-0.80	Both	Mostly Keyboard
12	Agree	Agree	Strongly Agree	Agree	Agree	Disagree	Undecided	Disagree	Agree	Undecided	Yes	Yes	4.20	2.80	1.40	Mostly BazerBow	BazerBow
13	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Disagree	Undecided	Disagree	Undecided	Disagree	Yes	Yes	4.80	2.40	2.40	BazerBow	Mostly BazerBow
14	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Agree	Agree	No	Yes	5.00	4.20	0.80	Mostly BazerBow	Mostly BazerBow
15	Strongly Agree	Agree	Agree	Undecided	Disagree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	3.60	3.60	0.00	Both	Mostly BazerBow
16	Agree	Strongly Agree	Agree	Agree	Agree	Agree	Strongly Agree	Undecided	Agree	Agree	No	Yes	4.20	4.00	0.20	Mostly BazerBow	Both
17	Undecided	Strongly Agree	Agree	Undecided	Agree	Undecided	Agree	Disagree	Undecided	Undecided	No	Yes	3.80	3.00	0.80	Mostly BazerBow	BazerBow
18	Strongly Agree	Strongly Agree	Strongly Agree	Undecided	Strongly Agree	Undecided	Agree	Undecided	Undecided	Agree	No	No	4.60	3.40	1.20	Mostly BazerBow	BazerBow
19	Strongly Agree	Agree	Agree	Agree	Agree	Undecided	Agree	Agree	Agree	Undecided	No	Yes	4.20	3.60	0.60	Mostly BazerBow	BazerBow
20	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	No	Yes	5.00	4.60	0.40	Both	BazerBow
21	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Strongly Agree	Undecided	Disagree	Strongly Disagree	Undecided	Disagree	Yes	No	4.80	2.20	2.60	Both	BazerBow
22	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Undecided	Agree	Agree	Undecided	Agree	Agree	No	No	4.40	3.80	0.60	BazerBow	BazerBow
23	Strongly Agree	Undecided	Agree	Strongly Agree	Undecided	Agree	Undecided	Strongly Agree	Strongly Agree	Agree	No	Yes	4.00	4.20	-0.20	Mostly BazerBow	BazerBow
24	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Disagree	Agree	Agree	Disagree	No	Yes	4.60	3.00	1.60	Mostly BazerBow	BazerBow
25	Agree	Agree	Strongly Agree	Agree	Undecided	Disagree	Agree	Agree	Disagree	Disagree	Yes	No	4.00	2.80	1.20	Both	BazerBow
Averages	4.44	4.60	4.56	3.84	3.80	3.36	3.60	3.16	3.68	3.40			4.25	3.44	0.81	3.68	4.24

Average Mc Likert score 4.25 — Average Kc Likert score 3.44 = Differential 0.81

Figure L.2: Likert data

Open Question 8

	8. What was your favourite/most memorable moment from:	
Participant Number	**8.1.a. the BazerBow**	**8.2.a. the Keyboard**
1	Seeing how different movements effect the sound	Pitch shift was quicker so more of an "effect"
2	When it was played as a guitar type instrument	The key playing sections.
3	The way the sound changed in relation to the position (angle) in which it was held.	The switch rollers on the side of the keyboard were very effective.
4	The movements of the instrument changing the sound.	—
5	Near the end of the performance when the "strumming hand" made a vibration sound	Beginning when the keys are played slowly-suspense.
6	Where it sounded hypnotic bit like Doctor Who	When the pedal changed the sound
7	Swinging the arm around	N/A
8	Just found the movement of the BazerBow to get different effects.	Had my eyes closed – focus on the sound.
9	I enjoyed movement of the BazerBow — reminded me of playing guitar	Less visually appealing and less engaging for me
10	Most of it.	The first few minutes
11	When the motions were similar to rock guitar	The use of finger span when selecting multiple (?) keys
12	The movement of the instrument	When both hands come together in proximity
13	The expressive movements.	The fingering.
14	The way the filters were triggered i.e. with the direction and height of the BazerBow	Using the joystick to change the sound.
15	The wrist moving away from the body of the instrument	Using more than the keys
16	High pitched moments made my skin tingle.	Lower pitched moments (lovely and deep).
17	The way he changed the sound and reverb on the BazerBow through movement of the instrument	The pedal changes to change the sounds rather than the BazerBows movement
18	The way it is played and moved to distort the sound.	The way the pedals and the buttons work with the note playing.
19	The movement	When the timbre changed
20	Physical gestures matched the timbre changes - effective theatre	Allowed more insight into the combinations of control
21	The movement creating and changing the sound	Hearing the sounds
22	Ethereal variation of sound	Variation of notes
23	Adjusting the “filter “of the notes by tilting and moving the BazerBow	The expression pedal controlling the notes played
24	I enjoyed the waves of sounds and the movement across the performers body: a very visual performance.	I enjoyed the technical aspect of the performance.
25	Movements which change the sounds i.e. moving palm of hand to make sound ‘echo’	Watching how pedal/s were used.

Figure L.3: Open Question 8

Open Question 9

	9. What do you find most interesting about:	
Participant Number	**9.1.a. the BazerBow**	**9.2.a. the Keyboard**
1	The audible options available to affect a guitar-like instrument – possibility of adding to regular guitar?	More defined notes (control of audio) but less interesting because of that.
2	The look of the instrument. Different to usual.	Not much!
3	The way the sound changed in relation to the angle it was held.	It just appeared as usual keyboard, nothing particularly stood out.
4	I'm intrigued to know how it works.	How the sound is changed with pedals/switches.
5	Interesting shape - dynamic performance	The "wobble" toggle thing
6	The shape/design and how you make sound with it	Can create many sounds
7	Use of movement of BazerBow	Use of knobs on keyboard
8	Like the look of the thing	Not a lot!
9	Visual dimension as well as the range of sound	Less expressive as a result of less visual aspect
10	How sound changes as the BazerBow is moved in the air.	The keyboard didn't need movement but sound changed with pedals
11	How it generated the music without any (or few) controls. Its minimalist appearance.	The variety and number of controls and its complexity
12	Appearance and gestures	None.
13	Novelty	Pedal use.
14	The newness. Interested to learn how to manipulate the sounds.	How you can change the sounds on the fly.
15	Movement needed to play it	Not just keys but controller dials, pedal, wheels etc.
16	The Bazer as a whole. Interested in how it's played.	I found the pedals interesting to watch.
17	On how movement of the instrument changed the reverb and echo on how it is control	The use of multipedal to control note change and reverb
18	The way you move your fingers up and down the neck of the BazerBow.	The way you have to work quite a lot to produce the sound.
19	The way the notes sliding can be expressed visually	The effects buttons, again to slide the notes
20	To understand the nature of the adapted tech. Tilt? Gyroscope?	Less interested because I understood the nature of these controls.
21	How moving the BazerBow creates the sounds	Hearing the sounds which are created
22	Visual movement and expression	Ability to control and form sounds
23	How each note and effect is played	Adjusting modulation and the filter
24	The performer is more outward facing and the instrument encourages movement.	All the buttons, keys and dials makes it feel complex and modern.
25	The range of sounds on a much 'simpler' looking instrument.	Pedals being used

Figure L.4: Open Question 9

Open Question 10

Participant Number	10. How would you describe the: 10.1.a. the BazerBow	10.2.a. the Keyboard
1	Looks good, looks like it would be ‘fun’ to play. Way in to playing music?	More options but less interesting
2	Guitar-based instrument	Computerised keyboard
3	Interesting, ‘new’.	As expected.
4	Interesting	Familiar
5	Electronic guitar/synth type instrument	A cool keyboard with extra gadgets
6	Japanese looking instrument with futuristic twist	Electronic keyboard
7	Future guitar	80’s keyboard
8	Digital guitar	A metal block with knobs! - Very "Softcell/Pet Shop Boys/Vangelis"
9	Attracted by the guitar element which enhanced the sound for me	Came out second-best, though it was first and suffered by comparison
10	Triangle shape with a long arm. Sound softer than the Keyboard	Sound was harder on the keyboard.
11	Shaped like a small sitar but used like a guitar. Produced a less electronic sound	Compact sound control desk. Good for electronic music like the Doctor Who theme.
12	Very interesting.	A Keyboard.
13	Very good	Good.
14	Much more fun/interesting to create the music rather than the keyboard.	Standard MIDI controller - so no newness/excitement connected to the device.
15	Unusual use of a multitude of controls	Normal controller keyboard controlling the synth
16	A syfi instrument that is mystical.	Interesting instrument that anyone can access!
17	Futuristic. A new way of playing an instrument	Normal Keyboard
18	A very thin long guitar with a strip of white down the middle. The sound it makes is quite distorted and interesting to the ear.	A small keyboard with lots of buttons. Again made a signifyer sound and was slight distorted and interesting to listen to.
19	Visually appealing in its simplicity looks enjoyable to play	Looks complicated - less accessible.
20	Innovative — strongly communicative re — gesture	Traditional
21	More interesting to look at and watching the performance is more engaging.	Less engaging to watch. Relies on the sounds generated.
22	A science fiction modern instrument	A controlling sound instrument
23	Really interesting new method of playing notes and midi, easily portable	Loads of different sounds and effects, not as a visually engaging but still diverse
24	Compact and portable visually more appealing as a performance instrument.	You don’t engage as much with the performer as it seems to require a heads down approach to playing.
25	Fascinating - intrigued to see more movements and gestures - how many different sounds/effects can it create/make?	Interesting and engaging to watch most of the time

Figure L.5: Open Question 10

Open Question 11

Participant Number	11. Please add any further comments here:
1	
2	Can see the BazerBow in a band which would add something different unlike the keyboard.
3	Enjoyed both performances, the BazerBow engaged me more than the keyboard.
4	I feel that Phil was more confident when playing the BazerBow.
5	BB - offers more dynamic performance opportunities. Keyboard in contrast leads to a more static/less interesting performance.
6	Interesting that they don't create sounds alone but need to be connected to a computer
7	Think both would be good for kids to play with
8	
9	Fascinating experience, which made me reflect on the nature of music/sound and the ways in which I respond to it, which is not simply an aural dimension. Over influenced by visual aspect?
10	Amazed that the BazerBow and keyboard sounded different.
11	
12	
13	
14	BazerBow is much more hands-on and creative to produce the music - mainly due to how you physically play it plus height/location of instrument.
15	An interesting device. Engaging to watch with such a wealth of opportunities it could lead to - DMX etc.
16	
17	N/A
18	
19	Very interesting to compare the way the same piece can be performed on two instruments and how this affects the listener's musical experience of the piece.
20	Are you studying the interface from performer perspective? What skills are adaptive. I would love to see some results from this.
21	I would much rather play the BazerBow than the keyboard!
22	The BazerBow is a fascinating addition to music
23	
24	
25	Looking forward to seeing more of the BazerBow!

Figure L.6: Open Question 11

Appendix M

ADM Data

This appendix includes the charts for the ADM analysis data.

Participant Number Plotted Against Mimetic Questions

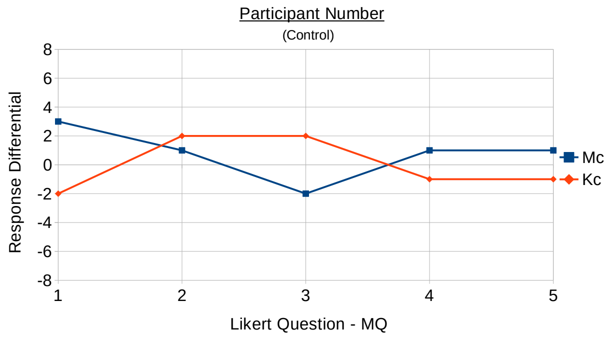

Figure M.1: Control

MUSE Section A Plotted against Mimetic Questions

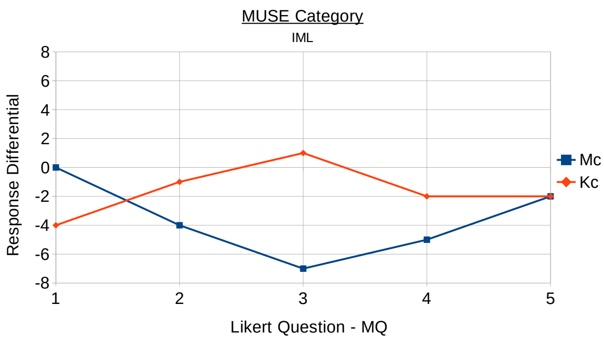

Figure M.2: IML

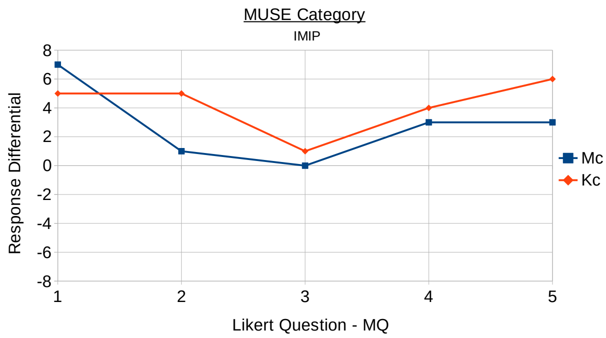

Figure M.3: IMIP

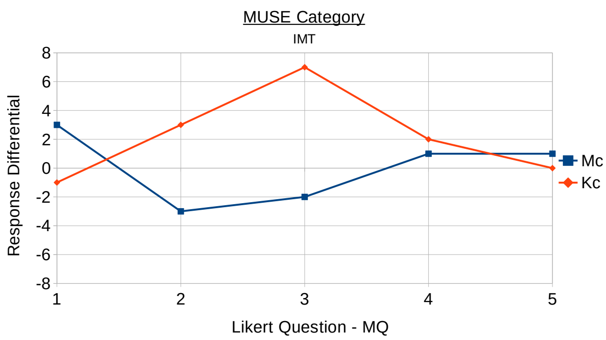

Figure M.4: IMT

MUSE Section B Plotted against Mimetic Questions

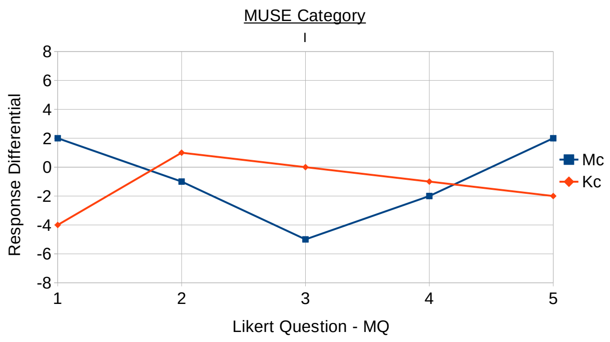

Figure M.5: I

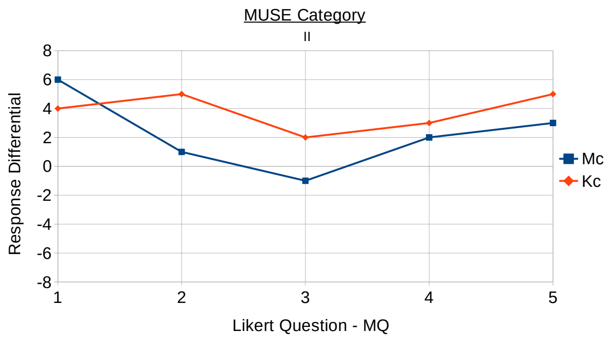

Figure M.6: II

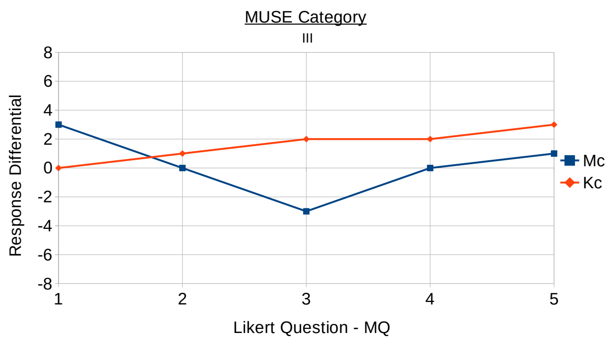

Figure M.7: III

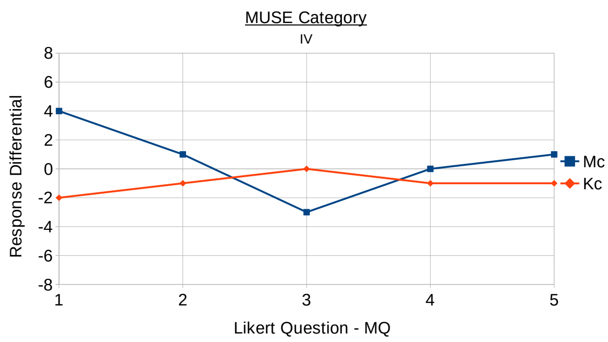

Figure M.8: IV

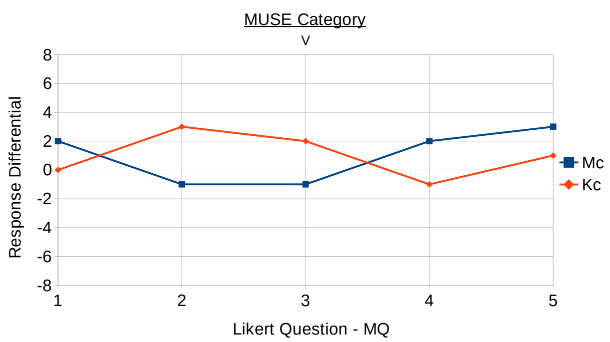

Figure M.9: V

Question 7 Plotted against MUSE Data

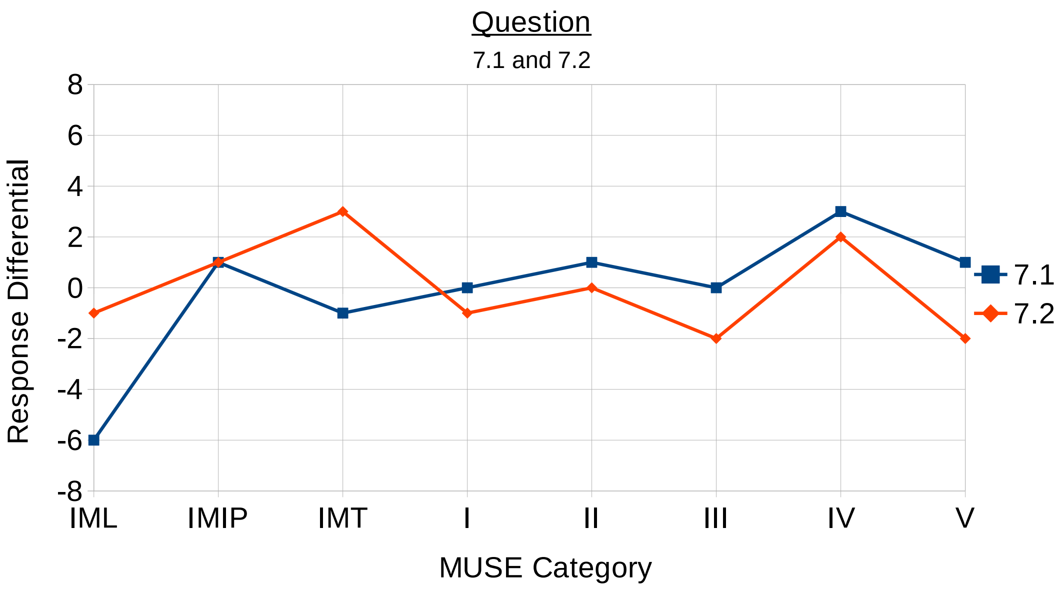

Figure M.10: Q7

Mimetic Index and Mimetic Index Differential plotted against MUSE Data

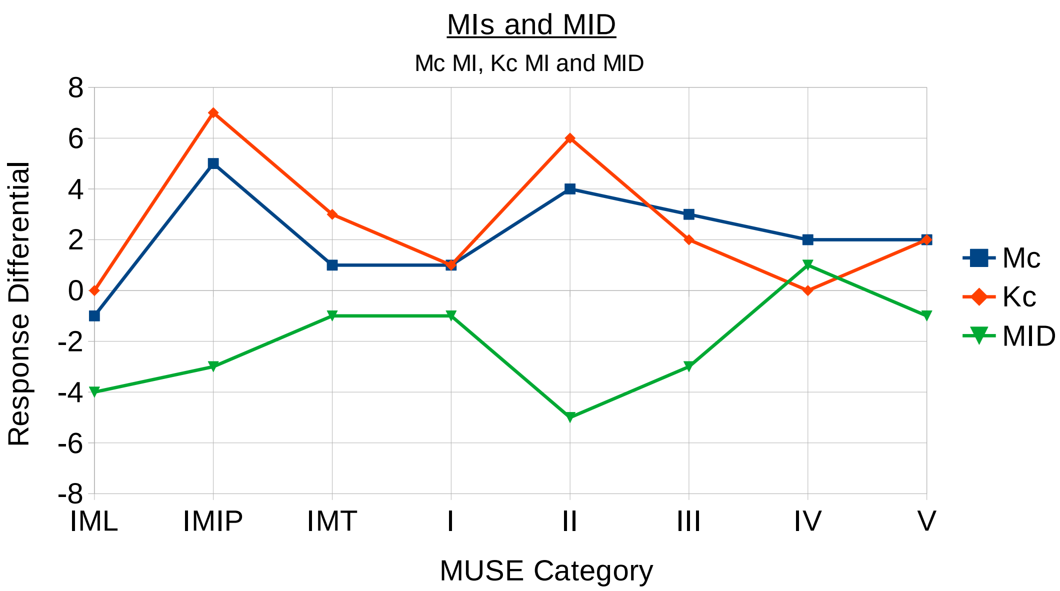

Figure M.11: MI and MID

Appendix N

Mimetic Chart

This appendix contains the mimetic chart that ties my music practice and research together.

Mimetic Chart

Mimetic Theories		DMI Design		Mimetic Design		Prototyping of BazerBows		Examination of Prototypes	
Mimetic Cognition	**Complimentary Theories**	**General DMI Theories**	**Challenges for DMI Design**	**The Three I's**	**Mimetic Design Principles**	**Manufacturing Considerations**	**Prototypes**	**Test Phase Data**	**Anecdotal Evidence**
Mimetic Engagement	Action Understanding	Gesture	Audience Engagement	Involvement	Mimetic Gestural Matrix	Manufacturing issues. Production of multiple quantities. Greater reliability and usability.	Prototype 1 Prototype 2 Various technical developments including manufacturing processes. Improvements in inclusion of mimetic design principles. Prototype 3...	Engagement Levels	A 60th birthday party
Mimetic Invitation	Communicative Musicality	Affordance	Aesthetics and Expression	Invitation	Mimetic Affordance Mapping			Desire to “have a go”	Another Dancer
Mimetic Participation	Empathy	Appropriation	Longevity and Popularity	Inclusion	Mimetic Appropriation Pyramid			Desire to “join in”	“Air BazerBow-ing”

Existing Research	Concepts and Evidences Developed for this Research

Figure N.1: Mimetic Chart

Appendix O

Published Papers

This appendix contains the following relevant papers:

Wigham, P. and Challis, B. (2020) 'Real-Time Measurement and Analysis of Audience Response.' en. *In Interactivity, Game Creation, Design, Learning, and Innovation*. Brooks, A. and Brooks, E. I. (eds.) Vol. 328. Cham: Springer International Publishing pp. 38–48. isbn: 978-3-030-53293-2 978-3-030-53294-9. doi: 10.1007/978-3-030-53294-9_4. [Online] [Accessed on August 7, 2020] http://link.springer.com/10.1007/978-3-030-53294-9_4

Wigham, P. and Boehm, C. (2017) 'BazerBows: Instrument Design and Mimetic Theory.' *Scottish Music Review*, 4(). [Online] [Accessed on June 1, 2022] http://www.scottishmusicreview.org/Articles/4/Wigham%2C%20B%7B%5C%22o%7Dhm%3A%20BazerBows%3A%20Instrument%20Design%20and%20Mimetic%20Theory.pdf

Wigham, P. and Boehm, C. (2016) 'Exploiting Mimetic Theory for Instrument Design.' *In Proceedings of the 2016 International Computer Music Conference, ICMC 2016, Utrecht, the Netherlands, September 12-16, 2016*. Michigan Publishing. http://hdl.handle.net/2027/spo.bbp2372.2016.008

Wigham, P. and Boehm, C. (2011) 'THE BASER BOW: AN INSTRUMENT BASED ON THE EXPLORATION OF THE CONCEPT OF MIMETIC PARTICIPATION FOR THE DEVELOPMENT OF MULTI-MODAL AND MULTI-GESTURAL DEVICES.'. *In Seventh International Conference on Interdisciplinary Musicology (CIM11)* (August 30–September 3, 2011). Glasgow, Scotland. [Online] [Accessed on June 1, 2022] http://www.n-ism.org/CIM2011/

Real-time Measurement and Analysis of Audience Response

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Abstract. How do you harness a "level" of emotional connectivity from audience/participants? Questionnaires, focus group discussions, interviews and other qualitative methods gather retrospective thoughts of the participant and may miss important insights or connections that could be discovered if a real-time response is recorded. The aspiration for real-time audience data recording is problematic in many areas of research, in particular performing arts where the work/research presented is time bound. In addressing this problem within research into the design of novel musical controllers, custom "sliders" were used to measure and examine real-time audience response to short musical performances. The audience moved their sliders in response to the performance, producing continuous data that was recorded into music software and timestamped. The initial test results have shown promising insights and usefulness for real-time data collection and examination. These results and possible methods of data analysis are presented along with discussion on how this approach may be applied in other research contexts.

Keywords: Audience · Response · Real-time · Measurement · Mimesis · Mimetic theory · Performance · Music · Haptic · Sensory · Kinaesthetic · Tangibility · Feedback · Analysis · Data

1 Introduction

This paper presents a possible solution to the problematic area of recording continuous real-time audience response data. It is hoped that it will prove to be a useful data gathering tool in areas of research looking to acquire this type of data. The conception, implementation and initial results of a real-time "slider" mechanism for examining audience/participant response, will be discussed further along with its application in the current research, and how the slider method may be applied in other contexts.

The test phases being described in this paper were conceived as a way of recording and examining real-time audience response to new mimetic digital music instruments (DMI) and comparing them with existing traditional DMIs. Custom built "sliders" were used to allow audience/participants to respond to musical performances. The slider is moved up or down in response to a question posed before the performance, in this case how "engaged/interested" they are at each moment of the performance. As the participant feels more engaged they respond by moving the slider upwards, and downwards when less engaged. This "slider" data was captured in real-time and then collated with other data collected through the questionnaires and group discussions. The slider data proved crucial to gaining further insight into the qualitative questionnaires and focus group discussions.

This method is proving to be an effective way to examine a participant's continually adjusting response to a live performance. The slider data has highlighted participant responses to the performance that did not appear within the questionnaires or post-performance discussions. This allowed further examination of those areas of the performance and instigated changes to the performance. Further testing showed that these changes in the performance had affected the slider data and therefore the audience response.

Although the mimetic design study is in its very early stages, the results are already showing very interesting and useful insights, which will be discussed in more detail below.

2 Research Context

The need for real-time participant response data came about through post graduate research into mimetic influenced digital music instrument design. The research has been comparing user perceptions of music performances using a custom-built MIDI[1] controller (inspired by mimetic theories[21]) alongside a traditional MIDI keyboard controller. This has required a method of data collection and examination of participant response to music performances. Each MIDI controller was connected to the same laptop running a software synthesiser which both controllers were able to play and control. A musical performance was devised that could be played with both controllers so that the sound elements of each performance were as identical as possible. This allowed for a fairer comparison of the actual physical and gestural performance of the instruments.

Cox's mimetic hypothesis[12] identifies overt and covert 'mimetic participation' as audience responses to musical performance. It was desirable to find a way to explore how audience participants may experience mimetic participation and though overt manifestations could be observed in the video, covert mimetic participation, by its nature, does not manifest itself. Though questionnaires and interviews were initially devised, it was important to find an effective method of investigating real-time response to discover any covert "mimetic participation"[11, 12]. Any post-performance data collection such as questionnaires and focus group discussions, being retrospective, may miss exposing this covert mimetic participation and any allusion to mimetic participation could not be precisely associated with an exact moment in the performance.

[1] 'MIDI is an industry standard music technology protocol that connects products from many different companies including digital musical instruments, computers, tablets, and smartphones.'[1]

In addressing this problem, a "slider" method was developed to enable response data to be recorded in real-time during the performances, which allowed audience members to respond continuously to how "engaged" they felt throughout the performance. The data from these sliders was recorded into a MIDI recording software[2] as MIDI data, simultaneously with the performance MIDI data, whilst two video cameras captured the audience and performer. This allowed the slider data to then be compared with various points within the performance, achieving continuous real-time snapshots of the level of audience engagement at each moment of the performance. This data was also compared with the demographic data, the post-performance questionnaires and the focus group discussions.

Although the findings from the mimetic design research are in the early stages of analysis, this quantitative slider data is providing more insight than any other isolated method, and is helping to expose moments of potential covert mimetic participation, that would have otherwise remain hidden. Synchronising the slider data to the video recordings allows for a very direct analysis of the performance in relation to the audience response. This slider method of data collection and analysis is discussed in more detail below.

3 Methodology

3.1 Existing Methods

The problem of recording real-time audience response data has been approached using several methods[10], the most prevalent of which include analysis of audience biometric data, detection of audience motion, and input devices for audience response.

The advantage of recording biometric data is its involuntary nature requiring no conscious effort to respond, therefore being completely unobtrusive to the experience of the performance. Galvanic Skin Response (GSR) and electrodermal activity have been used to suggest a biological response to performances[20, 14], as well as cardiovascular and respiratory measurements[9]. However it remains difficult to convincingly associate biometric data directly with a specific response to the performance, such as engagement. Latulipe et al.[13] attempted to resolve this issue by comparing audience GSR data with 'self-report scales' finding a 'strong correlation'. However, there are still problems with interpreting biometric data with any certainty in relation to audience levels of engagement.

Martella et al.[16] used accelerometers and infra-red sensors to record audience movement during a live dance performance to predict the outcome of post-performance questionnaires and motion capture techniques were used by Swarbrick et al. [19] to investigate audience response to live performances compared with recorded music. As with the biometric data techniques there is a difficulty with being able to directly link the movement of audience members

[2] For the purposes of this study, Ableton Live was used, though it would be feasible to use other digital audio workstations or MIDI recording software.

with a response to the performance, and although these methods have the similar advantage of being unobtrusive, they are difficult to interpret precisely.

The portable Audience Response Facility (pARF) utilises a personal digital assistant (PDA) as an input device[17] which allows input of two simultaneous data streams using the PDA stylus on an X and Y axis. This allows the audience to be asked to respond in a particular way, providing participant responses that are explicitly connected with the posed response parameter, such as "engagement". However, the stylus/PDA input device could be potentially distracting to the participant, having to look at the PDA to give an accurate response.

Stevens et al.[18] suggest that other suitable input devices might be used depending on the response being measured. Other input devices could include commercially available keypads[6, 4] and mobile phone apps[7, 2]. The keypads capture real-time data but only have the capability of an on/off style button response, and therefore do not give a scaled response. Although there are a range of mobile apps that can be used to collect audience response data, most of them cannot track scaled response. Reactor[5] is a mobile app that can record a scaled response via a slider-bar on the screen, but is aimed at pre-recorded video not live performance. Critically, mobile phone input could be a potential distraction to the user, having to glance down at the phone regularly to gauge their position on the screen.

The mimetic design project required a bespoke solution due to the specific context of the research. The music performance, not intrinsically an "event", was created to exploit the gestural nature of the DMIs. It was necessary to be able to scrutinise the detail behind individual participants, not a consensus across the audience, exploring the how, when and why of apparent response by individuals to specific gestures. In practice, during the testing phase using bespoke physical sliders, it was common for the participants to turn their mobile devices off (not having been previously encouraged to do so) and hold the slider in one hand, being entirely prepared for the task. The tactile and tangible nature of the physical slider meant that the participants could fully concentrate on the performance whilst also confidently controlling the slider.

3.2 Sliders

The sliders were made using a linear slide potentiometer soldered to an XLR socket. This was housed in a wooden enclosure designed to fit the size of an average hand, so that the thumb could move the slider (see Fig. 1). Ten sliders were made and connected with a cable to a micro controller unit (MCU). The MCU converts the movement of the potentiometers into digital signals through an ADC and then outputs this data in the MIDI format via USB interface. The MIDI protocol was chosen due to the availability of well established MIDI recording software capable of recording multiple streams of slider data.

It proved to be important to record calibration data (see Fig. 2 below) of the participants slider movement before any actual performance recordings took place. This involved asking the participants to move the slider as far to the top as they comfortably could and to the bottom again as far as they could,

Fig. 1. Custom Slider

and lastly to the middle. This made an important allowance for people who may have a limited slider range due to smaller hands or restricted movement. This calibration procedure was completed before each recording, due to the possibility that participants may start from a different "middle" position each time. Without this calibration the accuracy between multiple recordings and the recordings of other participants would be compromised.

Implementation of the sliders requires preparing the participants with the parameters for response, and the question they are to respond to with the slider. In this research the participants were asked to respond to how "engaged" they felt during the musical performance and to continually respond as necessary, moving the slider upwards as they felt more engaged and down when they were less engaged. The slider could, of course, be used with any question, providing illumination into many possible areas of audience response. It may be presented in a similar context to the standard Likert[15] scale, the middle being neither agree/disagree with the posed question, higher slider positions equating to more agreement and lower levels to disagreement. This data can then be analysed in the same way as Likert response data from questionnaires, the difference being that it is real-time and continuously changing with the response of the participant.

4 Data Analysis

4.1 Slider Data

Although the MCU could be configured to output the data in different formats, such as ascii sent via a serial connection, MIDI data is a convenient and well established way of recording the data in real-time. Once recorded, the MIDI slider data can be analysed in several ways. The slider data is recorded as MIDI

Continuous Controller (CC) data which has a range of 0 to 127 (7 bit). There are 128 independent CC's available, and each slider is recorded to an individual CC. Most MIDI recording software allows the MIDI data to be exported as a standard MIDI file (SMF).[3] These files add a timestamp to the recorded MIDI data to allow the data to be played back accurately.

The SMF file can be converted to text/csv and imported into a standard database and/or spreadsheet for further analysis. Fig. 2, below, shows two participant's slider data streams, overlaid on the same graph to allow comparison of levels of engagement over the period of the performance. The calibration process can be clearly seen on this graph with the initial high and low levels. The data for

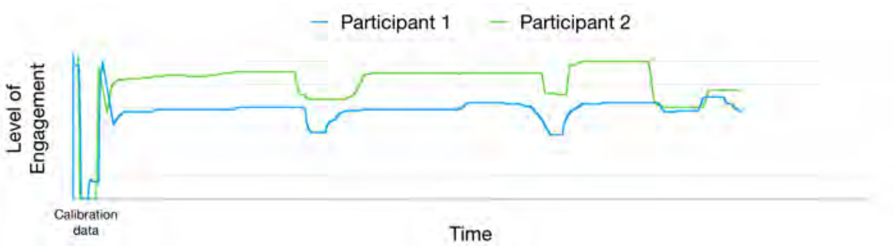

Fig. 2. Slider Data of Two Participants

each participant can be separated out, (due to the individually assigned CC's) and analysed individually. This is useful if slider data between two or more performances is to be analysed. This allows the data from each performance from the same participant to be examined.

The MIDI recording of a musical performance may be recorded directly from the MIDI controller alongside the slider data. This data can be processed in the same way as the slider data and then used to compare audience response with the musical gestures of the performance. This may also be possible wherever sensors/devices capable of producing MIDI data are used in the performance. This is a useful method of analysis for performances using such technology, however, synchronising the slider data to the video recording is a more universal approach, allowing the data to be analysed directly with the recorded performance. This approach will now be discussed in more detail.

4.2 Video Synchronisation

The MIDI slider data can be recorded into any MIDI capable software. To allow the slider data to be synchronised to the video of the performance, a sound/click

[3] 'Standard MIDI Files contain all the MIDI instructions to generate notes, control individuals volumes, select instrument sounds, and even control reverb and other effects.'[1]

should be placed at the beginning of the recording session in the recording software. This sound will then play at the start of the MIDI recording and will be heard on the video recording allowing synchronisation of the data with the video. A simpler alternative would be to make a "sync" sound or speak a specific word at the same time as starting the MIDI recording, which would serve the same purpose, as an anchor point to sync the MIDI recording with the video. MIDI software commonly synchronises with video editing software using the SMPTE (Society of Motion Picture and Television Engineers)[8] protocol. This would allow the MIDI software to playback the slider data concurrently with software running the video. This requires two separate software applications: one for MIDI and one for the video. An alternative method, requiring only one application, would be to use MIDI software capable of importing video, allowing the initial "sync" sound, to be aligned with the beginning of the recording. The slider data can then be played back along with the video, within the same software package.

4.3 Video with Slider Data Overlay

The methods of analysis described above both require specific software to view the data. A more accessible and potentially more useful way of processing the slider data with video, is to create a video that overlays the continuous slider data on top of the video recording of the performance. This video can then be viewed in any application capable of video playback, allowing more convenient analysis and sharing of data. This provides a very visual way of viewing the data in direct relation to the performance.

Firstly a video recording of the slider data playback needs creating. If the MIDI recording software has its focus set to follow the playback cursor, a video screen capture of the slider data playing back can be made. Using video editing software, this video can then be overlaid and aligned with the start/click sound on the performance video, allowing the movement of the slider data to be observed with the exact moment in the performance video when it occurred. Fig. 3 shows the red play cursor of the slider data and how that data has moved along with the performance video. This provides a very powerful real-time analysis

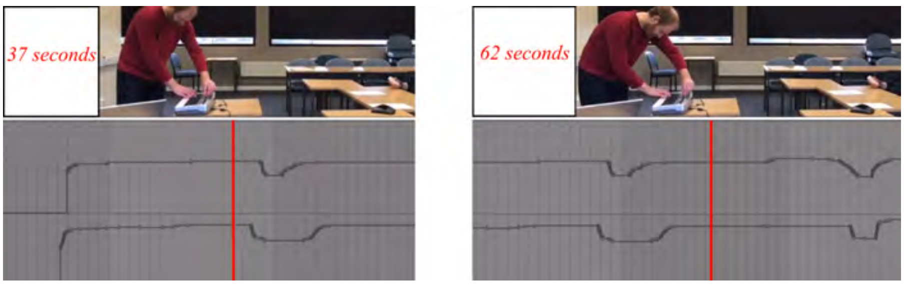

Fig. 3. Video with Slider Overlay

of the posed slider question, whether that is level of engagement, excitement, interest, immersion within a space or an evaluation of film, TV, gameplay, performance, dance, radio, theatre, etc.

5 Discussion

Although the mimetic design research is in the early stages, this "slider" method is already proving to be a powerful way of acquiring and analysing real-time data. A good example of this is provided in Fig. 2 which shows three distinctive dips for both participants, highlighting an area of interest requiring further examination. When comparing these points with the video data, it showed the dips occurring every time there was a slight pause as the synthesiser sound was changed. Neither of the participants eluded to this in the post-performance questionnaires. This discovery was only possible by finding out exactly where in the performance these dips occurred. As a consequence the performance was adjusted so there were no gaps, creating a more fluid performance from one sound to another. Slider data from this adjusted performance showed no more dips occurring on the sound change overs.

It is possible that even with showing a participant the slider data after the performance they wouldn't remember what they were responding to at that point, especially with longer performances. This demonstrates the usefulness of being able to analyse the slider data in real-time. Fig. 3 shows the first minute of the same participant slider results, overlaid onto the performance video. This photograph demonstrates how easily the slider response data from several participants can be compared with each other and the exact point of occurrence in the performance video. This is particularly useful when the performances have an important visual aspect, in this case the gestural movements of playing instruments.

Since, this initial test with two participants, the slider method has been tested with more participants and larger groups. This data has only recently been taken, and so has not been fully analysed, but is showing promising signs of similar discoveries. There were some improvements made from the initial test including the addition of questionnaires specific to the research, labelled with the number of the corresponding participant slider. The hope is to provide deeper insight into the slider data, looking at how participant demographics and musical experience may affect the way they respond to music performance. Post-performance focus group discussions are being digitally transcribed, enabling the open responses to be considered with the slider data.

6 Conclusion and Future Directions

6.1 Evaluation and Future Improvements

The results so far indicate that the slider method for recording and examining continuous real-time response data is a viable technique. However, more research is necessary to fully investigate its potential and explore other possible uses. Since the initial testing phase, several points have come in to focus, including some future improvements.

The calibration before each recording is crucial to successful comparison of results. Fig. 2 shows that participant 2 has a higher initial "middle" slider position than participant 1, which needs to be taken into account when comparing levels. Adjustments to overall levels can be made using this calibration data, and is necessary for each recording because the "middle" point for a participant can vary between performances.

The sliders work well for groups of up to ten, but with larger groups the cabling to each slider might become less manageable. This leads to the consideration of a wireless system, and of course points to a possible use of mobile phones as a replacement to the sliders, due to the ease of implementing a wireless configuration. However, as mentioned previously, the physical sliders provide a tactile, intuitive interface for audience response, that generates continuous input without unnecessary distraction from the performance. The tangibility of the sliders more than compensates for the complexity of developing a custom wireless slider system and with the availability of wireless mesh network technologies is not a huge issue to overcome. A wireless system would allow a larger audience participation, and with the MIDI system having 16 separate channels of input as well as the 128 continuous controllers (discussed above) this would give a potential possibility of 2048 participants slider data being recorded simultaneously.

MIDI data is a relatively old system and has a low resolution of 128 steps (7 bit). If a greater resolution is needed OSC[3] could be implemented, although it is not as well supported as MIDI. There is a new MIDI specification (MIDI 2.0) being developed which will provide much higher resolutions, but is still in a prototyping stage. It will be compatible with the original MIDI specification so it should be simple to accommodate the new MIDI 2.0 protocol into existing work, when it is finally confirmed and available.

Another consideration in terms of analysis of slider data would be to segment the data points into discrete groups i.e. dividing a scale of 0 to 100 into 5 groups: 0-20, 21-40, 41-60, 61-80, 81-100. These groups could then be analysed in a manner similar to a Likert scale using standard statistical methods.

6.2 Other Use Contexts

This paper does not present a completed project but is a contribution to facilitate other research, where the "slider" solution to recording real-time response data might prove to be a useful tool. It is advantageous for several reasons: the data recorded in real-time; the data being continuous, which may capture data that an on/off "button" response might otherwise miss; the tangibility of the slider; the potential for large participant groups; the possibilities for post-performance analysis and the integration and consolidation of this quantitative slider data with other available qualitative data. This method may also prove useful due to participants finding difficulty in describing a particular event they were responding to within the performance, during a post-performance questionnaire or interview. With the slider method the participant doesn't need to describe the moment because the response data is synchronised to that moment.

The slider method for recording real-time response data may be implemented in a variety of contexts where a continuous real-time response from participants is required. This may be useful for research in any situation requiring real-time response data, such as media, film, gameplay, etc., but in particular is well suited to live performances in theatre, dance, music etc. A dance performance, for example, may also record data from sensors attached to the dancer, allowing the gestures within the dance to be analysed with the slider data.

It is clear from these initial explorations that the slider method is worth further investigation and development, and it is hoped that it may provide an efficacious tool for other research.

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BazerBows:
Instrument Design and Mimetic Theory

Philip Wigham and Carola Böhm

Abstract

This paper will explore mimetic principles relevant for music performance and instrument design. It will describe elements important for understanding basic interaction between visual, sounding and gestural aspects of experiencing instrument performance and illustrate how music controllers may be enhanced through devising specific design concepts based on mimetic theory. Example instruments designed according to these principles will be presented, specifically the BazerBow and its various prototypes.

1: Background and Context

The experience of an instrument, whether playing the instrument actively, or experiencing as an audience member, will be influenced by gesture and inter-modal aspects. Gesture, although not always, nor necessarily directly connected to the sounds the instrument makes, can convey information important to the performance. It may also alter the perception due to inter-modal effects. Inter-modality describes how our mind creates a single perception from all its senses which may cause one sense to override another. This can cause illusions, such as the familiar optical or mixed optical/aural illusions, e.g. the double-flash experiment (McGurk and MacDonald 1976; Shams et al. 2002).

Davidson has explored the visual components of performance and how they affect perception. Her findings 'emphasise the need to consider visual as well as sound information in psychological enquiries into music perception' (Davidson 1993). Krumhansl and Schlenk gained similar conclusions, from an experiment involving a ballet performance played to an audience with just sound, sound and vision and just vision. They concluded that 'the dance conveyed much of the same emotional and structural information as did the music' (Krumhansl and Schenck 1997). The visual aspect of an instrument is important to the perception of musical performance which is essential for mimetic processes.

It follows that it might be interesting to ask what a new digital instrument would look like if devised using mimetic participation and its related theories? Is it possible to exploit the processes behind mimetic participation to further develop and enhance new musical instrument design to access the imitative, intuitive, and empathetic response of an audience allowing them to fully engage with new designs and musical concepts? Arnie Cox asks 'Do you ever find yourself tapping your toe to music?' and suggests that 'Informally conducting, playing 'air guitar', and 'beat boxing' are similar responses' (Cox 2006). This formidable force that demands its listeners to perform 'air guitar' at the most inopportune moment, if better understood, may give an insight into the relationship between audience, performer and instrument. With greater discernment of these relationships, design factors can be honed to create new digital instruments that, although maybe unfamiliar, can connect with both audience and performer allowing for an immersive and shared empathic experience.

2: Instrument Efficiency

In our modern world of endless possible designs and readily available technologies, the more important questions relate to expressiveness and the impact of acquiring performance skills. Jorda's work on digital instrument design (Puig 2005) attempts to find a method to compare the infinitely contrasting designs and their capabilities and define how to measure instrument efficiencies, applied in his creation of the 'Reactable'[1].

It is commonly agreed that for a new instrument to become popular in a similar fashion to guitar or piano it needs to be instantly playable by a beginner but have sufficient complexity to need time to develop necessary skills to master the nuances of the instrument. However there is no commonplace measurement for an instrument's complexity, nuances, or the skills needed to perform on the instrument. Jordà attempts to reconcile these issues in an efficiency formula which allows new instruments to be compared with established instruments such as piano (see Equation 1, (Jordà 2004)).

$$\text{Music Instrument Efficiency}_{\text{Corrected}} = \frac{\text{Musical Output Complexity} \times \text{Diversity Control}}{\text{Control Input Complexity}} \tag{1}$$

Although this might be considered a simplistic view of a complex process there is some merit in considering it as a starting point. However, the formula focuses on the instrument and its relationship with the player without consideration of the effectiveness of the instrument with an audience. Using this formula an instrument design may prove to be very efficient and so be popular to play, but it may also prove to be very inefficient at relating to, and communicating performance components such as gesture.

Thus the areas of affordance, gesture and mimesis are underplayed in their importance and impact on the perceived quality and experience of an instrument. It may be the case, as in the case of the BazerBow, that mimetic design criteria conflicts with the proposed parameters for instrument efficiency. Therefore it is logical to include mimetic principles into any instrument efficiency models.

3: Affordances

How the efficiency of an instrument might be affected by affordance becomes clear when comparing two very different instruments, the Kalimba and the Theremin. Jordà concludes that instruments that have obvious affordances, such as the Kalimba 'will probably not yet reach the 'expressiveness' of the violin or the piano, but they can surely be much more 'efficient' than traditional instruments tend to be.' (Puig 2005:176). However, when considering the example of the Theremin, with its easy production of sound, it could be seen to be initially 'efficient' like the Kalimba, but it is considered (and perceived by audiences) as very expressive, especially when time has been spent mastering the instrument. Billinghurst believes the Theremin is successful because 'there is a direct mapping of hand motion to continuous feedback, enabling the user to quickly build a mental model of how to use the device' (Billinghurst and Buxton 2011). This corresponds with the 'inevitability' design criteria, that Machover describes as allowing a new player of the instrument to instinctively 'know' how the instrument produces and affects sounds (Machover 2002). However, Jordà reasons that in the case of the Theremin 'that all types of difficulty may be rewarding for the performer and guide to better results. Could expressiveness be perhaps related to difficulty or effort?' (Puig 2005).

Tanaka describes affordance as: 'a concept fundamental to interaction design practice. Arising from Gibson's seminal work in perceptual psychology, it maps potential action relationships between subject and object based on qualities of the object and capabilities of the subject' (Tanaka et al. 2010).

Unlike acoustic instruments, digital instruments usually need a mapping interface which connects the gestures with the sound generation, and this integrates or exploits aspects of affordances. Paine argues that 'interfaces need to communicate something of their task and that cognitive affordances (Gibson 2014) associated with the performance interface become paramount if the musical outcomes are to be perceived as clearly tied to real-time performance gestures' (Paine 2009). This points towards the inclusion of mimetic participation in design considerations, with 'musical outcomes' being mapped to 'real-time performance gestures' (Paine 2009).

Dix, writing from a HCI perspective, suggests there are 'three "use" words that must all be true for a product to be successful; it must be: useful (accomplish what is required: play music, cook dinner, format a document); usable (do it easily and naturally, without danger of error, etc.); used (make people want to use it, be attractive, engaging, fun, etc.) (Dix et al. 2004). Relating this to music, Cano describes a similar mimetic process in his 'Proposal for a typology of music affordances'. He describes 'Executant mimesis' as 'Imitating the playing of musical instruments and other actions producing sounds as well as any associated kinetic activity.' (Cano 2006). He goes on to say that these imitations include: 'Imitations of a solo guitar player from a rock band or imitating the gestures of singers by singing along with them. Incipient music lovers belong to this category when they imitate the gestures of a conductor by moving a finger as if it were a baton while listening to the music. It also includes imitating the gesticulation often employed by musicians while playing their instruments.'

The mimetic process can thus be seen to be closely related to affordance theory.

4: Mimetic Principles

Trevarthen and Malloch have shown how important early musical mimesis is to cognitive and social development, (Malloch and Trevarthen 2009) and describes how this process may facilitate improved social empathy. Rabinowitch et al have been looking at emotional empathy in school children and whether empathy may be improved by a specially devised 'musical group interaction' (MGI) programme. The MGI programme consisted of interactive musical games using empathy-promoting musical components (EPMCs) (Rabinowitch et al. 2013). The results support the hypothesis that these musical programmes can increase empathy. This is supported by studies into early child development and the musical content of motherese which babies use to elicit a social, empathetic response from their primary caregiver (Malloch 2000b).

The concept of empathy overlaps with ideas of intuition and mimesis, except that in the case of empathy the process is in relation with another person or people, where intuition and mimesis may involve self and surroundings without invoking someone else. However, mimesis, unlike imitation may involve emotional and social understanding, and empathy. In discussing the premise of his mimetic hypothesis, Cox states that 'part of how we comprehend music is by way of a kind of physical empathy that involves imagining making the sounds we are listening to' (Cox 2011). Both mimesis and empathy may share similar mechanisms. Studies show that one of the functions of mirror neurons is mimesis or imitation (Rizzolatti1 and Craighero 2004). However Rizolatti states that 'evidence has been found that the mirror mechanism is also involved in *empathy*'. Molnar-Szakacs and Overy suggest that the motor process involved in the expression of emotion involves mirror neurons: 'Emotion, especially as communicated by the face, the body and the voice is an active motor process. Emotion and action are intertwined on several levels, and this motor-affective coupling may provide the neural basis of empathy' (Molnar-Szakacs and Overy 2006). Using the example of 'air guitar', mimetic participation allows the listener to imagine and imitate physically and/or verbally 'playing' the guitar, but may also produce an imagining or empathising of the emotional state of the performer. This empathy may play an important role in the proportion of mimetic effect experienced by the listener.

Intuition is also a very elusive concept. The Oxford dictionary defines intuition as 'a thing that one knows or considers likely from instinctive feeling rather than conscious reasoning'. It is certainly an area of keen interest for scientists and a rather too complex area of study to explore in more depth in this paper. In part intuition draws on experience and on memories, and the emotional states stored within those memories. In any given situation those memories will play an important part, especially when there is time for those memories to be fully considered and processed with the incoming information necessary for decision making. When there is little time for those memories to be fully processed decisions need to be made with less consideration (McCraty et al. 2004). Making a decision without due consideration may be interpreted as 'intuitive', drawing on the ability to preempt, predict and envisage a response outside of experience. Depending on the situation this may draw upon mimetic participation to allow mental preparation for a new physical response, and mimetic empathy if a judgment is needed. It may be that intuition plays a part in mimesis, and a better understanding of intuition may allow a better understanding of mimetic participation.

New techniques, such as in fMRI (functional magnetic resonance imaging) are providing an increasing body of evidence for understanding how intuition, empathy and mimesis works. With one hundred billion neurons in the brain (Philips 2006), each making connections with tens of thousands of other neurons, there is interesting evidence surfacing that the heart is also surrounded by approximately 40,000 neurons, (McCraty et al. 2001) thus of a similar scale to that of a small part of the brain. Up until now it has been thought that all cognitive processes occur in the brain, now experiments are beginning to show that the whole body, in particular the heart, has an impact on cognitive function. It seems that the heart plays an important role especially in intuitive decisions. During an experiment to test intuition (McCraty et al. 2004:133–143), brain and heart scans demonstrated that during intuitive decision making the heart responds before the brain, sending signals to the brain first. Further tests have shown that the heart's magnetic field can influence not only our own brain waves but others close by. Another experiment (McCraty et al. 2001:25) demonstrated that when two people hold hands the brain waves of one tend to synchronize with the heart pulse of the other. These early experiments seem to back notions of intuition and empathy which many people have experienced, specifically in collaborative live music making, but been unable to explain. As the mimetic is closely linked with intuition and empathy this new area of research may also begin to partly explain the biological and psychological processes behind mimetic participation.

The definition of mimesis in the Oxford dictionary is 'imitation, in particular: imitative representation of the real world in art and literature' with imitation being defined as to 'take or follow as a model; copy (a person's speech or mannerisms), especially for comic effect'. Most people are familiar with imitation, whether that is through consciously mimicking or impersonating someone, or by sub-consciously finding yourself following someone else's movements and gestures such as yawning, or crossing your arms. The boundaries become thus blurred between imitation and mimesis. However mimesis is a term frequently used in art works and religion to describe a process that is more than just a copy. Describing Mimetic Theory, Hardin says: 'Mimetic theory asserts that all desire is taught to us, 'mediated' by an Other. We only want what is first modeled to us as desirable. Of course, it is easy to recognize that this is precisely the way the advertising industry works by getting us to want what celebrities have. It is more difficult for each one of us to see this work out on a personal level since we would all prefer to believe that desire arises from within us autonomously[2]. Hardin goes on to say that 'Mimetic theory acknowledges that we are all interconnected'. This interconnected-ness leads toward the theories of empathy, discussed above.

Although mimesis may be directly translated or defined as imitation, it has connotations of something more than a purely physical copying. Mimetic Theory was disregarded in the 1970's when first postulated by Rene Girard, but has recently gained popularity within various areas of research[3]. Girard declares mimesis as a human trait, and describes how all human desire is mimetic and consequently is the force behind violence in society[4]. 'When you say 'imitation', everybody thinks of being sheep-like, gregarious, following people, and so forth. This is true in many instances, but what is also true is that imitation not only affects your gestures, your words, or ideas; you also imitate desires[5]'.

Child psychologist Colwyn Trevarthen has explored mimesis in new-borns, infants and young children, and how the process affects social and cognitive development. He shows that mimetic interaction between the child and its family and care-givers is essential for healthy growth and maturation (Trevarthen 2004). This interaction is complex and subtle but instinctive and innate for most people. From the moment we are born we have the ability to communicate with our primary care-giver through mimetic participation. This is essential for our immediate survival as we are not capable of providing the necessities of life for ourselves and so rely on the relationships with the people around us. This ability stays with us and is involved in our daily interactions with others, sub-consciously influencing our decisions and choices, the way we respond and empathise in order to interpret and respond to people and situations around us.

Trevarthen's work has been studied by Steven Malloch, an audiologist, analysing audio recordings of protoconversations for musical content. He has found strong elements of rhythm and melody in motherese, concluding that the instinctive communication between mother and baby is a delicately complex balance of precise intonations and rhythms, alternating between mother and child. Malloch describes this process as 'communicative musicality' and believes it an important part of cognitive and social development (Malloch 2000b). The conversations involve imitation and call and response, where the baby responds and imitates the sounds and gestures of the mother, who in turn responds and imitates the baby. Malloch's theory makes convincing links between the mimesis and the musicality of these early communications and has found evidence to link infant directed speech (IDS) and its musical nature. Using spectrographic analysis and other audio analysis techniques Malloch has found musical patterns in rhythm (pulse), melody (pitch and narrative) and timbre (quality) and concludes that this musical content is essential to successful and effective IDS: 'We have discussed communicative musicality in terms of pulse, quality and narrative. We have seen that in these areas systematic movement occurs between mother and infant — movement that allows mother and infant to express themselves in ways that are sympathetic with the other. Movement — gestural, vocal and emotional — is what allows communicative musicality to occur. When this movement is constrained or impeded, communicative musicality suffers, and companionship suffers' (Malloch 2000b).

These studies involve a range of ages including new born babies, which suggests that the aptitude for communicative musicality is inherent and innate, without learning or experience. However, learning and experience will improve the ability and generate memories from which the mimetic process can draw on further in future development. Malloch states that 'It appears that the mother's intuitive behaviour supports the infant's innate communicative capacities'. It is this innate mimetic ability that is attempted to be exploited within specific instrument design criteria that led to developing the BazerBow instruments described in the next section, enabling empathetic, intuitive mimetic participation.

5: Mimetic Participation and Instrument Design

The specific term of 'mimetic participation' is used in various areas. Biology uses it to refer to cell imitation (Gabius et al. 2004), and religious writings refer to it as an experiential sensation (Garrels 2011). In music and music performance mimetic participation can be seen as the driving force behind the familiar 'air guitar', which has become such a common phenomenon with annual 'air guitar' championships attracting thousands of entrants worldwide[6]. In child psychology Colwyn Trevarthen and Steven Malloch have found that mimetic participation occurs from the moment a baby is born, to establish a necessary relationship with a primary caregiver, and so mimetic participation is an intuitive ability that most people are born with (Trevarthen 2004). This innate ability is drawn on throughout our lives in most circumstances we find ourselves in, especially social situations, and is affected and evolves with experiences and memories. This mimetic process allows us to predict and make decisions about new situations by using mimetic participation to anticipate and visualise any given scenario, enabling us to mentally 'practice' and role-play the situation before committing to a decision. This process improves as memories are developed and can be drawn on, and mimetic participation can draw these memories together in such a way that situations may be pre-empted 'instinctively'.

Mimetic participation not only relates to movement and gesture. As Cox says 'we do more than visibly move to music; we also sing along, in real time and in recall, aloud and in our heads'. These mimetic vocalisations point towards a theory that any mimesis of gesture may include vocal mimesis. As Billinghurst says 'Gesture is also intimately related to speech, both in it's reliance on the speech channel for interpretation, and for its own speech like-qualities (Billinghurst and Buxton 2011)'. Cox says that 'it should not be surprising that we would draw on vocal imagery to understand instrumental musical sounds generally' (Cox 2006:49).

In terms of musical instruments, the listener through experience, has an understanding of their physical surroundings and the materials around them, and how these materials react when interacted with, such as concepts of hardness, density etc., and how these materials might 'sound' when plucked, hit or struck. Using this knowledge the listener can imagine what will happen when a string is plucked, and the type of sound that the string might produce, without having ever experienced a guitar-like instrument before. With this anticipatory knowledge, and having an understanding of their own motor-neuron system and how their body will need to impart appropriate forces to pluck the string, the listener can imagine playing this stringed instrument without any prior experience or knowledge, an important principle when devising new instruments.

6: Mirror/Sympathy Neurons

In neurological studies in sports, it has been discovered that actions involve neurons that fire when participating in the action, but also when only imagining the same actions. 'Mirror neurons are a particular type of neurons that discharge when an individual performs an action, as well as when he/she observes a similar action done by another individual' (Rizzolatti 2005).

This is believed to also occur with musical gesture and actions related to playing instruments but has yet to be confirmed. Molnar-Szakacs and Overy hypothesise that: 'the powerful affective responses that can be provoked by apparently abstract musical sounds are supported by this human mirror neuron system, which may subserve similar computations during the processing of music, action and linguistic information' (Molnar-Szakacs and Overy 2006).

These neurons allow the brain to prepare for actions that have never been performed before, which is essential in evoluntionary terms as the body needs to be ready and prepared for 'fight or flight' at any moment and able to act intuitively and able to improvise to survive. This neurological process may be the mechanism behind mimetic participation allowing the imagining of playing an instrument never previously played before. Molnar-Szakacs and Overy say that: 'The connection between music and motor function is evident in all aspects of musical activity-we dance to music, we move our bodies to play musical instruments, we move our mouths and larynx to sing.' (Molnar-Szakacs and Overy 2006).

Colwyn Trevarthen prefers to refer to mirror neurons as sympathy neurons: 'It might be better to call these the neural mechanisms of *sympathy*, which is a Greek word meaning 'moving and feeling with' (Trevarthen 2004). Not only may these neurons provide an understanding of the mechanics and physical processes of playing an instrument, it may also allow a connection or empathy between performer and listener facilitating a more complete understanding of the musical performance not confined by purely the visual gestures. Using the term sympathy may be a more applicable term as it suggests a more empathetic process: 'We intuitively get into other persons' minds by actively sensing the impulses to action in their brains that enable them move the way they do' (Trevarthen 2004).

7: The BazerBow: Prototype 1[7]

The BazerBow was developed to exploit mimetic theory, and thus to address some of the limitations in commercially available controllers, such as limited simultaneous control of independent parameters. The BazerBow first prototype, (the first of 3 designs so far) has a varied range of sensors to accommodate the independent manipulation of several controls simultaneously, as well as controlling the initiation, length and pitch of the notes. The integration of physical body/movement gestures rather than limiting gestures by using knobs, buttons and faders, allows a full range of small, medium and large gestures creating a much wider range of gestural movement to control the sounds[8].

The BazerBow design is based around the guitar and a modified version of Delalande's classification of gesture (Wanderley and Vines 2006), as discussed above, has been used to help develop the gestural elements of the BazerBow:

1. Initial gesture: this is the gesture that begins the sound wave transient, and is quite often percussive. With an acoustic instrument's sound this transient is quite often important for the recognition of the timbre (Malloch 2000a). The initial gesture requires the 'plucking' to initiate the sound, and the positioning of the 'fret board' hand to alter the pitch.

2. Modulating gesture: these are gestural movements that occur after the sound has been initiated, that modulate parameters that affect the sound in some way. Synthesisers generally have many parameters that may be changed during the sound production, and so there are several modulating gestures to complement these synth parameters. These modulating gestures may be split into three sizes: small, medium and large. Small gestures are difficult to see but affect the sound; medium gestures can be seen from a small distance; large gestures are movements that can be seen from distance.

3. Inter-modal gesture: this includes all components/features of the BazerBow that do not affect the sound but have a visual presence. Although the gestures do not directly change the sound, taking the McGurk effect (McGurk and MacDonald 1976) into account, they influence the perception of them.

An important visual aspect of the BazerBow is in the way that it looks and feels, attempting to create a device more like an acoustic instrument than a typical controller. It is made mainly from wood and great effort has been made to hide the technology where possible. This is not only so the performer may feel more like they are performing with an instrument, but so that listeners may be given the impression of a musical instrument similar to a guitar.

For the BazerBow, there is a compromise between a shape suited to synthesised sounds and one influenced by theories of mimesis, that will promote mimetic participation. The guitar base should afford users to know how to initially generate sounds from the BazerBow, which should in turn improve mimetic understanding of the instrument thereby enabling mimetic processes. The BazerBow is an attempt to balance many facets of instrument design: a unique digital instrument/controller vs traditional acoustic form; small nuance based performer orientated gestures vs large spectacle audience orientated gestures; ease of play for beginners vs complexity of play for mastery; simplicity of design and use vs complexity and flexibility of control. These facets are pulled together with the common thread of mimetic participation.

Besides devising a series of fun and effective instruments to play, based on mimetic principles, the BazerBow will in the future hopefully provide evidence for the success of Mimetic Influenced Instrument Design.

8: Conclusions & Future

The expansion and intensification of research in the field of new digital musical instruments and controllers has given rise to conferences and publications dedicated to the subject, such as NIME and ICMC conferences and journals such as Organised Sound and Computer Music Journal. Similar control technologies are also being developed for homes allowing full control of lighting, heating, infra-red devices, etc., directly from 'smart' devices or with gestural control (Leap Motion) or voice command (Apple iPhone).

Many areas of this research are already being explored including gesture, modality and mimesis, including mirror/sympathy neurons. However, the current instrument designs do not seem to give full credence to the potential influence of mimetic theory on instrument use and the potential considerations for design. Mimesis, as discussed above, overlaps with and draws in principles of inevitability, gesture, inter-modal perception, instrument efficiency and affordances, processes which are usually important to instrument design, and although it may contradict with ideas of instrument efficiency, it balances this theory allowing the incorporation of the relationship with audience-instrument-performer as well as only instrument-performer. The theory also pulls on other areas such as, empathy, intuition and heart-brain interaction, and sympathy/mirror neurons which may not have otherwise been considered in instrument design, but could lead to new developments which may have otherwise been missed.

Girard states that: 'All scientists know that many scientific innovations consist in importing into a neighbouring area something which has been invented elsewhere, something which has not only worked and produced things, but suddenly illuminated a problem that until then was totally obscure' (Garrels 2011:238). Importing these mimetic theories into the design and development of music control devices may lead to a new class of innovative digital instrument and controller.

Whilst there is still more scope to quantify the effectiveness of the BazerBow during its ongoing developments, this paper has explored how mimetic participation can be exploited in conjunction with more established design theories and principles and may enhance the ability of digital instruments to communicate and engage with an audience.

To date, two fully functioning prototypes have been built, another one in progress, all based on mimetic principles. Future areas of research are planned:

1. To look at the relationship of mimetic participation and instrument design through the use and exploitation of these devices through composition and performance, in varied performance situations and instrumentation/ensembles.

2. The mimetic theories may not only affect instrument design for purely musical performance, there may be a potential for the use of mimetically designed instruments to be useful in music therapy. Malloch and Trevarthen's work (Malloch 2000b; Trevarthen 2004) suggests that a lack of communicative musicality at an early age can affect cognitive and social development. These issues are currently being tackled with music therapy, with good success but with traditional instruments. A specially designed instrument which harnesses mimetic participation may prove even more successful in music therapy, supplying the 'communicative musicality' and mimesis which was lacking earlier.

3. To attempt to measure the effectiveness of mimetic principles by more empirical means. The theories of mimesis and mimetic participation may be explored through a series of musical 'experiments' using different devices and controlled environments/audience. These experiments have the potential to include sophisticated tests looking at brain function when experiencing mimesis, searching for mirror/sympathy neurons.

The BazerBow needs to be fully examined as a 'new instrument', further exploring key areas of instrument performance such as the capability/flexibility to improvise, the ease of initial use and further mastery, and also to confirm whether or not performances induce the 'air BazerBow' effect.

Developed as a performance device a mimetic controller such as the BazerBow, will give access to the control and performance of more complicated synthetic sounds. This may allow a greater audience appreciation of the instrument, performer and performance, in turn giving the perception of an instrument rather than a piece of control technology and possibly creating an opportunity for amalgamating new music synthesis with traditional instrumentation.

The BazerBow project has only just begun to scratch the surface of Mimetic Influenced Instrument Design and will endeavour to improve the efficaciousness of the mimetic effect of its new instruments.

9: Acknowledgements

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Exploiting Mimetic Theory for Instrument Design

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ABSTRACT

This paper will present a first instrument and discuss its design method, derived from principles informed by mimetic theories. The purpose of these design principles is to create new and innovative digital music instruments.

Even though mimetic theories are known to be important in the communication, engagement and expression of music performance, this ongoing enquiry represents the first consolidated effort to develop design principles from mimetic theories. [1], [2]

As part of the project, a development cycle is being followed to produce, evaluate and improve the design principles, and as part of this paper, a first prototype will be presented.

This paper covers a short description of the first prototype, describes the design process towards developing some generically applicable design principles and covers some of the underlying theories around empathy, communicative musicality and mimetic participation.

1. INTRODUCTION

This paper presents first outcomes and an initial prototype instrument, produced as part of a project that aims to develop instrument design principles informed by theories of communication and perception collectively referred to (in this paper), as mimetic theories. These theories include inter-modal perception [3], empathy [1], [2], [4], communicative musicality [1] and mimetic participation [2].

Existing digital music instrument (DMI) design theories have also been taken into consideration, looking at gesture [5], instrument efficiency [6], inevitability [7], affordances[8], [9] and Human Computer Interaction (HCI) [10], [11].

The first prototype was designed by applying these mimetic theories to the existing DMI theories, guiding the choice of features, instrument shape, materials and mapping of controls to synth parameters. We began with the premise that if design principles were to be developed that took mimetic theories into consideration the production of instruments following these principles should ideally improve what Trevarthen & Malloch have coined as communicative musicality [1] of the instrument (see chapter below). Thus an effective mimetic instrument should be successfully employed/exploited in therapeutic, community music and/or performance/audience contexts.

2. PROTOTYPE DEVELOPMENT

Figure 1. Prototype 1.

The first prototype (Figure 1, the first of three so far) was developed to explore the initial premise of these principles. All prototypes have some basic features that can be found in many gesture-based instruments and that allow simultaneous control of independent parameters. Basic features include a range of sensors to accommodate the independent manipulation of several controls simultaneously, as well as controlling the initiation, length and pitch of the notes. The integration of physical body/movement gestures rather than limiting gestures by using knobs, button and faders, allows a full range of small, medium and large gestures creating a much wider range of gestural movement to control the sounds.

The first design (Figure 1) was based around the guitar. A version of Delalande's classification of gesture [12], modified by applying mimetic principles, has been used to develop the gestural elements of the prototype:

2.1 Initial Gesture

Initial gestures begin the sound wave transient, and are quite often percussive. With an acoustic instrument's sound this transient is often important for the recognition of the timbre [13]. Daniel Levitin gives this description, "The gesture our body makes in order to create sound from an instrument has an important influence on the sound the instrument makes. But most of that dies away after the first few seconds. Nearly all of the gestures we make to produce a sound are impulsive" [14].

When a gesture is seen to be initiating the sound the two senses of sight and hearing are working together to create a perception of the instrument being played. Depending on the movement of the gesture it could be possible to either enhance the audience's perception of the instrument or conversely reduce its impact, by intentionally subverting the natural expectation of the audience. For example, the visual expectation of the audience, when hearing louder sounds, might be to see larger movements, which in acoustic instruments would be the case, but in electronic instruments could be inverted. In this situation smaller movements creating louder sounds might confuse an audience.

If further such subversion to audience expectancies is created the sounds being heard may no longer be perceived as being connected with the instrument on stage. If the listeners do not connect the sounds with the instrument then they may not be able to imagine creating those sounds on the instrument themselves. Therefore the affect of mimesis would be greatly reduced.

2.2 Modulating Gesture

Modulating gestures are gestural movements that occur after the sound has been initiated, modulating parameters that affect the sound in some way. Synthesisers generally have many parameters that may be changed during the sound production, and so there are several modulating gestures to complement these synth parameters. These modulating gestures may be split into three sizes: small, medium and large. Small gestures are difficult to see but affect the sound; medium gestures can be seen from a small distance; large gestures are movements that can be seen from distance.

As with the initial gesture, a compliance or subversion of expectation, using common parameters, such as pitch-bend, could have similar effects as discussed above. However, parameters that affect the sound in new ways, not analogous to an acoustic counterpart, may not be treated in the same way by the listener. The new sound and connected gesture may intrigue the listener with its uniqueness and unfamiliarity. This may allow new associations to be made with the instrument and how it should be played. This could lead to interesting relationships between the gesture and synthetic sound, and provide informative movement that enhances the sound rather than remaining abstract and detached from the aural information.

In conjunction with the initial gestures, carefully designed modulating gestures should strengthen the mimetic impact.

2.3 Inter-Modal Gesture

Inter-modal gestures include all components/features that do not affect the sound but have a visual presence. Although the gestures do not directly change the sound, taking the McGurk effect [3] into account, they influence the perception of them.

An important inter-modal consideration is in the way that the instrument looks and feels. The first prototype was created to look more like an acoustic instrument than a typical controller. It is made mainly from wood and great effort has been made to hide the technology where possible. This is not only so the performer may feel more like they are performing with an acoustic instrument, but also so that listeners may be given the impression of an acoustic musical instrument similar to a guitar.

Creating an 'acoustic' look to the instrument should elicit a mimetic response in the audience, allowing them to form an impression of the mechanics of the instrument.

3. PROTOTYPE 1

With consideration to mimetic theory the aforementioned guitar based design gives the observer a starting point from which to understand the performance motions and gestures. This allows an initial understanding of the controller and a basis to build in new gestures specific to the device.

The initial gesture requires the 'plucking' to initiate the sound, and the positioning of the 'fret board' hand to alter the pitch. This will be familiar enough for guitarists to immediately pick up the controller and begin playing with an intuitive sense of control, but will also be familiar enough for non-guitarists to gain a modicum of control with little effort.

The prototype utilises a variety of sensors to exploit the various movements that are possible with a guitar-based instrument, producing modulating gestures that control synthesizer parameters. Sensors placed at fret and bridge positions can detect small modulating gestures, mapped to appropriate synthesiser parameters.

Other sensors detect medium modulations from the hands, and large modulations from movements of the controller. Guitarists will be familiar with these larger gestures but in most cases, on an electric guitar they will be intermodal, (not actually affecting the sound). On the controller they are modulating gestures, and are mapped to additional synth parameters.

The concept of mimesis is an interesting one to consider when analysing the performer-audience relationship. However, this concept allows us to furthermore align instrument design not only to the creative aims of performers or instrument makers but to address specifically parameters that might be considerably involved in allowing audiences to feel that performed music on digital instruments is accessible to them. It is apparent through this research, so far, that the inclusion of mimetic theories during the design and development of controllers will open up interesting avenues for new devices.

There is a compromise between a shape suited to synthesised sounds and one influenced by theories of mimesis that will promote mimetic participation. The guitar base should afford users to know how to initially generate sounds, which should in turn improve mimetic understanding of the instrument thereby enabling mimetic processes.

The design is also an attempt to balance many facets of instrument design: a unique digital instrument/controller vs. traditional acoustic form; small nuance based performer orientated gestures vs. large spectacle audience orientated gestures; ease of play for beginners vs. complexity of play for mastery; simplicity of design and use vs. complexity and flexibility of control.

These design facets are pulled together with the common thread of mimetic theory, including empathy, communicative musicality and mimetic participation.

4. MIMETIC THEORIES

There are many relevant areas of research important to instrument design, such as affordance, gesture, inevitability and efficiency [6]–[10]. However the main thrust of research for this project has come from three key areas: empathy, communicative musicality, and mimetic participation.

4.1 Empathy

Empathy is intrinsic to the mimetic process. Trevarthen and Malloch [1] describe how musical mimesis may facilitate improved social empathy. Communicative musicality produces an empathy and understanding between mother and baby [15]. This imitative process is essential to creating empathy. How we understand each other and the way we communicate involves empathetic, mimetic response. Cox states that 'part of how we comprehend music is by way of a kind of physical empathy that involves imagining making the sounds we are listening to' [2].

Empathy and sympathy are key processes in communicative musicality, which Malloch [15] describes as 'movement that allows mother and infant to express themselves in ways that are sympathetic with the other'.

4.2 Communicative Musicality

Trevarthen's [16] studies of the earliest interactions between newborn babies and their mothers, known as motherese or proto-conversation have been shown by Malloch [15] to contain patterns, repetitions, rhythms, pitch and intonation variations which are very musical in nature. Trevarthen's collaboration with Malloch suggests that the presence of this 'communicative musicality' between mother and baby is essential for healthy social and cognitive development of the child [1], [15], [16].

This innate, imitative ability is utilised throughout our lives to communicate, empathise and to make sense of the world around us. We understand music and performance through this visceral 'empathy', wanting to 'join' in through mimetic participation.

4.3 Mimetic Participation

Mimetic participation can be used to describe how we understand and imitate a process such as playing a musical instrument. It can be an uninvited urge to copy someone or join in such as tapping your foot or humming to music [17]. Arnie Cox asks 'Do you ever find yourself tapping your toe to music?' and then suggests that 'Informally conducting, playing 'air guitar', and 'beat boxing' (vocal imitation of the rhythm section in rap) are similar responses' [17].

Through researching the mechanisms of empathy and communicative musicality it should be possible to emphasise/exaggerate the effect of mimetic participation, creating instruments that invoke their 'air' cousins in audience/listeners.

5. DESIGN PROCESS AND FUTURE EVALUATION

Figure 2 below shows the development cycle to be followed to produce, evaluate and improve the design principles.

Figure 2. Cycle of Development.

The design process of the cycle of development includes taking measurements at live performance events as well as using video interviews. Analysis of video footage and audience/performer sensor data provides additional data sets, to compare mimetic designed instruments with traditional instruments.

An instrument with greater mimetic effect should elicit more imitative gestures. To test this hypothesis design principles are developed throughout the research project duration using multiple iterations of the above process. All prototypes are created using these principles and examined in the following ways. Cox suggests that 'For many if not most of us, and for most kinds of music, music nearly demands mimetic participation (overt or covert)' [2]. Cox's 'covert imitation' involves imagining physical actions and 'overt imitation' refers to outward movements or gestures such as tapping your feet [2]. This overt/covert mimetic participation will be examined during a series of performances.

A composition using modulated, synthesised sounds will be carefully composed so that it can be performed identically, using the same sound generator, by both standard keyboard controller and BazerBow. The composition will be performed to a click track ensuring consistency in performance and time stamping for data analysis. Separate performances of this composition, one using keyboard, another the BazerBow, will allow a comparison of the 'mimetic' features of the BazerBow and their associative non-mimetic gestures of the keyboard.

At each performance the performer and audience (approximately 20 people) will be videoed to allow comparison of specific performance gestures and audience response. This video footage will show medium/large mimetic gestures of the audience, such as ‘air’ guitar type motions. Time stamped data from movement, force and vibration sensors arranged around audience seats will be analysed for small/medium gestures such as foot/finger tapping.

Due to the nature of convert mimesis, it will be necessary to investigate directly with the audience to understand their thought processes during the performance. Video interviews will be undertaken after each performance to discover how each audience member felt they were affected by the performance and if they had any desire to imitate or join in. The interview videos will also be analysed to look for imitative gestures used in the interviews.

Interviews will be retrospective and reliant on the interviewee’s memory. However an additional Likert[1] Slider test will be implemented during the performances. Before the performance, each audience member will be provided with a physical slider. They will be asked to move the slider during the performance from 1 to 10, in response to an appropriately designed question, such as how much they would like to join in with the performance, and/or how engaged they feel with the performance. These sliders will produce data that is time-stamped so the values can be compared with the other data/video analysis.
Once the data/video has been analysed it can then be used to compare the differences/similarities between the keyboard and BazerBow performances, looking to see if the features of the BazerBow have an increased mimetic effect causing greater imitation and desire to join in.

6. CONCLUSION

We believe that even though mimetic theories are known to be important to the communication, engagement and expression of music performance, this ongoing enquiry represents the first consolidated effort to develop design principles from mimetic theory. Our initial prototypes point towards the validity of the assumption that an instrument designed with mimesis in mind should elicit more imitative gestures.

This project, which is in the middle of the first iteration, will demonstrate a development cycle that produces, evaluates and improves the design principles, which are the core output of the PhD project.

These mimetic design principles will be tested and developed initially using progressive versions of the first guitar-based prototype design, following the development design cycle (Figure 2). A future paper will cover the results of these tests and the following iterations of design. To further develop the design principles, new and different mimetic prototype designs will be created and tested.

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[1] A Likert scale is a psychometric scale used in questionnaires, named after its inventor Rensis Likert.

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THE BASER BOW:[1] AN INSTRUMENT BASED ON THE EXPLORATION OF THE CONCEPT OF MIMETIC PARTICIPATION FOR THE DEVELOPMENT OF MULTI-MODAL AND MULTI-GESTURAL DEVICES

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ABSTRACT

The focus of this research enquiry is to consider and explore how the interactive experience between a performer and his/her tools can be further enhanced and refined beyond current state-of-the-art equipment by aligning the design of multi-gestural and intermodal midi controllers to support empathetic, mimetic participation.

The first project of this research includes the development of a controller, based on guitar, and using lasers and sensors detecting gestural parameters.

The visual aspect of the controller will inform the audience of the music and its relationship to the performer and controller, enabling the empathetic, mimetic participation, producing an immersive and shared experience. Arnie Cox asks “Do you ever find yourself tapping your toe to music?” [3] and goes on to say “we experience patterns of exertion by way of mimetic participation, and in this way it is as if we are acting - acting in a way that is more or less isomorphic with the sound producing actions heard (and seen).” [6]

This paper will cover the context around mimetic participation, intermodality, and gesture.

1. INTRODUCTION

This research forms part of a post-graduate thesis dealing with gesture and motion within musical performance. The initial design ideas have been born out of the desire to create an instrument or controller that can be used to play electronic music and synthesised sounds that give the performer comprehensive musical control of the sounds being performed. Basing the controller on a guitar like design will allow anyone with a familiarity of guitar techniques an immediate starting point for playing the controller. However, the additional gestural motions will give the instrument a degree of difficulty that will require some practice to master. Also the incorporation of lasers and sensors requiring relatively large movements will create a greater visual impact than that of existing devices.

Since the introduction of electronic instruments many people have begun to use a multitudinous variety of controllers and devices, to control and perform music. This has led to a proliferation of commercially available electronic devices, by large companies and individuals alike. The market for ‘home-made’ devices is growing due to the increasing affordability and availability of electronic components. This allows the development of sophisticated controllers that address specific areas, such as the device proposed in this paper, focussing on accommodating potential of the concept of mimetic participation.

1 “Baser” is derived from bass and laser, and “Bow” comes from “Diddley Bow”, a one-string instrument, recently seen played by Seasick Steve. [18]

2. EXISTING MIDI CONTROLLERS

The traditional design for midi control is based on some form of keyboard. However, nothing has captured the imagination of the general public quite like the electric guitar, giving rise to the air guitar world championships [15] and consumer console games such as Guitar Hero [1][20]. It may be a surprise to some, then, that when the 'midi guitar' [21] was introduced it failed to gain widespread popularity. Even with improved technology it has still remained in obscurity. The shoulder keyboard or 'keytar' would seem to fit the bill, with a keyboard input and held in a similar manner to guitar. It has been utilised recently by Lady GaGa and Muse. [22] The keytar has the advantage of having controls which the left hand can manipulate the sounds with. This has the corresponding disadvantage of removing the left hand from playing notes. A hybrid midi-guitar/keytar, the 'ztar' has been developed by 'Starrlabs' [29] and also recently seen in use by 'Pendulum'. [21] The ztar is played like guitar but the fret board consists of buttons that are pressed to select notes. The 'Eigenharp', [19] a similar but more complex design has been created by John Lambert. It utilises the same idea of buttons along the fret board, and these buttons can be manipulated to affect the sound. There are a range of additional sensors, including a breath controller which can allow the controller to be played like a wind instrument.

The most visually striking controller must be the laser harp, designed in 1976, by Geoffrey Rose, and made famous by Jean Michel Jarre. [24] It looks impressive, especially at a distance, but has much less control over sounds than alternatives.[2] Breaking the lasers produce midi-note information and the height of the hand can be detected, to control a single midi parameter. Other controllers can create additional note parameters, such as midi-note velocity, after-touch, pitch-bend and modulation, as well as having controls that can be assigned to more synth parameters. There are many less conventional designs, most notable the Tenori-on, by Yamaha[3] [30] and the Reactable[4] [27] Both these devices need a new approach to performing with them, as their designs are so far removed from traditional instruments, and because of this there are no transferable techniques from previously acquired abilities.

It seems, because of the current interest in new midi controller designs, that there is a desire for a controller that can control and communicate synthetic sounds and nuances, as successfully as the electric guitar.[5] Electronic sounds and styles have become a major influence on pop music in the last few years. ‘Electropop’ artists frequently topping the charts in both the US and UK.[6]

2 Little Boots made use of a laser harp in her 2010 tour. [25]
3 Little Boots uses Tenori-on. [30]
4 Bjork uses the Reactable. [28]
5 Considering that the basic design for the electric guitar hasn't changed since it was first introduced.
6 “In 2009 James Oldham, head of artists and repertoire at A&M

[16] These artists are looking for new and innovative ways to perform electronic sounds.

The questions raises itself is there scope to maximise the acceptance of experimental controllers into the commercial markets by exploiting the mimetic possibilities in the design of controllers.

2.1. Hardware

The initial idea for the design of the controller came about when experimenting with how to perform electronic music, that would be visually engaging with an audience, developing an interest in the skill of the playing and a desire to play the controller themselves. As mentioned, the laser harp is visually spectacular, but has no refined musical control beyond 2 – 3 parameters. The design could be abstract, like the Reactable, but it was decided that the basic design and playability would be established on an existing instrument, allowing players of the acoustic instrument to translate some of their skills over to the controller. One obvious instrument design seemed to be guitar. Although a laser guitar is not a unique idea [23][14] lasers have been incorporated into the design. It is possible to derive hand position from the lasers, (using some type of light detection [12]) but soft-membrane potentiometers provide a more reliably accurate signal. [9] The use of lasers provides an ideal design feature for exploring ideas of intermodality due to their high visibility.

A photodiode detects a break in the laser beam to create midi note on/off messages. Other various sensors give scope for musical movement and gesture. The sensors are connected to a micro-controller which is already programmed as a USB midi device, sending midi-note and controller information to the USB port.

2.2. Software

The software interface has been created in Native Instruments Reaktor. [26] This interprets the raw midi data, received from the micro-controller, into useable midi-note and controller data. The software interface is designed to produce note information in a similar manner to the note pitches created on guitar.

3. MIMETIC PARTICIPATION, INTERMODALITY AND GESTURE

Jane W. Davidson discusses the shared experience of performer and audience at a Robbie Williams concert, “The physical movement is evidently pleasurable, perhaps adding to the sense of cohesion, as they all literally coordinate in their body movement, as well as, of course, sharing in singing the song.” [7] The new controller has been created to communicate electronic music in a new way and in some way involve the audience. It is common that when people go to a pop/rock concert they like to sing along, dance and play various 'air' instruments. This is a communal experience, with the performers.

When experiencing electronic music in a concert environment, for example Jarre,[7] the musical aspect of the show is accompanied by a dazzling lighting and multimedia show. When perceiving music that consists of only synthesised timbres, that are unlike any known acoustic sounds, it is difficult to imagine playing those sounds on any existing (or imagined) instrument. Therefore the listener cannot ‘play’ or ‘sing’ along with the music. Jarre, stands behind a set of keyboards, showing little movement, and as a listener, the lighting can become more interesting than the ‘musical performance’. However, the laser harp focuses the audience attention onto Jarre.

The role of musical gesture and gestural movement have been considered in the design and implementation of the controller. This has led to further inquiries into research concerning intermodal perception and mimetic participation.

3.1. Intermodality

The most striking example of intermodal perception, in relation to sound (and therefore quite possibly music), is the McGurk effect [2]. This experiment shows quite clearly that we do not perceive exactly the sounds that we hear, but that vision has an astonishing effect on how our brain interprets the sound.

This experiment, amongst many others, shows that our senses are inextricably linked and that if we are to take this into consideration, how an audience might perceive a performance, becomes more complex when we consider the other four senses, in addition to hearing.

Robert Hatten links intermodality with gesture, “gesture involves the coordination of intermodal syntheses, based upon the functional coherence of movements as events, and their emergent meanings.” [8]

3.2. Mimetic Participation

Arnie Cox looks at evidence for mimetic participation, “sounds are evidence of the motor actions that produce them, and our comprehension of the sounds involves comprehension of the relevant motor actions.”[4] Initial thoughts of mimetic participation lead to “air guitar” [3] and how popular games such as “Guitar Hero” have become. This is in some part, down to people wanting to emulate their musical hero’s and becoming legendary musicians themselves, albeit imaginary.

People engaged in listening to music have the capacity to imagine playing the instrument that they are listening to, whether the performance is being watched or heard only. This is true even when the listener has had no musical training or experience with the instrument. There needs to be only an idea of the kinds of movement necessary to play the instrument in question. Having seen a particular instrument being played it is then possible for the listener to extrapolate the motions to similar instruments, thereby being able to imagine playing a larger group of instruments than actually seen, i.e. after seeing a clarinettist it is easy to imagine playing the saxophone. Arnie Cox discusses this in more detail, “Yet even having never played the same instrument or any instrument at all, we will automatically have some idea of what it must feel like to move one's fingers and arms in a certain way.” [5]

3.3. Gestures

It seems that the visual and aural elements of performance are elaborately intertwined. It may even be possible that the visual element could actually change how our brain ‘hears’ the aural element, as shown in the McGurk [2] effect. Musical gesture generates much of the visual performance of musicians and singers, and

Records was quoted as saying "All A&R departments have been saying to managers and lawyers: 'Don't give us any more bands because we're not going to sign them and they're not going to sell records.' So everything we've been put on to is electronic in nature."” [17]

7 Jean Michel Jarre arena tour in 2009.

without the lighting, video and special effects of commercial concerts it may be the only visual information the audience receives. There have been many ways that gesture has been described and categorised. Marcelo Wanderley and Bradley Hines describe Delalande's classification of gestures as “(1) Effective gestures, those that actually produce the sound; (2) Accompanist gestures, expressive body movements; and (3) Figurative gestures, gestures perceived by a listener, but without a direct correspondence to a movement of the performer. Examples include changes in note articulation and melodic variations.”[13] For the purposes of this project three types of gesture, named and described below, will be investigated to inform the design and development of the controller.

3.3.1. Initial Gesture

‘Initial gesture’ is to be described as the motion which initiates the sound. This quite often is the initial transient of a sound which contains the timbral information that gives an instrument its unique and identifiable sound. Daniel Levitin gives this description, “The gesture our body makes in order to create sound from an instrument has an important influence on the sound the instrument makes. But most of that dies away after the first few seconds. Nearly all of the gestures we make to produce a sound are impulsive” [10][11] This utilises intermodal perception and may affect the experience of mimetic participation.

When a gesture is seen to be initiating the sound the two senses of sight and hearing are working together to create a perception of the instrument being played. Depending on the movement of the gesture it could be possible to either enhance the audience’s perception of the instrument or conversely reduce its impact, by intentionally subverting the natural expectation of the audience. For example, the visual expectation of the audience, when hearing louder sounds, might be to see larger movements, which in acoustic instruments would be the case, but in electronic instruments could be inverted. In this situation smaller movements creating louder sounds might confuse an audience. If further such subversion to audience expectancies is created the sounds being heard may no longer be perceived as being connected with the instrument on stage.

If the listeners do not connect the sounds with the instrument then they cannot imagine creating those sounds on the instrument themselves. They could not involve themselves in mimetic participation, unless they actually experience playing the instrument first.

3.3.2. Modulating Gesture

‘Modulating gesture’ will be defined as motion, after the initial gesture, that modulates or changes the sustained sound in some way. This could be as simple as vibrato or pitch-bend or a more subtle control of synthesiser parameters. As with the initial gesture, a compliance or subversion of expectation, using common parameters, such as pitch-bend, could have similar effects as discussed above. However, parameters which affect the sound in new ways, not analogous to an acoustic counterpart, may not be treated in the same way by the listener. The new sound and connected gesture may intrigue the listener with its uniqueness and having no familiarity, may begin to make new associations with the instrument and how it should be played. This could lead to interesting relationships between the gesture and synthetic sound, and provide informative movement that enhances the sound rather than remaining abstract and detached from the aural information.

3.3.3. Intermodal Gesture

The term ‘intermodal gesture’ will be used to refer to gestural or other visual aspects of playing the instrument which do not physically affect the timbre of the sound in any way. As already discussed, there may be a change in perception of the sound due to intermodal perception, but the motion will not directly effect any synthesiser parameters.

The main reason to include lasers in the design of the controller, was to provide a way of more effectively visually representing the performance. The large movements of a guitarist can be seen at a distance, as the said guitarist may swing the guitar around his head, for example, but the smaller nuances of the playing, in particular the hands, are not easily seen. With the use of lasers the gesture and motion of the hands and fingers, will be high-lighted in greater detail and distance than an electric guitar, thereby intensify the visual aspect of the performance.

This also may create more interest for the viewer, in how the controller is being played and the skill involved in performing with the controller. This would be more akin to a classical performance where the audience admire the skill involved in playing a particular acoustic instrument. It seems to be that someone’s skill on an instrument can be appreciated more if the performance can be seen in more detail.

4. DESIGN FEATURES

With consideration to mimetic participation the, aforementioned guitar based design will give the observer a *starting point* from which to understand the performance motions and gestures, allowing an initial understanding of the controller and a basis to build in new gestures specific to the device.

The initial gesture uses the combination of soft-membrane potentiometer 'fret board' and laser 'pluck' which will be familiar enough for guitarists to immediately pick up the controller and begin playing. A potentiometer is used to create the note velocity and the laser positioned near the right hand in conjunction with a photodiode, creates the midi-note on/off. However, the laser positioned on the “fret-board” is purely visual and therefore only for intermodal gesture.

Modulating gestures utilise a variety of sensors. The potentiometer placed on a force sensing resistor creates pressure sensitivity on the 'fret board' akin to applying pressure on a string to increase pitch. This pressure sensor could be linked to pitch in the same way. A gyroscope attached to the end of the 'neck' of the controller detects the vertical & horizontal movements of the controller. Guitarist will be familiar with these gestures but in most cases, on an electric guitar they will be intermodal. On the controller they are modulating gestures. An infra-red proximity detector is placed near the right hand. This could be used like the “whammy bar” on a guitar.

The concept of mimetic participation is an interesting one to consider when analysing the performer-audience relationship. However, this concept allows us to furthermore align instrument design not only to the creative aims of performers or instrument makers but to address specifically that parameter that might be considerably involved in allowing audiences to feel that performed music on digital instruments is accessible to them. It is apparent through this research, so far, that the inclusion of mimetic participation during the design and development of controllers will open up interesting avenues for new devices.

5. FUTURE DEVELOPMENTS

So far a single 'string' prototype has been created, (the Baser Bow). The next step is to build a four 'string' version, (Baser). It has become popular for hardware and software manufacturers alike to add eight controls: knobs, buttons, faders and the like to their designs, attaching the controls to the most obvious parameters, and in some cases user defined parameters.[8] In all the existing designs researched so far, none allow for the simultaneous, but independent control of all eight parameters, while still being able to use both hands to play the musical notes. Even with the use of pedals most existing controllers cannot come close.

The four 'stringed' version will have sensors incorporated in such a way that, whilst using both hands to play the musical notes, eight gestures can be made independently and simultaneously to control eight midi parameters of connected synthesisers. These may include switches to change instrument patches, transducer “pads” for tapping, and a joystick control for x-y vector parameters such as surround panning. It would also be desirable to include an interface with the computer so that functions, not directly linked with the playing of the sounds, such as the choice of synthesiser, mixer volumes etc. are accessible. This would allow the computer to be hidden from view and still maintain access to any necessary functions.

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