Body as Instrument:

An Exploration of Gestural Interface Design

Mary Mainsbridge

University of Technology Sydney

Submitted to the Faculty of Arts and Social Sciences

in fulfilment of the requirements for the Degree of

Doctor of Philosophy

2016

Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Mary Mainsbridge 2016

Acknowledgements

Principal supervisor: Dr Jon Drummond

Co-supervisor: Dr Andrew Johnston

Co-supervisor: Professor Anne Cranny-Francis

Editing: Dr Guenter A. Plum

I wish to thank my principal supervisor, Dr Jon Drummond, and co-supervisors, Dr Andrew Johnston and Professor Anne Cranny-Francis, for their ongoing guidance and encouragement. I would also like to thank my former supervisor, Dr Kirsty Beilharz, for coaching me in the initial part of my research.

To the musicians who took part in the study, thank-you for sharing your time and valuable input. Thank-you to Robbie Mudrazija for being part of the performances. To J D Young, thanks for offering live visuals, camera support and sound system provision for the Beams Arts Festival. Thank-you also to Melanie Russell for the photos of the *Bodyscapes* performances.

I'd like to thank Fiona Andreallo for sharing her ideas and inspiring me to keep 'turning up,' particularly during the final writing stages. I am also grateful to the students and researchers at Creativity and Cognition Studios, FASS and Sense-Aware Lab, for their feedback, advice and discussions,

Finally thank-you to my family for your endless patience and unwavering support.

Table of Contents

List of Figures

List of Tables

Abstract

Gestural interfaces broaden musicians' scope for physical expression and offer possibilities for creating more engaging and dynamic performances with digital technology. Increasing affordability and accessibility of motion-based sensing hardware has prompted a recent rise in the use of gestural interfaces and multimodal interfaces for musical performance. Despite this, few performers adopt these systems as their main instrument. The lack of widespread adoption outside academic and research contexts raises questions about the relevance and viability of existing systems.

This research identifies and addresses key challenges that musicians face when navigating technological developments in the field of gestural performance. Through a series of performances utilising a customised gestural system and an expert user case study, I have combined autoethnographic insights as a performer/designer with feedback from professional musicians to gain a deeper understanding of how musicians engage with gestural interfaces. Interviews and video recordings have been analysed within a phenomenological framework, resulting in a set of design criteria and strategies informed by creative practitioner perspectives.

This thesis argues that developing the sensorimotor skills of musicians is integral to enhancing the potential of current gestural systems. Refined proprioceptive skills and kinaesthetic awareness are particularly important when controlling non-tactile gestural interfaces, which lack the haptic feedback afforded by traditional acoustic instruments. However, approaches in the field of gestural system design for music tend to favour technical and functional imperatives over the development of the kinaesthetic sense.

Building on a growing body of gestural interface design and human–computer interaction (HCI) literature, this research offers practice-based insights that acknowledge the changing face of musicianship in response to interaction with gestural sensing technologies. To encourage enhanced physical aptitude and more nuanced movement control amongst musicians, I have applied embodied interaction design and dance-based perspectives to musical contexts, developing a multimodal environment that provides a range of design strategies for musicians to explore relationships between sound and movement while developing an awareness of their own movement potential.

Chapter 1: Introduction

1.1 Introduction

For electronic musicians seeking richer modes of expression, gestural interfaces offer opportunities to incorporate greater physicality into their performances. The increasing affordability of camera tracking and other gestural sensor technologies in gaming and mobile applications has inspired a rise in gestural systems designed to reflect the physical nuances of the performer. Despite these advances, relatively few musicians adopt gestural systems as their main instrument.

The lack of viable commercial systems and standardisation in gestural interface design (Norman & Nielsen 2011) leaves performers with few guidelines to develop or adapt existing systems. Performers with little or no programming experience can find setting up software to control motion-sensing devices a complex undertaking, making it a significant barrier to accessibility (Murray-Browne & Plumbley 2014, p. 213). To create a design that reflects their personal movement style and preferences, performers need to be able to capture and interpret movement in a meaningful manner, coupled with a detailed understanding of their own movement potential.

Similar to trained dancers, musicians using gestural systems need to acquire physical mastery "to deliver a truly embodied performance with electronic music" (Schacher 2012, p. 199). However, musicians often lack formal movement training, and must therefore attain these skills through direct engagement with the gestural interface, processing visual and proprioceptive feedback in order to orient and calibrate their performance gestures with adequate precision.

Through critical analysis of performances integrating gestural control and a case study of professional musicians engaging with a customised gestural system, I have identified and assessed key design strategies aimed at promoting the movement skills and awareness needed to achieve the level of nuance musicians require from movement-based performance.

1.2 Motivations for this Research

In an area in which individual expression and nuance are paramount, gestural interfaces provide opportunities for more detailed manipulation of sound and stronger communication with audiences. Existing gestural controller technologies also give vocalists opportunities to expand their inherent vocal capacity through movement-based control over processes ranging from digital signal processing to sound synthesis, by tapping into the body as a natural instrument.

This potential first drew me to this field in 2008, when I began experimenting with gestural control of the voice and digital audio software during a residency at the Underbelly Arts Festival[1] in 2008. A tactile mixing surface (TMS) and vocal effects application controlled by spatial movements were developed using ReacTIVision[2] software. This experience led me to reflect on areas for development in gestural interface design for musical performance, particularly in relation to the subtlety and aesthetic possibilities of these types of gesture-based systems.

---

[1] Underbelly Arts Festival 2008, *Underbelly arts festival*, viewed 17 August 2015, <http://underbellyarts.com.au/about/>.

[2] reacTIVision, viewed 17 August 2015, <http://reactivision.sourceforge.net>.

Figure 1: Underbelly Festival performance in the Figure Eight geodesic dome

As a vocalist and keyboardist, the potential to seamlessly blend vocal and instrumental performance with digital sound synthesis and processing techniques became a primary motivation for this research. An intention to engage more openly with audiences prompted me to find methods for accessing digital audio hardware and software remotely, in ways that were compatible with my usual playing style.

When playing electronic keyboards and synthesisers, I missed the depth of expression, immediacy, tactility and direct energy input offered by my main instrument, the piano. As Don Ihde (2013, p. 109) observes, this is a common frustration among pianists who transition to electronic keyboards: “One might appreciate the disdain that skilled piano players might feel since bodily skill could not produce nuanced sound differences on such machines”. This inability to translate my acquired physical skills and musicianship during electronic performances caused nuances inherent in my movements to be lost in performance.

To manipulate timbre over time when performing with a synthesiser, I often needed to operate parameters such as frequency, resonance and oscillation with knobs, buttons and sliders using the left hand, leaving only one hand available for playing and thus limiting my technique. This physical restriction was compounded by having to stand or sit still at the keyboard, inhibiting my ability to move freely around the stage and constraining my vocal performance.

The addition of a laptop on stage further restricted my range of movement, requiring a stationary posture and fixation on a screen. Kim Cascone (2002, p. 4) argues that this phenomenon leaves the audience with few of the visual cues that are typically associated with performance:

> Gesture and spectacle disappear into the micro-movements of the laptop performer’s wrists and fingers. From the audience’s view the performer sits motionless, staring into the luminous glow of the laptop screen while sound fills the space by an unseen process.

When a performer is making small-scale movements including pressing buttons and operating knobs and sliders, their physicality is diminished. Audiences cannot observe or feel the physical presence of the performer when their movement range is so greatly reduced. Thus, the presence of computers in live performance obscures the causal link between a musician's actions and the sounds produced for observers (Schloss 2003). This missing perceivable link between action and sound can lead to a sense of disconnection with the audience (Roddy & Furlong 2013).

In stark contrast to the sensorimotor engagement underpinning vocal and instrumental performance, David Wessel (2006, p. 93) argues that "electro-acoustic music has for the most part been a studio art and modern computer-based musical instrumentation remains far from involving the body". For Wessel (2006), the consequences of "using technology more at home in an office cubicle than in a musical performance" (Cascone 2002, p. 4) not only reduce a performer's connection with the audience but also affect the development of musical virtuosity.

In addition to the physical restrictions of instrumental and laptop performance, the presence and nuances of the body are sometimes either lost or not represented completely in the sound. In reference to a range of art forms, Maxine Sheets-Johnstone (2013) considers that the qualities inherent in a performer's movements are inscribed in the evolving dynamics of creating or performing a work and "are naturally *embodied* in the work itself" (Sheets-Johnstone 2013, p. 21). This physical imprint, indicative of a performer's movement style, is notably absent in the operation of conventional controllers for electronic music: "Music that uses electronically generated sound from synthesisers or computers suffers from the problem that one cannot actually get one's fingers into the generation of the sound" (Ostertag 2002, p. 14). Whereas before, the body was a fundamental component in producing live music, it is less important in a context where music-making rests on machines with the capacity for automated processes that minimise the body's input (Ostertag 2002).

The body's unique signature is more evident in the performance of acoustic instruments, as it is in handcrafted artefacts, where the "traces of physical presence" (Ishii 1998, p. 55) left by the artist are revealed in the details and irregularities of the work. Hiroshi Ishii is struck by the contrast between a hand-written manuscript of a poem by a favourite Japanese author and the "dry" digital version to which he has become accustomed. When observing the original document, Ishii can envisage the author gripping the pen, causing him to reflect on "those vestiges of the original artists that are lost when a work is converted into a standard expression-format" (Ishii 1998, p. 55). Ishii (1998) cautions against the trend to compress information in the digital world in the interests of technical efficiency, which sacrifices the human warmth and emotions inherent in the creator's physical nuances and idiosyncrasies.

Gestural performance offers the potential to interface with digital technology in a way that represents a greater range of individual movement characteristics and physical nuances, conveying expressive information that is often lost in the regulated movements associated with traditional controllers such as mouse and keyboard interfaces.

1.3 Research Questions

The research questions emerged from previous experiences of performing with gestural systems and themes from a review of relevant literature in HCI, gesture and music research and performance studies. In examining why gestural systems are not generally considered a viable alternative to traditional instruments and instrument-inspired musical controllers, this research focuses on the nature of musicians' engagement with gestural interfaces, guided by the overarching question: *What is the influence of gestural control on my own and other musicians' performance experiences?*

The following questions were posed at the outset of the investigation to assist in identifying the key features of effective gestural design in performance practice:

1. What are the main control features that characterise effective gestural systems?
2. How do musicians integrate gestural interaction into their existing performance practice?
3. What design strategies can be applied to improve discoverability, explorability and nuance in gestural instruments?

These questions were intended to discern common themes relating to the application of gestural systems in performance practice. In a field dominated by customised approaches, with few design templates or standards to follow, musicians must find ways to navigate available gesture sensing and recognition techniques, defining relationships between gesture and sound to suit individual creative and project aims. To gain a more systematic and comprehensive understanding of the way musicians engage with gestural systems and how they balance design with performance, this practice-based inquiry aimed to discover insights into the ways in which musicians navigate different aspects of gestural performance and interface design.

1.4 Thesis Structure

In Chapter 2 I review systems for classifying gesture and movement across a range of disciplines. I explore gestural interaction applications for musical performance, focusing on core design issues, including strategies for translating movement into sound. The technical and functional focus of much research in this area exposes the need for design approaches that reflect a greater understanding of performer experiences and physical engagement with gestural systems.

Chapter 3 presents a summary of the methodology framing this research, drawing on phenomenological, autoethnographic and user-centred design influences. Theories of embodiment provide a foundation for the development of this practice-based investigation. In addition to autoethnographic material gathered during gestural prototyping and performances, I conducted an expert user case study to gain insight into musicians' experiences of gestural control. The findings were analysed within a phenomenological and embodied framework, placing the living body at the centre of the investigation. The data collected focused on felt-bodily experience in movement-based interaction by comparing first-hand accounts gathered from preparatory and post-performance experiences with those of musicians recruited for the study.

Chapter 4 presents a series of formative works and associated performances for gesturally augmented voice and piano. The dual function of the body as an instrument in a vocal and a gestural context becomes a point of intersection that inspired *Concentric Motion*, a concerto blending orchestral instrumentation with gestural processing of digital audio effects. This theme was explored further in the *Gestural Études*, a collection of works contributing to the formulation of my approach to gestural composition and performance.

Through a series of creative works analysed in Chapter 4 and Chapter 7, I identified issues related to the efficacy of existing strategies of mapping gesture to sound mapping, with a view to understanding more nuanced and controlled forms of gestural interaction in musical performance.

Insights gained from these performances informed the development of Gestate, a gestural system intended for the augmentation of vocal and instrumental performance, presented in Chapter 5. The chapter also introduces a set of design criteria focused on attaining a fit between existing performance practice and gestural control methods.

In Chapter 6, I present the analysis of interviews with professional musicians who improvised with Gestate. The musicians provided feedback on three applications that typify the system. The study was designed to gain a broader understanding of user experience with gestural interfaces in order to identify the needs and preferences of musicians from a range of backgrounds. The findings from interviews conducted with participants assisted in refining the original design guidelines and devising a key control feature list to be incorporated into future design iterations of the system.

Informed by these findings, a new version of Gestate is presented in Chapter 7. A shift from upper-body to whole-body interaction embraces a more detailed exploration of the body's capacity as an instrument. A new virtual instrument is introduced that couples hybrid physical models directly to the body's proportions and ratios, forming the basis of an embodied mapping strategy. I have evaluated the effectiveness of this approach through the work, *Bodyscapes*, documenting the bodily felt experience of exploring associations between movement and sound through improvisations, prototyping and performance.

The main themes emerging from the performances and case study are presented in Chapter 8, which reflects on the impact of embodied mapping strategies and visual feedback on musicians' movement awareness, performance approaches and their overall satisfaction with gestural interfaces.

1.5 Conclusion

This chapter has outlined the creative motivations inspiring this research, which examines the challenges musicians experience when aiming to achieve precise and nuanced control through gestural systems in a live-performance context.

A literature survey in Chapter 2 outlines current approaches to gestural interface design informed by widely varying gesture definitions drawn from a range of disciplines, including anthropology, linguistics, HCI and performance studies.

Chapter 2: Literature Review

Despite the significant body of research into gestural systems since Richard A. Bolt's Put-that-there voice- and gesture-controlled graphical interface (Bolt 1980), gesture-based interaction remains something of a novelty (Rico, Crossan & Brewster, 2011). Gestural interfaces are not widely used in the broader musical community, tending to belong to a specialised area of musical performance. This chapter examines the issues that can affect the viability and accessibility of gestural systems for a broader group of musicians.

2.1 Overview of Related Work

The relationship between sound and movement has become an increasingly popular research topic, fuelled by a rise in the development of digital musical instruments and multimodal interfaces for computers (Cadoz & Wanderley 2000; Camurri et al. 2005; Maes et al. 2010). Despite these rapid technical advances, performers seeking to adopt gestural systems in their work face a number of significant challenges, which are outlined in the following sections. In addition to selecting an appropriate sensor and deciding what types of movements to capture, establishing meaningful links between gesture parameters and sound properties (gesture-to-sound mapping) (Bevilacqua, Muller & Schnell 2005) remains a persistent challenge for artists and designers aiming to translate the nuances of human movement into sonic processes.

By incorporating broader findings from the related areas of gesture theory, embodiment and interaction design, this review specifically addresses design issues associated with non-contact gestural interfaces that rely on motion tracking; a technique for sensing movement using video cameras connected to computers.

This chapter firstly presents the philosophical framework for this research before exploring definitions of gesture derived from a range of disciplines, including linguistics, anthropology and musicology. This overview is followed by a contextual review of gestural interface applications in live electronic music, followed by an explanation of the stages involved in designing gestural systems for performance, including examining common strategies for capturing gesture and mapping it to sonic processes. Technical and creative practitioner perspectives on mapping human movement to sound are compared, revealing a multitude of approaches that potential designers and performers entering the field must navigate.

The final part of this chapter focuses on design approaches aimed at promoting discoverability as well as sensitive and subtle control of gestural systems during musical performance. Among these are techniques that capitalise on musicians' existing skills, incorporating embodied metaphors and visual feedback to strengthen the movement awareness and sensorimotor skills necessary to perform effectively with gestural systems. This under-represented area of gesture and music research acknowledges the necessity to discover design approaches that promote development of musicians' movement abilities in line with technical developments in gestural interface design. Design strategies to support this aim are drawn from conceptual metaphor theory (Lakoff and Johnson 1980; Johnson 2007) and its applications in HCI, encompassing computer and cognitive science, embodied interaction design and interactive dance approaches.

2.1.2 Embodied Cognition

The theory of embodied cognition, which has gained traction over the past two decades, highlights the primacy of bodily experiences in shaping thought. This theory evolved from the works of philosophers Heidegger, Husserl and Merleau-

Ponty and cognitive scientists including Varela, who oppose the separation of body and mind introduced into Western thinking by René Descartes. It arises from the phenomenological tradition founded by Husserl, which values embodied experience over a disembodied notion of thought and knowledge.

Merleau-Ponty advances this idea by highlighting the body's central role in experience and engagement with the world, as summarised in his assertion "I am conscious of my body *via* the world" (Merleau-Ponty 1999). Musical scholarship on gesture continues this critique of Descartes' separation between mind and body (Funk and Coeckelbergh, 2013, p. 120). Breaking away from Cartesian mind–body dualism, the theory of embodied cognition shares similar territory with action-based studies of gesture that pay heed to both movement and the mental intentions behind it (Jensenius et al. 2010, p. 12).

The reaction against Cartesian mind–body dualism also informs Michael Polanyi's theory of tacit or implicit knowledge, which is based on understandings derived from physical and sensory activities that cannot be easily verbalised. The corporeal basis of this type of knowing is typified by Polanyi's proposition: "I shall reconsider human knowledge by starting from the fact that *we know more than we can tell*" (Polanyi 2009, p. 4). This concept can be used to help us understand the unique experiential knowledge that musicians incorporate into the performance of meaningful movements, without necessarily being able to explain the process with strict words or concepts (Funk & Coeckelbergh 2013, p. 119).

The research presented in this thesis is grounded in the emerging acknowledgement of the multimodal and embodied nature of human perception and cognition. Embodied cognition theory, applied by Marc Leman (2008) to the musical field, centres around the premise that musical involvement is dependent on musical imitation. This imitative behaviour, or motor mimesis, is expressed through our spontaneous tendency to mentally imitate the movements we observe other people making (Godøy 2010). Embodied music cognition, introduced by Leman in his book, *Embodied Music Cognition and Mediation Technology* (Leman 2008), affirms that the body is central to our experience of music, underpinned by the notion "that music is performed and perceived through gestures whose deployment can be directly felt and understood through the body, without the need for verbal descriptions" (Leman 2010, p. 127).

The neuroscientific discovery of mirror neurons in the brain supports the notion of embodied cognition. This class of premotor neurons is activated when an action is performed or observed, facilitating social interaction and empathy (Gallese 2009). Gallese (2009) introduces the concept of embodied simulation, drawing evidence from the neuroscience field on mirroring mechanisms in conjunction with phenomenological philosophy. Connections between action and empathy also emerge in Merleau-Ponty's work:

> The communication or comprehension of gestures come about through the reciprocity of my intentions and the gestures of others, of my gestures and intentions discernible in the conduct of other people. It is as if the other person's intention inhabited my body and mine his. (Merleau-Ponty 1999, p. 185)

The implications of these insights into imitation for music form the basis for an understanding of how and why listeners spontaneously move to music by imitating sound-producing gestures or related gestures that they associate with musical experience (Godøy 2010, p. 109). Through a series of observational studies, Godøy (2010) investigates how sound is gesturally rendered by listeners, representing various levels of musical expertise, who are asked to make spontaneous gestures in response to musical excerpts (Godøy 2006). Listeners from all experience levels are able to produce gestures that correspond to certain individual or combined features of musical sound, confirming links between perception and action that have been demonstrated in the neuroscientific field. The revelation of listeners' pronounced embodied involvement in musical listening and production suggests possible inherent connections for configuring sound-controlling gestural systems.

Leman and Godøy (2010) emphasise the role of action in music by analysing the ways in which we experience sound through our bodies. This growing field of research ties in with broader theories of embodiment including activity and enactive theory, where human perception is guided by body movements, creating an embodied awareness that influences the way we relate to the world (Varela, Thompson & Rosch 1992; Nardi 1996; Noë 2004; Kaptelinin & Nardi 2006). Cognitive science has recently turned to research on the importance of the body in cognitive processing. This research is grounded in highly influential enactive theory that emphasises the central role actions play in shaping perception and conscious thought, sensory and motor processes. Varela, Thompson and Rosch (1992, p. 173) summarise the enactive approach in two ways:

> (1) Perception consists in perceptually guided actions, and;
>
> (2) Cognitive structures emerge from recurrent sensorimotor patterns that enable action to be perceptually guided. (Varela, Thompson & Rosch 1992)

This embodied approach to practical and theoretical understandings of movement frames the following discussion on prevailing definitions of gesture.

2.2 Defining Gesture

A large body of interdisciplinary literature on gesture and movement shapes gestural interface design approaches. Existing definitions of 'gesture' stem from a range of fields, including linguistics, psychology, neuroscience, anthropology, musicology and performance studies. No standardised definition of gesture yet exists; however, the scope of gestures selected for a system will impact on the interactive experiences it evokes (Rico, Crossan & Brewster 2011). This section considers a range of definitions focused on the functional and communicative aspects of gesture, and their influence on the decision-making process of performers and designers.

The term 'gesture' varies in interpretation according to context and discipline; a recurring definition characterises the term as directed body movement that conveys an idea or meaning, which can either be learned or spontaneous (Leman & Godøy 2010, p. 5). The partnering of movement (action) with meaning (significance) applies not only to musical gestures but also to gestures in dance, theatre and everyday life (Funk & Coeckelbergh 2013, p. 116). As Leman and Godøy (2010, p. 8) argue, "gesture can be defined as a pattern through which we structure our environment from the viewpoint of actions". This definition acknowledges the cultural and environmental context that frames gestures.

Although the terms 'gesture' and 'movement' are not synonymous, they are sometimes used interchangeably within gesture research. However, gestures cannot simply be equated to movement, as this would reduce the meanings and expressive intentions behind actions to purely physiological factors (Leman and Godøy 2010, p. 6). Alexander Jensenius (2007, p. 42) and Matthew Rodger (2010) replace the term 'gesture' with 'music-related movement' and 'action' to denote chunks or individual units of motion, due to inconsistencies between definitions in different fields such as HCI. Despite contradictory definitions across disciplines, the term ‘gesture’ continues to provide a useful way of incorporating interpretations from related fields into a broader understanding of the types of gestural input incorporated in gestural interface design.

Unlike physical movement, which can be objectively measured, gesture is a self-contained segment or unit of action (Jensenius et al. 2010, p. 19). Gestures offer a convenient way of researching and analysing the role of the body in interactions by organising movement into smaller units (Mewburn 2009). Although discrete gestures do not accurately represent the continuous streams of motion that characterise our everyday movements (Mailman & Paraskeva 2013, p. 37), they can function as manageable chunks of information that assist in identifying salient features, motifs and patterns of movement. Furthermore, gesture offers a way of describing musicians’ or dancers’ motions in such a way that integrates the two aspects of meaning and motion, matching it with theories of embodiment:

> *Movement* denotes physical displacement of an object in space, whereas *meaning* denotes the mental activation of an experience. The notion of gesture somehow covers both aspects and therefore bypasses the Cartesian divide between matter and mind. In this sense, the notion of gesture provides a tool that allows a more straightforward crossing of the traditional boundary between the physical and mental world. (Jensenius et al. 2010, p. 3)

Bridging this divide epitomises the dominant approach to gesture research in musical scholarship, which is founded on a critique of Descartes’ separation between mind and body (Funk & Coeckelbergh 2013, p. 120).

Definitions of gestures adapted from the classification frameworks of Liwei Zhao (2001) and David McNeill (2000) organise gesture according to the categories of communication, control and metaphor (Jensenius et al. 2010, p. 14). Communication relates to gestures that convey meaning in social interaction — a common interpretation in the fields of linguistics, behavioural sciences and social anthropology. Control encompasses gestures that form an input into interactive systems and is often applied to HCI and computer music contexts. Metaphor refers to gestures that form ways of portraying physical movement or sound to other cultural topics, and is applied in cognitive science, psychology and musicology. This research is primarily concerned with the categories of communication and control.

The communicative potential of gestures is explored within the broader gesture studies field, where much of the research is concerned with the relationship between gesture and speech. The gesture communication area, which incorporates linguistics, behavioural sciences and psychology, focuses on areas such as non-verbal communication and sign language. Gesture as a term is used to denote hand motions and facial expressions that at some times accompany and reinforce the meaning of words and at other times refine and qualify verbal expression (Kendon 2004). Adam Kendon's (2004, p. 15) definition of gesture as a "label for actions that have the features of manifest deliberate expressiveness," highlights the role of intentional gesture in conveying meaning during social interaction. Building on Kendon's work, David McNeill (2005, p. 15) perceives gestures as an embodied form of mental imagery that occurs during speech, underpinned by a belief that "language is inseparable from imagery" (McNeill 2000, p. 57). McNeill regards gesture and speech as equally important in expressing thoughts.

A psychological perspective of the communicative role of gesture is expressed in Susan Goldin-Meadow's book in the field of psychology, *Hearing gesture: how our hands help us think* (2003). This work examines how gestures help children learn mathematics and how new ideas may first appear in gestural form. Goldin-Meadow (2003) recognises gesture as superior to language in representing visuo-spatial information, making it an invaluable guide to learning and comprehension of unfamiliar abstract concepts.

Several designers of interactive systems have seized upon the potential of gesture to demonstrate ideas and aid comprehension of abstract musical processes such as harmony in learning environments (Antle, Droumeva & Corness 2008; Wilkie, Holland & Mulholland 2010; Antle, Corness & Bevans 2013). As Lane Kuhlman (2009, p. 61) argues, the social benefits of gestural interaction include "person-to-person communication and learning benefits that arise from observation of knowledge externalised by others through gestures". This communicative function is particularly important when aiming to reveal music production processes to an audience, adding a sense of inclusion and dynamism to a performance by building transparent connections between performer movements and generated sounds.

Musicologist Robert S. Hatten's theory of gesture in music belongs to the category of metaphor, as it relates to gestures inherent in sequences of events within musical scores or sound, rather than to the physical movements that create the sound. Hatten's influential text, *Interpreting musical gestures, topics, and tropes* (2004), analyses musical gestures in classical piano performance according to the following definition:

> Gesture is most generally defined as communicative (whether intended or not), expressive, energetic shaping through time (including characteristic features of musicality such as beat, rhythm, timing of exchanges, contour, intensity), regardless of medium (channel) or sensory-motor source (intermodal or cross-modal). (Hatten 2004, p. 95)

In this description, “energetic shaping through time” can apply to musical elements such as rhythm, pitch contour and intensity (Hatten 2006, p. 1). Hatten’s definition emphasises the energetic and temporal aspects of physical gesture, regarding musical gestures as valid even when performed unconsciously, if perceived as significant by the viewer (Hatten 2006, p. 1).

This perspective serves as a starting point for many researchers in the field (Gritten & King 2011, p. 1), inspiring Anthony Gritten and Elaine King’s definition of gesture as “movement or change in state that becomes marked as significant by an agent” (Gritten and King 2006, p. xx). Hatten argues that gestures that do not intentionally convey information still represent richness and subtlety, which reveal important aspects of the human character and play a valuable role as vehicles for expression. This contrasts with the views of Kendon and similar theorists, whose definitions focus on the intentionality and external perceptions of gesture.

The semiotic approaches of Kendon also contrast sharply with Maurice Merleau-Ponty’s work, particularly his theories of gesture and the moving body presented in *Phenomenology of perception* (1999). Rather than viewing words and speech as designated thoughts, Merleau-Ponty highlights the independent existence of thought in the phenomenal world, which possesses its own existential meaning. In opposition to the Cartesian mind–body divide, Merleau-Ponty describes the source of our constantly updating movement awareness and physical nature of being. The body is viewed as central to our understanding and involvement in the world: it assumes the basis for our experiences and belonging to an environment. Gestures are interpreted as modes of expression that situate the body in a particular cultural or existential context, as Merleau-Ponty explains about body schema in his chapter, 'The spatiality of one's own motility' in *Phenomenology of perception* (1999):

> In so far as I have a body through which I act in the world, space and time, are not for me, a collection of adjacent points nor are they a limitless number of relations synthesised by my consciousness, and into which it draws my body. I am not in space and time, nor do I conceive space and time; I belong to them, my body combines with them and includes them. (Merleau-Ponty 1999, p. 140)

Gestures and spatiality thus cannot be reduced to a series of absolute geometrical points, but are intertwined with the environment in which they are performed. Our body explores the world through gestures, acting as "our anchorage in a world" (Merleau-Ponty 1999, p. 144).

This inseparable link between the body's gestures and the environment also features in Carrie Noland's (2008; 2009) interpretation of gesture. Noland recognises gestures as an embodiment of cultural conditioning, referring to them as learned techniques of the body, a term adopted from Mauss (1973):

> Gestures are a type of inscription, a parsing of the body into signifying or operational units; they can thereby be seen to reveal the submission of a shared human anatomy to a set of bodily practices specific to one culture. (Noland 2009, p. 2)

The way in which individuals enact gestural routines and reinterpret them through their actions reveals the potential for individual behavioural variations (Noland 2009) represented in the inflections and nuances of each person's movement style.

These techniques or gestural routines of the body are referred to as 'body schema' in Merleau-Ponty's work, a notion used to describe an individual's intuitive understanding of their own body in relation to space:

> The theory of the body schema is, implicitly, a theory of perception. We have relearned to feel our body; we have found underneath the objective and detached knowledge of the body that other knowledge which we have of it in virtue of its always being with us and of the fact that we are our body. (Merleau-Ponty 1999, p. 206)

This concept of body schema is extended by Shaun Gallagher, who defines the concept as a set of sensorimotor functions that influence posture and movement at a preconscious, almost automatic, level (Gallagher 2005, p. 26). Such motor programmes underlie the accomplishment of everyday tasks, such as lifting a glass, and more complex processes like expert musical performance, where technically difficult passages can be performed with minimal effort by executing physical patterns that emerge from mental patterns or goals formed beforehand or "out of time" and then deployed through the body "in time" (Leman & Godøy 2010, p. 8).

Body schema, according to Gallagher, offers a way of organising consciousness without explicit awareness, such as habitual movement behaviours involved in assimilating to an environment (Gallagher 2005, p. 32):

> My consciousness of this environment and the location of things that I need to reach will guide my movement, and will help my body gear into that environment in the right way. In that sense, consciousness is essential for the proper operation of body schema.

Gallagher draws on Merleau-Ponty's distinction between body image and body schema, describing it as "the difference between a *perception* (or conscious monitoring) and the actual *accomplishment* of movement, respectively" (Gallagher 2005, p. 24). In contrast to body schema, body image denotes an awareness of the body connected to the environment. This distinction offers a useful framework for studying the difference between gestures that are performed almost automatically and those that are shaped by deliberate intention.

The two concepts overlap when body image exercises an influence on the performance of body schemas (Gallagher 2005, pp. 24-25). The investigation of this blending forms an essential starting point for my research into how musicians interact spatially with movement-based instruments. As a dancer practices extensively to gain proficiency, guided by conscious awareness of each motion (Gallagher 2005 p. 35), they reach a level where the movement is integrated into their body schema and can be performed without conscious reflection.

Musicians can benefit from applying the same attention to developing skills in spatial performance. Therein lies the transformative power of movement awareness, where the musician has agency to move past acquired habits in order to develop more mastery of movement. Accommodating this deliberate process can potentially contribute to improving overall satisfaction with gestural instruments in performance.

Designs that capitalise on musicians' existing physical patterns and skills, or body schema, may enhance exploration and mastery of gestural systems. By experiencing an exploratory interaction, performers can develop new ways of moving, by firstly observing and then stepping beyond their usual physical patterns to build more nuanced styles of movement-based performance. This potential can be used to inform design strategies that focus on enriching the movement experiences of musicians playing gestural instruments (see Section 2.4.3.2, Kinaesthetic Feedback).

Recent cognitive research acknowledges the notion of body schema and the importance of embodied, or sensorimotor, knowledge. The influence of the moving body on action and perception is fundamental to the enactive approach (Varela, Thompson & Rosch 1992; Noë, 2004), providing a foundation for investigating musical gestures that reject Cartesian thinking (Funk and Coeckelbergh 2013, p. 123).

Embodied music cognition is based on a similar understanding, viewing the musical mind as embodied and mediated by the human body (Leman 2008, p. 235). It originated in response to the need for a new theory of music research that is action-oriented and focused on the body, providing a framework that unites musical mind with matter (Leman 2008, p. 26). This framework provides a useful tool for researching gesture in the fields of performance studies, dance ethnography and new media theory (Noland 2008).

The HCI field is dominated by a more functional interpretation of gesture, treating it primarily as a control input. An early and influential definition of gesture by Gordon Kurtenbach and Eric A. Hulteen (1990, p. 310) states:

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

The reduction of human movement to a single finger press on a QWERTY keyboard reveals an interaction design approach regulated by the physical interface

(Jensenius et al. 2010, p. 16). Caroline Hummels, Gerda Smets and Kees Overbeeke (1988, p. 2) broaden this definition to include the transference of meaning to another human or computer.

In relation to multimodal systems, bodily motion is either event-based, divided into geometrical patterns with definite start and end points, or continuous motion interaction that relates movement data directly to sonic or visual parameters in real-time (Fdili Alaoui et al. 2012). According to Wanderley and Orio (2002), gesture can refer to movements detected by interactive systems or actions performed by instrumentalists (Wanderley & Depalle 2004).

The trend to embrace a greater diversity of human motion expression has led to the creation of systems that regard gesture as an expressive and emotionally-motivated form of communication. This view plays an important role in design approaches that aim to extract expressiveness from movement (Camurri, Largelöf & Volpe 2003; Camurri et al. 2005; Camurri & Moeslund 2010), achieved by identifying and isolating expressive characteristics from observed movement, and constituting a pronounced departure from the previously outlined definitions originating from linguistics that emphasise the meaning behind gesture (Jensenius et al. 2010, p. 17). The concept of expressive gesture as a form of control input is explored further in Section 2.2.2, Expressive Gestures.

In the absence of a universal definition of gesture, this section revealed a range of approaches for studying gestures, focusing primarily on functional and communicative definitions. It also provided an introduction to the potential roles, physical qualities and meanings assigned to gesture, which influence key considerations of gestural interface design for musical performance.

So far in this review of the gesture studies literature, the expressive and communicative aspects of gesture have been explored, emphasising how linguistic or psychological information is conveyed through movement (Zhao, 2001, p. 4). The difference between spontaneous and intentional movements has been examined in relation to the distinction between body image and body schema originally presented by Merleau-Ponty.

For the purposes of this research, the term 'gesture' refers to patterns or phrases of physical movement that occur deliberately or spontaneously when controlling interactive musical systems, conducting, or during vocal and instrumental performance. This definition also relates to music-related movement (Jensenius 2007), which comprises actions that possess communicative and functional aspects in relation to musical performance and computer-assisted music creation. I also adopt the term, 'musical gesture' from Leman and Godøy (2010, p. 3), to denote relationships between sound and movement that occur during music creation, are encoded in music, or are produced in response to music (Jensenius et al. 2010, p. 19).

The next section discusses gestural typologies commonly applied to musical performance, to better understand the potential of specific types of bodily movement as an input into gestural systems.

2.2.1 Instrumental Gestures

Gestural typologies perform a central role in the design of gestural input devices and in shaping interactive performance works that highlight physicality. These insights are equally significant in informing gestural interface design as inspiring movement-based creative works. This section deals specifically with gestures linked to performing an instrument, in order to gain a better understanding of the ways in which musicians physically express themselves on stage.

Claude Cadoz and Marcelo M. Wanderley (2000) present a range of gestural definitions that are relevant to this research, particularly the distinction between ‘effective’ and ‘ancillary’ gestures that differentiates sound-producing gestures from supporting movements. Instrumental gestures are viewed as a subset of ‘effective gestures’, the first category in Francoise Delalande’s (1988) three-tiered gesture typology developed to study the playing technique of pianist Glen Gould. Delalande defines effective gestures as motions that produce and manipulate instrumental sound. They are comprised of mechanical actions such as bowing, blowing or striking a key on a piano.

The next level in his typology covers ‘accompanist gestures’, which include motions that occur in conjunction with effective gestures, such as movements of the head, torso and breathing in an instrumentalist. Accompanist gestures are discussed in more detail in the following section.

The third layer, ‘figurative gesture’, is purely symbolic and not linked to motion, making it less relevant to this research. Wanderley (1999) also uses the term ‘performer gesture’, incorporating gestures relating to performing an instrument that encompass the first two categories of Delalande’s typology. Performer gesture thus encompasses movements responsible for sound generation and manipulation and accompanying motions and postures (Wanderley 1999, p. 2).

Cadoz defines ‘instrumental gestures’ as an interaction between the musician and instrument, acting as a physical means of communicating information:

> The instrumental gesture is a direct causal component of the sound phenomenon. Along with the instrumental object to which it is applied, it participates in producing this phenomenon from a physical and energy point of view. (Cadoz 1988, p. 5)

Cadoz (1988) offers a framework for the study of gestures in instrumental music, separating modulation, selection and exciter gestures (Cadoz 1988, p. 7). Exciter gestures describe the mechanical process of transferring energy to a vibrating instrumental object, such as a violin bow, causing the string to vibrate. Whereas the violinist's fingering belongs to the selection category, the left hand's movements along the neck are categorised as manipulation gestures, as they alter the sounds produced by the right hand, which is performing the bowing.

The communication function of gesture is also recognised in Cadoz's gesture typology (1998). The gestural channel, as one type of human communication, is unique in its dual role as a form of physical action and also as a means of communication (Cadoz & Wanderley 2000). This simultaneously communicative and interactive role informs Cadoz's typology of different functions relating to the gestural channel, based on three classifications of hand gestures:

- *Ergotic*, referring to the energy transfer between hand and object;
- *Epistemic*, relating to touch and muscular/articulatory perception; and
- *Semiotic*, or the communication of meaning or intent.

The third type, semiotic, is the only function pertaining to free or empty-handed gestures such as sign language, pantomime and conducting. For this reason empty-handed gestures present in conducting or gestural instrument control only fit one of the functions of the gestural channel. Such gestures cannot be regarded as instrumental, even in the case of a conductor manipulating a baton, as there is no direct transfer of energy between the conductor and the listener (Cadoz & Wanderley 2000, p. 79). In the case of 'instrumental gesture', or movements resulting in sound during performance, these functions can be interdependent.

While instrumental gestures are primarily functional in nature, expressive gestures communicate artistic intentions, personality traits and inclinations. The next section examines the concept of expressive gesture as a way of better understanding the nuances introduced by individual performers, noting the cultural associations and semantic meanings underlying gestures in this category. This focus goes beyond instrumental technique to investigate how performers physically express their individual musical style.

2.2.2 Expressive Gestures

This section examines gestures that are not directly related to sound production but support or accompany sound producing gestures. These movements are variously referred to as ancillary; accompanying (Delalande 1988) or accompanist (Jensenius et al., 2010); non-obvious (Wanderley 1999); expressive (Davidson 1993); or as body language (Dahl & Friberg 2007), characterising body motions that do not directly produce sound (Wanderley & Depalle 2004).

Ancillary gestures are rarely intentional, yet they co-exist with sound-producing gestures, or even stem from them (Jensenius et al. 2010, p. 26). Godøy identifies ancillary gestures as those that musicians make spontaneously. He sees them as coarticulatory gestures "shaping the performance on a higher level of motor control and musical intention" (Godøy 2011, p. 75). For instruments such as piano and strings, it may be difficult to differentiate between expressive and sound-shaping gestures and theatrical gestures.

Ancillary gestures are often perceived as secondary to effective gestures, with their indirect impact on sound creation that often resides outside of the deliberate control of performers (Schutz & Manning 2012). To avoid the secondary status implied by the term 'ancillary', I refer to supporting movements either as expressive gestures or body language. As expressive gestures do not involve direct manipulation of an object to produce sound, they can inform an understanding of "empty-handed" gestures that are common in vocal performance and conducting (Cadoz & Wanderley 2000), and also provide insights about full-body interaction and non-contact movements associated with the control of gestural interfaces.

Although they are not directly responsible for sound production, as is a key strike on a piano, expressive gestures convey artistic intentions and visual cues to the audience, as empirical studies of Western art music performance reveal (Davidson 1993, 2001, 2007, 2012; Delalande 1988; Wanderley 1999; Davidson & Correia 2002; Vines et al. 2004; Dahl & Friberg 2007; Castellano et al., 2008; Broughton & Stevens 2009; Thompson & Luck 2012), making them as significant as purely functional gestures.

Motion tracking studies of pianists' and clarinettists' performances reveal that ancillary gestures such as head and torso sway correlate with emotional expression, establishing a sense of timing, demonstrating structural transitions and promoting performer/audience communication (Wanderley 2002; Vines et al. 2004; Dahl & Friberg 2007; Davidson 2007, 2012; Castellano et al. 2008).

Wanderley and Depalle (2001) observe that a clarinet performer's expressive gestures have a definite impact on the resulting sound, including significant amplitude variations. In a related case study of clarinet players, Wanderley (2002) characterises ancillary or non-obvious performer gestures according to movements of the instrument, including up/down motions and quick tilts. Ancillary gestures are shown to align with phrasing during clarinettists' performances (Wanderley 2002), represented in the circular movements of the instrument's bell. Unique gesture patterns with varied degrees of gesture amplitude emerge for individual wind players in Wanderley's case study (Wanderley 1999, p. 6). Buck, MacRitchie and Bailey (2013, p. 110) make a similar observation in motion studies of pianists, uncovering patterns of phrasing motion that are highly idiosyncratic, varying greatly between performers. They identify repeated curved motions in the upper body movements of pianists that radiate from the body's centre. A quantitative study reveals that individual performers execute unique versions of motion pattern shapes (Buck, MacRitchie & Bailey 2013). This idiosyncratic aspect of expressive gesture is viewed by Imogene Newland (2014) as a type of choreography that reveals the expressive intentions of the performer.

Even though they are not directly responsible for producing sound, non-obvious performer gestures affect resulting sounds (Wanderley 1999). Wanderley observes that these types of gestures convey additional information to that which is relayed by the sound, serving to "accompany (augment or complement) the information that is conveyed by the primary channel (the sound) and give extra (visual) clues on the performer's musical intentions to the audience" (Wanderley 1999, p. 7). This insight is also confirmed by other observational studies that uncover the influence of visual information provided by performer movements on audience perception (Davidson 1993; Dahl & Friberg 2007; Broughton & Stevens, 2009). With no direct sonic effect, these gestures instead form a type of visual support to musical ideas (Rosen 2002).

One established method for comparing the impact of expressive gestures is to compare overt and subdued performance. While Jane W. Davidson (1993) analyses actions performed in three varying ways (deadpan, projected and exaggerated), Wanderley (2002) observes quantitative motion data emerging from three styles of clarinet performance (standard, immobilised and expressive). Interestingly, when asked to perform with no extraneous gesture, the clarinettists observed in Wanderley's study could not completely suppress their expressive movements (Wanderley 1999, p. 7). Even when they were required to play immobilised, all of the clarinettists continued to perform similar types of gestures and gestural patterns to those that accompanied the more exaggerated performances, only on a smaller scale. Often the performers were not even aware that they were doing this, so integral were these gestures to their body language as a musician.

Findings from studies of skilled solo pianists indicate that repeated movement patterns in general upper body motion, particularly head and shoulder movements, tend to align with the structural elements of a piano piece (Thompson & Luck 2012). In their analysis of classical piano performances, Thompson and Luck (2012, p. 23) found that ancillary head movements increase during climactic and/or structurally important sections of a piece. Davidson (2007) also notes that pianist head and torso movements are connected to metre, rhythm and structural features of music. She highlights an association between the motion shapes formed by the head and torso and the expressively significant parts of a piece.

The sitting position in piano performance is found to regulate movement expression (Davidson 2007). Torso movements convey general expressive intent, while the hands convey more local information, explaining why they do not always deliver a similar level of clear expressive information to larger-scale gestures (Davidson 2007, p. 386). Thus, the torso provides a context for Davidson to interpret other more localised body movements. She acknowledges the global swinging movement of the torso in relation to her ‘centre of moment’ concept, where it acts as a physical core from which expressive content can be spread to the rest of the body.

Castellano et al. (2008) also examine the emotional expressiveness of motion cues during piano performance. Analyses are conducted with an automated system, contributing to an exploratory approach for analysing expressive movement in musical performance. Like Davidson, they identify the velocity of the head as an important expressive indicator, as well as the overall amount of upper body movement.

Expressive gestures can either be executed consciously, in the case of communication between ensemble members and overt signals to the audience, or may occur spontaneously as a manifestation of the musician’s inherent body language. In musical performance, Newland (2014, p. 152) views expression as:

> the musician’s physical presence and facility to realise musical features through a visible corporeal embodiment of sonic qualities that may be understood as intrinsic to musical expression.

Expressive gestures are influenced by a range of factors, including cultural and situational aspects, from the style of music to the size of room or audience, or the technical difficulty of a piece (Wanderley 1999).

Camurri et al. (2001), employ the term expressive gesture to explain qualities of body movement that communicate emotion and affect:

> It seems likely that expressiveness in gestures is conveyed by a set of temporal/spatial characteristics that operate more or less independent from the denotative meanings (if any) of those gestures. In that sense, gestures can be conceived as the vehicles that carry these expressive characteristics and it is likely that expressiveness as such subsumes certain universal patterns and rules. (Camurri et al. 2001, p. 1)

These expressive characteristics are extracted from streams of motion data through analysis based on motion qualities initially identified by movement and dance theorist, Rudolf Laban (Laban & Lawrence 1974).

Baptiste Caramiaux (2014) argues that valuable expressive content is embedded in the variations between gestural performances. Building on existing gesture recognition techniques, Caramiaux (2014) presents an algorithm, the Gesture Variation Follower (GVF), that estimates the change in scale and speed of a gesture in real-time in order to capture the variations that differentiate individual performers and gestural performances.

This work relates to earlier research that distinguishes between sound-producing gestures and nuances (Orio 1999). Nicola Orio (1999) finds that gestures associated with classical guitar playing influence pitch and loudness, whereas nuances relate to timbre. The ability to accurately represent gestural nuances with a gestural system thus becomes a significant component in conveying the richness of expressive gestures, which Orio (1999) argues convey the intentions and feelings of the performer. Capturing and interpreting these nuances accurately is a significant challenge faced by designers of gestural systems.

2.3 Gestural Systems for Musical Performance

Gestural interfaces cover a broad range of devices, from tablets and mobile phones to wearable and remote sensors. Gestural research in HCI aims to widen the available gestural repertoire for users of computer systems. In conventional WIMP (windows, icons, menus, pointer) systems, the body's movement range is largely ignored. Motions are restricted to small-scale gestures that are highly repetitive, minimising the physical inclinations and imagination of the user. This has led to an array of societal health problems associated with stationary technological activities such as prolonged sedentary office work, passive web surfing and gaming (Kjölberg 2004, p. 353).

The increased dependency on laptops in live electronic music has also reduced the movement range available to musicians. The appropriation of a tool originally designed for office use in musical performance lacks the visual spectacle and theatrical codes that usually accompany musical performance, obscuring the cause-and-effect relationship between performer gestures and sonic outcomes (Cascone 2002, p. 4). The result is a displacement from the audience, argues Kim Cascone (2002), in which the authenticity of the laptop performer/DJ is questioned, rendering the transaction more one of a broadcast than of a performance.

The device-centric nature of live electronic music, with its reliance on hardware sequencers, analogue synthesisers and effects units, has introduced a type of virtuosity based on manipulating an electronic signal with control knobs, switches and sliders (Ponce 2007, p. 47). This has created a situation in which the visual and corporeal elements of performing with computers and digital technology must be re-evaluated to deliver effective performances (Schloss 2003, p. 239). One of the vital aspects where these two elements intersect is visible effort, according to

W. Andrew Schloss (2003), who recognises it as a sign that a musician is dedicated to their performance. Yet many controllers from the commercial music industry aim to deliver *effortlessness*, mimicking the labour-saving capacity of the computer (Ryan 1991).

Although reducing physical effort may be pertinent to office applications, in musical performance effort is necessary to play all acoustic instruments: “Effort is closely related to expression in the playing of physical instruments” (Ryan 1991, p. 7). To dispense with effort is to lose important information conveyed through a performer’s movement style. Preserving the manner in which a musician transfers their physical energy into sound thus becomes a primary design consideration for gestural systems, in order to achieve nuanced control.

In an interview with Joel Chadabe, gestural musician and innovator Michel Waisvisz advised: “I’m afraid it’s true one has to suffer a bit while playing; the physical effort you make is what is perceived by listeners as the cause of manifestation of the musical tension” (Chadabe 1997, p. 228). Waisvisz was not so much attracted to the technology itself but to the opportunity of creating unity between his mental and physical activities through new physically oriented instruments.

The shift to new paradigms of expressive interaction with machines in the music computing field forms the backdrop for systems that rely on gestures to generate and process musical signals and control hyper-instruments (Machover 2004) or virtual instruments. Within this context, immersive Multimodal Environments (MEs) facilitate multimodal user interaction, incorporating full-body movements, dancing and singing (Castellano et al. 2007).

Multimodal interfaces and digital musical instruments (DMIs) (Miranda & Wanderley 2006) are used to augment audio or visual performance, explore links between movement and sound, and expand the palette of sounds and control methods available to musicians. Interactive multimedia platforms provide tools for exploring the artistic potential of gesture and working with sonic, visual and haptic data (Leman and Camurri 2006).

Marcelo M. Wanderley (2001) divides interactive systems influenced by performer movement into three categories:

- Digital musical instruments (DMIs);
- Sound installations;
- Dance-music interfaces.

The main focus of this research is the first category. DMIs, as defined by Wanderley (2001), feature a gestural interface (or gestural controller) that receives physical input from a performer, separated from a sound generation unit, as shown in Figure 2. The two parts are linked by mapping strategies that determine how performer actions are linked to the controls of a sound-generating process such as a synthesis algorithm.

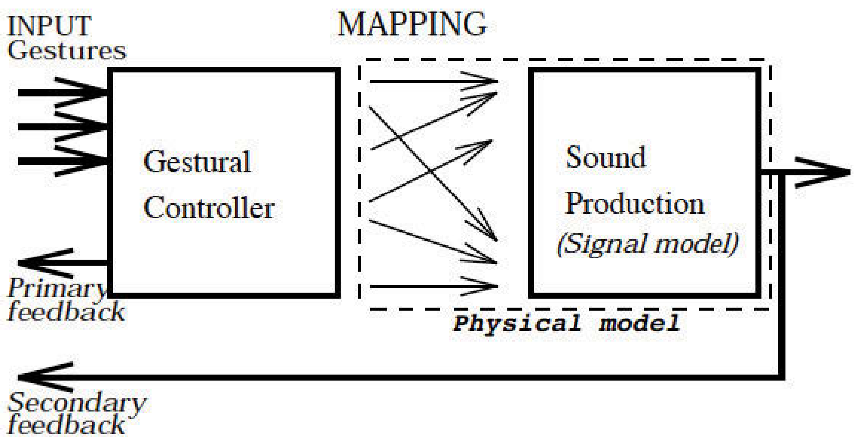

Figure 2: Digital Musical Instrument representation (Wanderley 2001, p. 16)

Because of this separation between the controller and the sound-generating device, gestural interfaces, unlike traditional acoustic instruments, impose no physical constraints to regulate the types of gestures that control sound (Mulder 2000). Daniel J. Levitin, Stephen McAdams and Robert L. Adams (2002) argue that this separation offers an opportunity to rethink controller design beyond integrated musical instrument constraints (Levitin, McAdams & Adams 2002). To explore this opportunity, designers must confront the challenge of designing mappings that make sense to the performer, audience and allow for musically expressive control (Bencina 2005).

Further challenges when performing with the computer as an instrument include the limited style of physical interaction, the amount of musical parameters that can be controlled simultaneously, and the lack of standardised interfaces available to control computer music systems (Behringer 2007). This is particularly challenging for designing clear mappings to support gestural control of music, where the use of gestures to manipulate computer-generated sound belongs to a specialised field of HCI encompassing the control of multiple parameters, including timing, rhythm and timbre (Wanderley 2001).

Transforming streams of captured movement data into useful musical and control material is another challenge for musicians and performers. The absence of a consistent approach to mapping in DMI and gestural interface design research presents musicians with seemingly limitless design decisions when first adopting and customising gestural systems in performance:

> Existing electronic music systems are still struggling with finding a good strategy for the mapping from sound to control parameters. Unlike acoustical instruments, where the one-to-one mapping allows the continuous fine-grained modulations of all the sound parameters, interactive music systems have quite often an arbitrary relation between the control device and the sound source. (Leman et al. 2010, p. 206)

This arbitrary connection can result in feelings of disconnection and a perceived absence of detailed and nuanced control among users (Leman et al. 2010).

In Todd Winkler's book, *Composing Interactive Music: Techniques and Ideas Using Max*, he states that the role of an interactive composer "is not only to map movement data to musical parameters, but to interpret these numbers with software to produce musically satisfying results" (Winkler 1998, p. 320). Winkler regards consideration of the physical idiosyncrasies and limitations of body movements as vital to this process, imposing limitations different from the structure of acoustic instruments:

> Rather than simply simulate the irregularities of a human performer, actual phrasing, timing and dynamic information can be captured from a performer and applied as input to compositional algorithms. (Winkler 1998, p. 214)

Winkler (1995) proposes that an understanding of the physics of motion can form the basis for creating innovative relationships between movement and sound. The ways in which gestural systems channel this highly individualised movement data into useful control information, and the issue of balancing the simultaneous control of musical parameters, are explored in the following sections.

2.3.1 Non-tactile Systems

This research is concerned primarily with non-tactile gestural controllers, which are defined by Joseph Rovan and Vincent Hayward (2000) as alternative performance interfaces that rely on remote sensing technologies such as near-field capacitive measurement, infrared, ultrasounds and video. Also known as free-gesture controllers (Paradiso 1997), they are controlled by 'open air' gestures that are not traditionally associated with music making, except in the case of conducting. Alternatively, Axel Mulder (2000) refers to non-contact interfaces as immersive controllers, where the sensing field surrounds the performer to establish an all-pervasive control surface.

Without the physical constraints of hardware, non-tactile gestural controllers are potentially more adaptable to performer capabilities and ways of moving. Due to their non-invasive nature, these types of systems are prevalent in dance, interactive installations and conducting applications.

However, non-contact interfaces pose several major challenges, notably the absence of tangible feedback to establish precise control and repeatability for the performer and transparency for the audience. In their review of non-tactile gestural controllers, Rovan and Hayward (2000, p. 356) point out that in systems reliant on remote sensing technologies "the tactile feedback loop is broken, forcing performers to rely on proprioceptive, visual and aural cues”, as demonstrated in Figure 2:

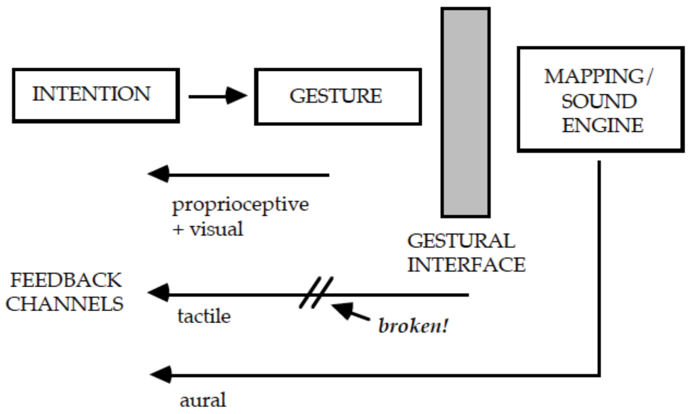

Figure 3: Broken feedback loop affecting performance with open-air controllers (Rovan & Hayward 2000, p. 356)

‘Open air’ or ‘immersive’ gestural controllers thus demand highly developed proprioception, requiring musicians to acquire body control similar to that of a dancer (Pedrosa & MacLean 2008, p. 22). Well-developed proprioceptive or kinaesthetic awareness of individual body states, such as position, velocity and forces exerted by the muscles through receptors located in the skin, joints, muscles and tendons, is essential when using alternative controllers (Rovan & Hayward 2000).

The term ‘proprioception’ relates to a sense of movement and position that encompasses “tactility and gravitational orientation through vestibular sensory organs as well as kinaesthesia” (Sheets-Johnstone 2010, p. 218). ‘Kinaesthesia’ refers more broadly to our experience of movement or bodily awareness. Proprioceptive information received by a musician during performance enables them to regulate the position, speed and force of their body movements accordingly in real-time (Acitores 2011, p. 219).

Unlike dancers however, musicians often acquire these skills through direct engagement with the interface rather than through formal movement training. Musicians accustomed to performing with acoustic instruments are faced with the need to develop a greater awareness of the feelings associated with their movements within space to extract maximum nuance from gestural systems during performance.

Although Rovan and Hayward (2000) consider it important for a dancer to possess well-developed kinaesthetic awareness, as it provides feedback in the exercise of motor control, they find it an inferior form of feedback for musicians. Compared with the immediacy of tactile feedback, they identify several drawbacks of relying instead on proprioception, including difficulty in enacting gestures accurately, achieving repeatable and precise results consistently, and the need for extensive physical training. This view is indicative of the general disregard for the importance of proprioceptive and kinaesthetic awareness among designers of gestural systems in the musical sphere, though it has been recognised as a significant factor in the wider interactive arts field (Levisohn 2007).

Although there have been suggestions that dancers need to behave more like musicians when controlling interactive systems (Coniglio 2002), less is written about musicians modelling their movement awareness skills on those of dancers. Mark Coniglio (2002) acknowledges the value of dancers moving like musicians in order to perform with his system, MidiDancer[3], to illicit more audience understanding. Yet musicians and designers of gestural systems can benefit from

[3] MidiDancer (Coniglio 2000) is a bodysuit equipped with sensors measuring the angles of the performer’s main joints to control music, video and lighting. The system was first used by Mark Coniglio and Dawn Stopiello in 1989.

studying dancers to gain greater insights into non-tactile interaction, as dancers are not generally reliant on external tools or props (Burt 1990).

2.3.1.1 Dance Systems

Interactive dance has an extensive history, dating back to the collaborative experiments of John Cage and Merce Cunningham, *Variations V* in 1965, in which the movements of two dancers are translated into sound. The information received from proximity-sensing antennae and light beams are applied to triggering and interrupting sounds. Gordon Mumma and David Tudor designed the interactive system, transforming the floor into a musical instrument.

Dance company Troika Ranch has incorporated movement sensing and multimedia technology in their performances over the past two decades. To help realise live video mixing and effects, the creative directors, Mark Coniglio and Dawn Stopiello, developed the mapping software, Isadora (Coniglio 2015), which provides a visual programming environment that allows users to control video effects through a variety of movement, MIDI[4] and audio inputs.

Composer Warren Burt used Simon Veitch's multi-camera setup, 3DIS (Three Dimensional Interactive Space) (Veitch, Veitch & West 1991) to detect large motion from a greater distance in Brisbane Expo '88, and again in 1989 with composer Ros Bandt in collaboration with dancers. While musicians are more accustomed to body-external tools, the dancer relies solely on the body. However with this technology, as the dancer becomes a musician, Burt observed a blurring of roles between dancers and composers, where "composers could not think in purely sonic terms, and choreographers could not think in purely kinaesthetic ones" (Burt

[4] MIDI (Musical Instrument Digital Interface) is a technical standard that enables electronic musical instruments and devices from different manufacturers to communicate with one another. The standard was introduced in1983.

1990, p. 40). This led to a mutual negotiation of spaces and sounds to realise the artistic potential of converting sequences of movement to sounds.

The limitations of the 3DIS system became evident when a solo dancer in Burt's piece, *Inside/ Out* encountered the challenge of playing an invisible drum-kit suspended in space without tactile feedback. A decision was made to explore the contradictions of the system by triggering percussive sounds with non-percussive gestures. Turning off the sound in the last section of the piece let the dancer use gestures previously employed to generate sound to fulfil the *opposite* function of bringing down the energy level of the piece (Burt 1990, p. 41).

German-based dance company Palindrome developed a custom-built system called EyeCon (Wechsler, Weiß & Dowling 2004), which utilises qualities of dance movement to alter musical phrases and influence projected images, text and stage lighting. The video-based motion sensing system first appeared in 1995, and offers a visual-graphical environment suitable for users without programming experience. The Studio for Electro-Instrumental Music (STEIM) produced another camera-based system, BigEye.[5] Performer movements are captured through video cameras and converted to MIDI signals to allow them to trigger sonic and visual events from certain areas of the stage.

These systems encourage collaborations between musicians, dancers and designers in the field of interactive dance and choreography, which can yield insights for gestural interface design and facilitate transfer of knowledge and physical skills between the different art forms (Hewitt, 2011; Newland, 2014). As

[5] STEIM. 2000, *BigEye*, viewed 15 August 2015 <http://steim.org/2012/01/bigeye-1-1-4/>.

Newland (2014) argues, pieces such as Palindrome's work with Butch Rovan, *Seine Hohle Form* (2002), provide insights into how musicians realise:

> gestural embodiment of sonic ideas and how this process of embodiment shapes the intrinsically subjective perception of emotional qualities within a given work. (Newland 2014, p.153)

With this knowledge, performers of gestural instruments can shape their physical expression in more conscious and deliberate ways, thereby maximising the potential of existing systems.

2.3.1.2 Music Systems

The theremin was the first movement-controlled instrument. Invented in 1919 by Leon Theremin, it is played by moving both hands within the space surrounding two antennas. Pitch can be changed within a three to four octave range based on the distance of the right hand from the first antenna: "So initially the invisible string could be played changing the distance of the hand from 50 to 10 cm for each octave, or else through moving the wrist and fingers" (Theremin 1999, pp. 4-5). Hand distance from the second antenna controls amplitude. The performer's movements produce fluctuations in the electromagnetic field, which, unlike a digital system with its potential for limiting or clipping, results in uncontrolled sounds when the player wanders into unstable zones of the active electrical circuit (Erkal 2012, p. 57).

The instrument is difficult to master as there is no felt resistance like frets or keys to touch, compared with traditional acoustic instruments that provide a tangible form of feedback to reinforce the performer's learning (Ihde 2013, p. 108). The theremin's longevity can be partially attributed to its success in establishing a direct relationship between hand motion and continuous feedback, allowing the performer to rapidly construct a mental model of how to play the instrument (Billinghurst & Buxton 2011). Perhaps for this reason, it continues to be one of the few non-tactile instruments through which virtuosity can be achieved. Another important factor contributing to performance mastery is that the theremin exists as a complete instrument and is not subject to design developments and upgrades to which a performer must continually adapt (Ostertag 2002), unlike many other non-contact musical systems.

The theremin is the first example of the human body assuming the role of an instrument, and it continues to influence gestural instrument design. The use of skin capacitance is a fundamental aspect of the control interface, resulting in less technological intervention between the input action and the resulting sound (Ostertag 2002). Yet this strength also translates into a weakness; inducing rigid postures and strictly controlled movements. Theremin virtuoso Clara Rockmore advises prospective players:

> Don’t forget your whole body is an electro-conductor, in the electro-magnetic field and it is therefore necessary to control the slightest motion – not only of hands and fingers. Any involuntary motion, such as the head or shoulders can interfere with pitch and volume (Rockmore 1998, p. 2).

Figure 4: Clara Rockmore at the theremin

The instrument is also limited to monophonic sounds and a single timbre, restricting it to specific repertoire. The theremin thus relies on the performer's skill to introduce the subtlety and nuance required for an expressive performance.

Leon Theremin (1999) compared the hand movements controlling the theremin with the gestures of a conductor. The popularity of applying a conducting metaphor to the design of sensor-based interfaces is evident in a range of virtual conducting applications for non-contact interfaces, spanning a range of wearable and camera-based systems (Marrin 1996; Nakra 2000; Sapir 2002; Rosa-Pujazón et al. 2013). Frequently, conducting is compared with dance, as Jordan observes: "the conductor's 'dance' reminds us of the crucial link between music and the body" (Jordan 2011, p. 57).

Teresa Marrin Nakra's *Conductor's Jacket* (2000) draws on the gesture-based art form of conducting. Without instruments to constrain their movements, Nakra finds that conductors exhibit great diversity in their individual gestural styles, which incorporate a combination of large-scale and minute gestures that represent all parts of the upper body (Nakra 2000, p. 20). By using the conductor metaphor, she aims to capture a universal gesture language through the device.

A recent conducting application inspired by the theremin tradition is the *Disembodied Voices* project (Mandanici & Sapir 2012). This virtual-conductor program controls a score using a choir master metaphor, with hand gestures captured by a Kinect[6] camera. It is also an interactive composition system, in which gesture may control musical features in a pre-established framework. The direct relationship between hand position and control space with continuous auditory feedback enables the performer to assemble their own mind map[7] for playing the instrument.

Unlike the theremin, which can create notes and rhythms much like an acoustic instrument, *Disembodied Voices* is a system that plays a compositional algorithm that triggers vocal samples in four vocal sections according to the traditional choir division: soprano, alto, tenor and bass. Digital signal processing, including a ring modulator and two frequency shifters, is added to bring expressivity to pre-recorded samples. *Disembodied Voices* is one example of the many artistic projects that have embraced contactless sensors, such as the Kinect and other cameras types (Murray-Browne & Plumbley 2014). Released with a development kit in 2012, Kinect has been favoured by a range of interactive artists and designers for its skeleton tracking capacity, enabling rapid prototyping and experimentation with whole body movement-based interaction.

Handel is another vision-based gesture recognition system by Leonello Tarabella (2004) and used in his interactive computer music performances. It

---

[6] Microsoft Kinect® depth camera, viewed 15 August 2015, <http://www.xbox.com/en-AU/Kinect/>.

[7] A cognitive map, adopted from psychological research (Tolman 1948), or mental model, is a mental representation a musician relies on to assist learning and recall when playing an instrument.

translates data measuring the data from *x* and *y* positions, shape (posture) and rotation of the performer's hands into controller messages to operate real-time musical software.

Tarabella supports the idea of systems that do not impose specific behaviour on performers, instead allowing them many degrees of freedom to control and simultaneously communicate their emotions. This is why he favours non-intrusive interfaces, based on remote sensing of bodily postures, that give the player a strong sense of being *bathed* in sound (Tarabella 2004, p. 140). The algorithm he uses to capture movement is simple, yet still allows for a wide range of dynamic figurations to engage the audience over an extended period of time. The performer/composer is also able to determine their own mapping, selecting from a range of postures and movements.

In addition to technical considerations, Tarabella describes the problem of gesturing in the air in front of an audience, without the movement prescriptions of traditional musical instruments. This leads to a situation in which the hands are both instrument and player. The performer thus faces the challenge of finding a new sense of coherence and elegance in order to be completely free when performing (Tarabella 2004).

Tarabella has addressed this problem by observing the gestures of magicians and also conducting his own personal research into improving the control and coordination of the hands through the spiritual discipline of Tai Chi, applying insights from personal Tai Chi lessons to develop refined control and coordination of his hands in gestural performance (Tarabella 2004, p. 147).

Tarabella's observation reflects a need to consider the creative decisions performers must make when engaging with non-tactile interfaces operated by user-defined gestures. To use gestural systems effectively, a whole new form of stagecraft is required that demands an understanding of the aesthetics associated with particular gestures and the ways they can be used to embody sonic ideas.

2.3.1.3 Interactive Installations

Remote sensing is popular in public arts installations because it does not interfere with the movements of participants entering the space. Movement-sensing installations invite audience members or amateur 'performers' to directly engage in the manipulation of image and sonic material from a computer (Winkler 2010). The goal is to detect and analyse natural movements so that participants can create their own experience of shaping the elements of an interactive artwork, without any prescriptions of how it should be done.

Figure 5: Video still from VIDEOPLACE by Myron Krueger (1974)

Myron Krueger's evolving iconic work, VIDEOPLACE, is a vision-based system that tracks hand, finger and whole body motions, allowing individuals to physically manipulate graphic objects with varied and unencumbered gestures. VIDEOPLACE represents one of the earliest examples of augmented reality, blending a participant's live image with a computer graphic environment (Krueger 1983). A two-dimensional virtual reality world is generated using cameras and projectors to enable multiple users, represented as silhouettes, to interact with digital objects, using a rich set of gestures. The work, which predates the widespread adoption of the mouse, was partially aimed at illustrating potential alternatives to keyboard terminals, which dominated computer systems in the 1970s.

Krueger identifies several ways of conceptualising a control system incorporating hardware and software that can be programmed by the artist to create different interactive experiences (Krueger 1977, pp. 430-31). These categories include:

- Creating a dialogue between human and machine, where the person's motions receive audio and visual answers;
- Presenting an environment that can amplify an individual's actions;
- Exploring the potential of a responsive environment to transform the participant's body into an instrument.

The final point, that of the metaphor of body as instrument, underpins the Very Nervous System (VNS) by David Rokeby, which uses a combination of video cameras, image processors, synthesisers and a sound system to track the movements of installation visitors and convert them to sound or music. Various segments of the camera screen are mapped to an assortment of instrumental controls. The system has also been adapted to performance applications. The work strives to create an intimate experience within space scaled to the human form, in response to the logical detachment of the computer: "Because the computer removes you from your body, the body should be strongly engaged" (Rokeby

2010). The body thus assumes a central role in the interaction, becoming an instrument directly responsible for sound generation and manipulation.

2.3.2 Body as Instrument

The notion of body as instrument has emerged in both musical and general cultural contexts. Anthropologist Marcel Mauss, in his seminal paper *Techniques of the body*, refers to the body as "man's first and most natural instrument" (Mauss 1973, p. 75). Yet within the technologies and techniques characteristic of modern computer music, the body is historically relegated to a secondary role in performance (Roddy & Furlong 2013, p. 3). Dating back to the advent of *Musique Concrète*, pioneered by Pierre Schaeffer in the 1940s, sounds have been separated from their source. For the audience this translates into an absence of causal effect between performer action and sonic outcomes.

Nicholas Brown observes this tendency in John Cage's absolute music, which he sees as a refusal to accept the human source behind musical sound (Brown 2006, p. 43). He argues that computer-assisted performance restricts bodily movement and that modern notation attempts to control and regulate the natural phenomena of sounds and their originating gestures, denying embodied musical practice (Brown 2006, p. 42). Bahn, Hahn and Trueman (2001) also argue that Western music, keyboard instruments and music notation privilege mental abstractions over the irregularities and inconsistencies of the body.

Drawing on phenomenological perspectives, Franziska Schroeder and Pedro Rebelo (2009, p. 139) offer an alternative treatment of the body in relation to performance technologies, proposing a performative layer that acknowledges the embodied position of the performer and their way of being in the world (Schroeder & Rebelo 2009, p. 139). Their approach characterises a move towards more embodied understandings of the relationship between body, instrument and performance.

In a study of networked music performance, Schroeder and Rebelo (2009) expose the various strategies musicians use to deal with unexpected and discontinuous events, demonstrating how the performative layer is constituted. Shifting circumstances associated with distributed performance, such as latency and lack of visual cues between performers, force musicians to adapt and relearn strategies to "re-address their relationship with their instrument in order to maintain a believable state of performance" (Schroeder & Rebelo 2009, p. 138). Schroeder and Rebelo's study introduces a conceptual framework to help understand how the performer adjusts to novel virtual environments or musical instruments by breaking out of habitual practices and adopting new bodily behaviours (Schroeder & Rebelo 2009, p. 138).

The performative layer is presented as a way of comprehending the two-way connection between the instrument and performer, with potential implications for the design of performance technologies, from new virtual environments to musical instruments (Schreoder & Rebelo 2009, p. 140). This phenomenological approach to the performing body is directly relevant to gestural interface design by providing insights into the association between body, instrument and performance (Schreoder & Rebelo 2009, p. 140).

Similar ideas are explored in the collaborative solo performance work, *Pikapika,* which places the body in a central role, re-integrating physicality into technological music and dance performance by mapping the character's body as sound (Bahn, Hahn & Trueman 2001). These body-centric approaches to electronic performance are echoed in the gestural experiments of Bencina, Wilde and Langley

(2008), who invent new gesture-sound mappings through a series of movement and vocal improvisations, with the intention of making sound production “an inherent and unavoidable consequence of moving the body” (Bencina, Wilde & Langley 2008, p. 197).

Even more intimate physical control can be achieved by channelling bio-electrical signals directly from the muscles of the body, as in Atau Tanaka’s performances with electromyogram (EMG) sensing where arm muscle tension is translated into musical control data. Tanaka, of the group SensorBand worked with BioMuse (Tanaka, 1993) and other EMG-based systems (Tanaka and Knapp, 2002). BioMuse is an eight-channel ‘biocontroller’ developed through Stanford’s Centre for Computer Research in Music and Acoustics (CCRMA) by Hugh Lusted and Benjamin Knapp in 1989. Tanaka worked extensively with the system, developing concert pieces that triggered both sound and images. Recent work in this direction includes Marco Donnarumma’s musical performances, which rely on bimodal muscle sensing to achieve motion signification (Donnarumma 2014).

Another prominent innovator in body-based performance is multimedia artist Laurie Anderson, who has a long history of extending the body through technological enhancements. Anderson’s incorporation of body instruments in her performances becomes a way of integrating herself into the broader scheme of her art (Goldberg 2000, p. 139). She transforms her body into a projection screen for film images with the Screen Dress, and into a percussive interface through the Drum Suit. Appearing in her film, *Home of the Brave*, the Drum Suit features electronic drum sensors sewn into the seams of a garment that produce loud percussive sounds when she taps her knees or chest forcefully: “Because the sound was so loud, so out of proportion, I had to make the movements bigger, wilder. I had to dance" (Anderson cited in Goldberg 2000, p. 141). Anderson also augments her body visually in the film by placing a light bulb into her mouth to illuminate her cheeks.

Adapting everyday objects with simple technology, Anderson alters consumer products like Pillow Speaker, a language-tuition device designed to recite German phrases while a student sleeps, into a vocal effects unit by placing it in her mouth and modulating the sound with her lips. Anderson also adopts ready-made designs like the Talking Stick, an interface equipped with force-sensing resistors that controls granular synthesis throughout her show, *Songs and Stories from Moby Dick.* The commercially available BodySynth[8] designed by electrical engineer Ed Severinghaus and performance artist Chris Van Raalte, features during her 1992 European tour. The BodySynth promises to transform the body into a musical instrument through electrode sensors that measure EMG signals.

Merging choreography with musical performance, Schroeder and Newland (2013) make the body the focal point in their performance of Karlheinz Stockhausen's *Tierkreis*. Their physical approach to performance enables the body to shape the interpretation of the piece:

> By exploring instrumental interactivity and bodily presence, guided by a choreo-musical approach to staff-notated repertoire that considers music beyond purely sonic terms, we explored the musical and physical relations implicit in the tactile engagement between body and instrument. (Schroeder & Newland 2013, pp. 107-108)

---

[8] Bodysynth n.d., *Bodysynth*, viewed 15 August 2015 <http://www.synthzone.com/bsynth.html>.

Newland (2014) continues this focus in collaborations with dancers, exploring the choreographic potential of her expressive movements as a pianist in the work *Woman=Music=Desire*. The choreography is created from repetition of common phrases that characterise Newland's body language as a pianist.

Designer Lise Amy Hansen (2011, p. 252) also values the choreographic approach for its history and practice of composing new movements. In her view, choreographic resources can inform interaction design, and enrich and broaden design considerations based on full-body interaction (Hansen 2011, p. 252). Hansen argues that accessing these resources can lessen the reliance on functional, controlling and prescriptive gestures, allowing for more expressive movement. The conception of body as interface is central to advancing design potential in digital interaction, according to Hansen:

> By drawing on the particularities and potentials of the moving body as interface such as those explored through choreographic practice, we may avoid imitating existing exchanges with technology and create novel interactions. (Hansen 2011, p. 247)

Guided by the physical constraints and possibilities of the body in motion, gestural interaction has the potential to reflect the idiosyncrasies of the individual performer if sufficient opportunities for movement exploration are made available.

2.3.3 Gestural Systems for the Voice

The voice is considered the body's original and most intimate instrument (Overholt 2009), as the vocal sound emanates from the body, bearing the personal and emotional expressive imprint of the performer (Emmerson 2007). Although it is an invisible acoustic instrument contained in the body, the singing voice acquires visibility through facial expressions and body movements (Schloss 2003, p. 2). This individual body signature is further magnified when the voice intersects with movement in a motion-controlled interface. The fact that the voice emerges from and resonates through the body makes it a natural partner to what some theorists view as the body's primary language: movement (Halprin 2003; Sheets-Johnstone 1999). Our bodily signature is imprinted on both our vocal sounds and movement patterns.

The clearest link between musician and dancer is in vocal performance. In choreographing many pieces to vocal music, Mark Morris highlights the connection between the bodies of vocalist and dancer in an interview with Joan Acocella: "Singing is like dancing. It's the body, the body in the world, with nothing in between, no instrument between" (Acocella 1993, p. 82).

This view is reinforced by Don Ihde (2013), who considers singing and other protomusical sounds like whistling, yodelling and throat singing to be the simplest and most physically expressive types of human-produced music (Ihde 2013, p. 103). The voice is characterised by a physical expressivity that "should also be expanded to variations on whole body movement, such as dance, even self-percussion such as slapping oneself or other objects" (Ihde 2007, p. 254).

Much has been written about technical approaches for mapping performer gestures to musical processes in relation to digital musical instruments (Winkler 1995, 1998; Hunt et al. 2000; Overholt 2001). There is less literature available on movement-enhanced vocal performance (Wu 2015). Yet the mutual influence of movement and the voice has inspired a diverse range of gesturally augmented vocal systems, some of which are discussed briefly here.

Several notable gesture-based vocal systems have been developed by and for performers. These include Laetetia Sonami's Lady's Glove (Bongers 2000); Michel Waisvisz's The Hands (Waisvisz 1985); Donna Hewitt's eMic (Hewitt 2006), Sidney Fel's Grassp system (Fels, Pritchard &Vatikiotis-Bateson 2009) and Elena Jessop's VAMP system (2009). Waisvisz's gestural controller manipulates a range of sound sources and his own voice, with small keyboards worn on the hands incorporating force and tilt sensors to sense hand inclination. The performer's fingers control the keys, while the thumb operates a pressure sensor and ultrasound transducers measure distance between the hands. The movement information collected by the sensors can be mapped to diverse sound parameters, from pitch to loudness and timbre (Bongers 1998).

Hewitt (2006) treats the voice as an abstract sound for processing, reconfiguring it to transcend the gender and cultural conditioning usually associated with the female vocal sound: "Electroacoustic technologies allow us to overcome certain biological, physical and emotional limitations of natural embodied voices" (Hewitt 2006, p. 13). Hewitt's work explores the ability to capture and reproduce the human voice, allowing it to be removed from the body and its associated biological limitations, such as breath, pitch range, timbral quality and volume/amplitude. In this way, gestural systems can extend or expand the existing vocal instrument (Hewitt 2006, p. 40).

Hewitt uses digital signal processing to explore the emotive content of the voice, as well as the expressive associations between voice and music (Hewitt, 2006). Her main system is the eMic controller, or 'extended microphone-stand interface controller'. The device is an altered microphone stand, equipped with sensors to capture common gestures and movements of vocalists performing with microphones and microphone stands in electro-acoustic performance. Her primary goals in developing the eMic were to extend natural vocal capacity through digital signal processing, give the performer more control over their sound on a sound reinforcement system, improve visual communication with the audience, and enable digital vocal control away from the computer, thus enabling the performer to move freely about the stage. These goals are common among other vocalists who employ gestural systems to augment their voice.

Another example of a gesturally extended vocal system is the Bodycoder system, created by Mark A. Bokowiec and Julie Wilson-Bokowiec. This wearable full-body gestural controller is used in a range of gestural control applications, including vocal performance (Bokowiec 2011). An example of a solo vocalist/performer application of the Bodycoder is demonstrated in the interactive work *VOC'T (Ritual)* (2011), composed by Mark A Bokowiec. In it, the vocalist wears a sensor array to orchestrate and manipulate pre-defined compositional structures and distribute the sound through an eight-channel monitoring system. While one hand sets a pulse, the other arm moves in continual, sweeping gestures to activate sonic processes including granularisation, looping and filtering (Bokowiec 2011, p. 41).

Several vocal systems specifically explore the connection between verbal communication and gesture, exemplifying Jane W. Davidson's (2001) finding that a singer's gestures share similarities to gestures that occur during speech. Gestures during vocal performance can emphasise lyrical content and meanings (Hewitt 2006). The overlapping rhythms associated with gestures accompanying speech and the natural phrasings of conversations provide inspiration for artist Greg Beller. His work with the Synekine project (Beller 2014) aims to create a fusional language integrating voice, hand gestures and bodily movement.

Another work that examines the intersection of gesture and speech is Joan La Barbara's audio-visual performance, *Messa di Voce*, which explores the visualisation of two vocalist's utterances. In an interactive environment created by Golan Levin and Zachary Leiberman, the head movements of both performers are tracked and their vocalisations transformed into visualisations on screens behind them, making the voice visible in the form of projected speech bubbles. In a case of phonetic symbolism, the sounds of the words are translated into associated forms, shapes and textures (Levin et al., 2003).

The works summarised here highlight the creative opportunities for vocalists to extend the natural capacity of their voice through common gestures employed during vocal performance and speech. Gestural control appears particularly well suited to vocal applications because of the ability to capitalise on existing free air gestures. Most current gestural systems for voice are highly customised and designed by and for specific performers, resulting in individualised mapping and design strategies and highlighting an absence of standardised approaches in the area.

2.3.4 Augmented Instruments

Augmented instruments are created by modifying a traditional acoustic instrument with added sensors so that it can interact with a computer (Overholt et al., 2009). Altering existing instruments provides one entry point into gesturally-controlled performance for instrumentalists, who can leverage existing skills to extend their available sound palette electronically. This type of control enables musicians to utilise their usual performance gestures without having to learn a new gestural vocabulary.

In this category are Tod Machover's Hyperinstruments, which offer virtuoso musicians added layers of expression and control through digital enhancement of traditional instruments. Designs like Hypercello and Hyperbow (Machover 2004) capitalise on traditional playing skills by analysing performance information, extracted from audio and movement data, to alter the original sound of the acoustic instrument. More recent gesturally-augmented string instrument designs include Dancing Viola (Todoroff et al. 2008) and Mari Kimura's augmented violin (Kimura et al. 2012).

Examples of augmented piano systems include a gesturally-controlled improvisation system for piano by Gillian and Nicolls (2011), a gesturally extended piano by Brent (2012), and Yang and Essl's (2012) augmented piano keyboard. Other augmented instruments range from the saxophone (Melo, Gómez & Vargas 2012) to pitched percussion instruments (Michael et al. 2012).

Research aimed at finding ways of extending traditional instrumental technique by utilising non-sound producing gestures reflects a range of mapping approaches. Within augmented instrument design, direct casual relationships between movement and sound are commonly favoured, using sound producing gestures to alter sound or add new interfaces with direct mappings (Lähdeoja, Wanderley & Malloch 2009). Yet the role of non-sound-producing gestures in influencing musical elements like tempo, articulation and timbre illustrates expressive potential that can be effectively channelled into digital manipulation techniques; for example, controlling digital audio effects, which "may provide coherent relationships between this control and the musical interpretation" (Wanderley & Depalle 2001, p. 5).

Systems that take advantage of this potential include Wanderley and Depalle's (2001) flanger effects control of a clarinettist's motions. Another example, the Multimodal Music Stand System (MMSS) (Bell et al. 2007), employs non-sound-producing gestures and communicative gestures to extend an instrumentalist's technique. The MMSS is equipped with a camera, microphone and electric-field sensor inputs that combine visual and audio analysis with gestural recognition (Overholt et al. 2009). The stand tracks the instrument's tilt and the musician's head motions simultaneously, supplying control data for audio synthesis and processing. The MMSS is more versatile than the majority of augmented instruments; as a general-purpose device, it allows any instrumentalist to modify their own sounds and trigger pre-composed material.

A significant challenge identified by Lähdeoja, Wanderley and Malloch (2009) in instrument augmentation is the limitation imposed by the musician's physical and psychological capacities to execute several simultaneous tasks. They address this challenge by identifying non-direct gesture–sound links between non-sound-producing gestures and subtle sonic manipulations that do not require the full conscious control of the performer.

Lähdeoja, Wanderley and Malloch (2009) present an augmented guitar interface with a two-layered mapping strategy that combines direct mappings and focused gestures to control the main parts of the system with secondary features that are influenced by non-conscious movements. The motions are detected with a two-axis accelerometer positioned on top of the head and a board beneath the feet sensing weight distribution. The sensor data travels through a mass spring model based on a kinetic metaphor in which the performance gestures correspond to energy-inducing motion, before being converted to digital signal processing parameters.

Tests carried out with this system provide insights into the ‘feel’ of the non-direct mapping relationships. Head movements, for example, are found to relate well to minute, high-frequency alterations of the sound’s spectrum and space, whereas weight-shifting motions appear more suited to slower and more significant changes in the soundscape (Lähdeoja, Wanderley & Malloch 2009, p. 329). Whether to assign some control to the system to lessen the cognitive demands on the performer, however, is a design choice that must be balanced with a consideration for the autonomy of the musician.

Lähdeoja, Wanderley and Malloch’s (2009) approach highlights the distinct roles that both deliberate and unconscious gestures assume in augmented instrument performance. From a performer’s perspective, the experience of performing with augmented instruments constitutes a significant departure from their usual playing technique. Pianist Sarah Nicolls, discusses the impact of transforming sound-accompanying movements into control gestures when playing her augmented piano:

> Imagine the pianist lifting the arm away from the keyboard, perhaps signifying a breath between musical phrases. By using this gesture to generate data and in turn the processing of sound, I found, in making such a gesture, I was now focused on playing the sensors and NOT the previously almost subconscious movement—thereby turning the gesture into a material action. As a solo performer is only one body, one mind, these cycles of complexity and confusion in fact perhaps begin to disrupt the artistic spontaneity and intuitive physical sense and the original meaning of the gesture is potentially undermined. (Nicolls 2010, p. 50)

When the performer consciously controls expressive movements, the usually intuitive flow of energy through the body is altered. The recognition of physical abilities and a performer's need to recover are important design considerations in Nicholl's summation: it is therefore important to examine how the use of non-conscious gestures as a control input can alter their original intention and meaning. The transformative impact of these types of decisions are examined further in the following sections, which discuss the stages involved in designing gestural systems for performance.

2.4 Design Stages

This section explores the main design phases involved in gestural interface design, drawn from a framework explaining the chain of decisions that shape DMI design (Miranda & Wanderley 2006, p. 4):

1. Decide on the types of gestures to control the system;
2. Design gesture capture strategies to convert these movements into electrical signals – using sensors to measure different body movements, velocity, pressure or another variable;
3. Develop sound synthesis algorithms to create sounds, or select musical software to control pre-recorded music-control inputs;
4. Map sensor outputs to synthesis and musical control inputs;
5. Decide on what types of feedback modalities to use, e.g. visual, tactile or kinaesthetic.

The most crucial of these phases is perhaps the initial selection of gesture types that will act as control inputs and the design of strategies for interpreting these movements. The next section addresses techniques and challenges for capturing the complexity of nuance of performer gestures within DMI design.

2.4.1 Gesture Capture

Performer movements can provide a highly varied and individually nuanced form of input into an audio-visual control system: "Through our movements we provide a rich performative, communicative visual expression onstage and in other unscripted scenarios" (Hansen 2013, p. 135). However, capturing the richness and subtly of human movement digitally remains a complex task for designers. Current gestural systems are still limited in the intricacies and nuances they can capture. Hansen reflects on the tendency of camera-based sensing to simply "read" motions, losing the full range and detail of whole body movement (Hansen, 2013, 135). Methods for extracting movement qualities that are clear to the naked eye are still quite primitive and are hampered more by inadequate real-time motion analysis techniques than motion capture hardware (DeLahunta & Bevilacqua 2007, p. 6).

A range of technological approaches for integrating body movement as an input into visual and audio control systems have emerged over the past thirty years (Badler & Smoliar 1979; Mulder 1989; Camurri et al. 2000; Camurri, Lagerlöf & Volpe 2003; Castellano, Bresin, Camurri & Volpe 2007a). Antonio Camurri has been active since the late 1980s in dance and music applications, concentrating on isolating the expressive information contained within physical movement and gesture (Camurri 2004). His work draws on the concept of KANSEI (Hashimoto 1997), an information processing framework for analysing the emotion present in human movement, and also on Laban's theory of movement (Laban & Lawrence 1974).

Camurri contributed to one of the most influential systems for interpreting expression from movement, EyesWeb (Camurri et al. 2000), a platform for multimodal analysis and the development of interactive systems and MEs. The software is designed to extract expressive indicators and categorise movements according to simple emotions. Performance movements are analysed in relation to Laban's Effort–Shape parameters (Camurri et al. 2000).

The EyesWeb expressive gesture processing library offers modules for motion, space and trajectory analysis (Camurri, Mazzarino & Volpe 2004a). By utilising Laban's Effort–Shape parameters to interpret the dynamic character of movement, segmenting it into the fundamental blocks of space, time, weight and flow, forms the basis for identifying expressive indicators in human movement: "in measuring expressiveness, we are not interested in *what* kind of gesture is performed, but *how* the gesture is performed" (Camurri & Moeslund 2010, p. 257).

EyesWeb belongs to a category of motion sensing called *computer vision*, which visually analyses movement data captured in video form. A range of other computer vision software toolkits is available to assist designers in gesture interpretation, including cv.jit[9] and OpenCV (Open Source Computer Vision Library).[10]

Previously only achievable with expensive multi-camera systems such as the Vicon 8, which was reserved mainly for laboratory research environments, camera-based systems are now more accessible and affordable. The Kinect depth camera, originally designed for gaming purposes, has been appropriated for numerous interactive musical and graphic projects (Gillian & Nicolls 2011; Yoo, Beak & Lee 2011; Gelineck & Böttcher 2012; Mandancini & Sapir 2012; Murray-Browne 2012; Hansen 2013) that have broadened the user base for gestural

---

[9] Pelletier, J. 2015, *cv.jit*, version 1.8.0, viewed 16 August 2015 <http://jmpelletier.com/cvjit/>.
[10] Itseez. 2015, *OpenCV*, version 3.0, viewed 16 August 2015< http://opencv.org/>.

experimentation, especially with regard to full-body movement. The Kinect's capacity to track skeletal joint positions facilitates rapid prototyping with minimal programming and financial outlay. Other recent camera solutions that have attracted the attention of interactive artists include the Leap Motion[11], a three-dimensional controller that allows more detailed gestural control based on hand and individual finger sensing.

2.4.2 Mapping

A prominent theme in digital musical instrument design literature focuses on the relationship, or mapping, between the physical gestures of the performer controlling an instrument and resulting sounds. Many authors in the NIME[12] community have addressed the challenge of mapping movement to sound in a meaningful, intuitive and precise manner (Drummond 2009; Johnston 2009; Murray-Browne & Plumbley 2014). According to Halmrast et al. (2010 p. 209), mappings must undergo continual refinement in order to feel natural and intuitive for a musician. Murray-Browne, Mainstone and Bryan-Kinns (2011 p. 2) "propose an approach to instrument creation as an art form in itself where instrument, mapping and music are an integrated part of a greater composition".

One challenge in mapping is dealing with the large number of sonic outcomes achievable when manipulating digital sound, either by modifying (audio effects) or by generating digital sounds (sound synthesis) (Verfaille, Wanderley & Depalle 2006). Electronic music algorithms combined with real-time synthesis

---

[11] Leap Motion 2015, viewed 16 August 2015 <https://www.leapmotion.com/>.
[12] New Interfaces for Musical Expression 2001-2015, *NIME*, viewed 16 August 2015 <http://nime.org/>.

engines can potentially create a vast number of variables that need to be controlled simultaneously in an electronic music interface.

Granular synthesis methods, which have been broadly adopted in interactive music and dance systems, also have the potential to produce a large array of sounds. Granular synthesis evolves from short samples, or grains, of sound that are segmented, reordered and manipulated to create sonic textures. These sound recordings are decomposed into fragments and then recomposed in response to gestural input (Bevilacqua, Schnell & Fdili Alaoui 2011). This intensive process makes matching selected control parameters with appropriate and coherent gestures in real-time challenging (Van Nort 2010, p. 183).

A large body of mapping literature presents mapping strategies that address this challenge (Winkler 1995; Hunt & Kirk 2000; Wanderley & Battier, 2000; Fels, Gadd & Mulder 2002; Cont, Coduys and Henry, 2004; Bencina 2005; Verfaille, Wanderley and Depalle 2006; Tanaka 2010). However, these mapping approaches are more suited to electronic instruments modelled on traditional acoustic instruments than those modelled on more complex interactive instruments (Chadabe 2002). For interactive systems with complex relationships between cause and effect, such as those controlled by an independent algorithm, Chadabe considers mapping is not sufficient to capture the shifting variables of the controls, preferring to adopt a network structure to describe relationships between performer actions and resulting sounds in an interactive system.

Existing mapping literature is divided into two main approaches: indirect or implicit mapping, based on the use of neural networks, feature extraction or pattern recognition as a foundation for mapping; and explicit mapping, where input-output relationships are defined explicitly by the designer (Hunt & Wanderley 2002, p.

98). The benefits of using machine learning techniques such as neural networks include assisting in the interpretation of sensor parameters to avoid complex programming, as even the simplest gestures can generate a substantial amount of movement parameters and complicated data parameters (Bevilacqua, Schnell & Alaoui 2011). This enables the development of a gesture vocabulary, built up from phrases or gestural units recorded during a training phase. This process gives the performer the freedom to define individually tailored input gestures (Bevilacqua, Schnell & Fdili Alaoui 2011).

Explicitly designed mapping strategies allow a designer to control each aspect of the instrument's component parts (Hunt & Wanderley 2002, p. 99). The application of explicit mapping, where input parameters and output parameters are clearly defined, provides "a better visibility on what is being computed" (Arfib et al. 2002). To achieve this type of specific control in all aspects of a design, I have adopted explicit mapping strategies in the systems presented in this thesis.

A consistently used classification, introduced by Rovan et al. (1997), divides mapping strategies into three groups:

- One-to-one mapping, where a single gestural output is linked to one musical parameter;
- Divergent mapping (also known as one-to-many mapping), where one gestural input affects a variety of parameters;
- Convergent mapping (also referred to as many-to-one mapping), in which multiple gestures control one musical parameter.

The simplest mapping strategy, one-to-one is mapping, is generally considered the least expressive, whereas convergent mapping is viewed as the most expressive, though initially harder for the performer to master (Rovan et al. 1997).

To promote exploration and incorporate the subtle nuances of a performance, complex mapping schemes are often favoured (Dobrian & Koppelman 2006), as they help designers of new instruments create more engaging interfaces. In the work of Winkler (1995); Rovan et al. (1997); Arfib et al. (2002) and Hunt and Wanderley (2002), multi-layered mapping approaches are linked to increased levels of expressiveness.

Wanderley, Schnell and Rovan's (1998) mapping approach involves 'composed instruments', meaning that the synthesis model and gestural controller are independent from each other. The mapping can be adapted through a layer of abstraction to enable simultaneous control of a range of synthesis variables, potentially addressing a range of synthesis techniques, controllers, artistic aims and skill levels. Cross-coupling a range of controls with synthesis parameters can contribute to an intuitive understanding of the instrument (Goudeseune 2003), making it potentially more interesting to the musician than one-to-one mappings.

2.4.2.1 Embodied Mapping Metaphors

In traditional acoustic musical instruments, physics underlies the mapping between action and sound. The mechanical systems of such instruments result in a mapping that is easily understood by player and audience alike. The well-established cultural associations underpinning traditional instruments also reinforce the expectation of specific inputs relating to specific outputs. Even when the audience lack the proficiency to play an instrument themselves, it is still possible to understand how control gestures map to sound output.

In the case of electronic musical instruments, where relationships between movement and sound must be constructed, mappings can appear difficult to understand for both observer and performer. When an opaque mapping is complex to learn and comprehend, expressivity can be problematic. To overcome this lack of familiarity, Fels, Gadd and Mulder (2002, p. 11) recommend that "metaphor can be used to relate new technology to the known, cultural basis of the literature". The notion of meaningful metaphors that provide a transparent mapping between gesture input and sonic output is applied by Fels, Gadd and Mulder (2002) to the design of a series of installations, including the *Iamascope*, an interactive video kaleidoscope that uses a guitar metaphor to explain its underlying musical mapping to participants. In the same series, *Sound Sculpting* employs the metaphor of sculpting clay to change the shape of a virtual object. The shape of the object influences FM synthesiser parameters. *MetaMuse* relies on a rainfall metaphor to match the process of the synthesis engine, specifically granular synthesis.

Metaphors are particularly important in promoting the usability of non-tactile gestural interfaces. By capitalising on pre-existing knowledge in a movement-based system, users can perform input actions unconsciously or automatically, without needing prior instruction on how to interact with the system. Wessel and Wright (2002) embrace this approach, advocating for the integration of metaphors in the design of computer-based instruments, implementing 'drag and drop', 'scrubbing', and 'dipping' metaphors to promote usability in their controller software (Wessel & Wright 2002).

The definition of 'metaphor' is adopted from the work of George Lakoff and Mark Johnson (1980, 1999), establishing meaning by viewing one concept from a 'source domain' in relation to another in a 'target domain.' Metaphors are ‘cross-domain mappings’ in this sense. Lakoff and Johnson (1980, 1999) argue that individuals interpret abstract concepts through the lens of sensorimotor experience.

The related concept of image schema refers to patterns formed from internal representations of the body and its movements. These patterns derive from our physical experiences. Image schematic theory owes much to the work of George Lakoff and Mark Johnson (1999). Johnson presents the concept that physical experiences contribute to the formulation of structures and patterns he calls image schemas in *The body in the mind* (1987). These basic structures of sensorimotor experience “define the contours of our world and make it possible for us to make sense of, reason about, and act reliably within this world” (Johnson 2007, p. 136).

Common image schemas informed by bodily movements include UP – DOWN (verticality), BALANCE, TOWARD – AWAY FROM and STRAIGHT – CURVED. These concepts have a bodily basis, particularly verticality, as it relates to gravitational forces and our ability to stand erect, reaffirming that movement experiences form a core part of how we construct meaning and learn to make sense of our world.

In a musical context, the “moving music” metaphor shown in Figure 2 illustrates how the physical forces of motion shape our understanding of key musical concepts.

Source (Physical Motion)		Target (Music)
Physical object	→	Musical event
Physical motion	→	Musical motion
Speed of motion	→	Tempo
Location of observer	→	Present musical event
Objects in front of observer	→	Future musical events
Objects behind observer	→	Past musical events
Path of motion	→	Musical passage
Starting/ending point of motion	→	Beginning/end of passage
Temporary cessation of motion	→	Rest, caesura
Motion over same path again	→	Recapitulation, repeat
Physical forces (e.g., inertia, gravity, magnetism)	→	"Musical forces" (e.g., inertia, gravity, magnetism)

Figure 6: Musical motion metaphor (Johnson & Larson 2003, p. 67)

This image–schematic logic, which stems from bodily experience, is considered fundamental to performing abstract reasoning (Johnson 2007, p. 181). Johnson (2007) enlists discoveries from neuroscience to support the argument that physical experience aids the understanding of abstract concepts. He adapts the notion of image schema from Immanuel Kant, who considers imagination structuring as a bridge between a physical object and material thing, constituting a way of understanding experience. Imaginative experience is not just isolated, but is also rooted in our everyday experience. A less confusing term is embodied schema, which more adequately depicts the intention to incorporate all types of sensory-perceptual information, not just visual.

Images schemas that emerge from bodily movement can then be applied to conceptual domains through conceptual metaphors. Conceptual metaphors emerge as a cognitive structure for explaining experience in Lakoff and Johnson's work (1980, 1999). The spatial metaphor of up and down, for example, is often used to frame our understanding of emotions, consciousness and health (Zbikowski 2002). A widely used example in music is the conceptual metaphor that relates pitch to positions in vertical space. This metaphor maps spatial orientations like up–down onto the pitch scale (Zbikowski 2002, p. 66) and is reflected in standard musical notation, where notes of a higher frequency are placed above notes of a lower frequency. This mapping is particularly prevalent in Western culture.

Differences in interpreting pitch can be found in a range of cultures; for example ancient Greece, where high pitch was described as 'sharp' and 'pointed' and low pitch as 'heavy'. However, the spatial metaphor has some relationship to general embodied experience, particularly in relation to how vocal pitches reside and resonate in different parts of the body. Most importantly, it allows us to structure our understanding of pitch in a way that is reinforced by physical experience:

> Mapping *up-down* onto pitch allows us to import the concrete relationships through which we understand physical space into the domain of music and thereby provide a coherent account of relationships between musical pitches. (Zbikowski 2002, p. 71)

A number of studies in the interaction design field have suggested that conceptual metaphors that exist at the sensory motor level can contribute to the development of more intuitive interfaces. Experiments by Hurtienne and Blessing (2007) apply examples of common conceptual metaphors such as 'more is up', 'good is up', 'virtue is up' and 'more is right' to an arrangement of button and slider controls. Participants are supplied with spoken phrases and asked to press the appropriate button or move a slider to indicate the most suitable direction. The results show that response times are reduced when control layouts are designed to support the conceptual metaphor inherent in the task. However, because this study is small and only tests two user-interface components, more research is required to test this hypothesis further.

In related work in the sound–interaction design field, Antle, Droumeva and Corness (2008) and Antle, Corness and Droumeva (2009) search for evidence that placing an embodied metaphor in the mapping layer between movement-based input and sound can enhance intuitive interaction. A series of experiments compare embodied metaphor and non-metaphor based mapping systems to see how well they enable children to learn musical concepts from sounds. The results indicate that the embodied metaphor-based system supports clearer comprehension of abstract musical concepts, though children tend to use spatial metaphors rather than physical metaphors, so the mapping needs to be easily discoverable as well as metaphorical to be useful.

In a review of the application of conceptual metaphors in music interaction design, Wilkie, Holland and Mulholland (2010) outline the potential of creating intuitive interaction models for expert and novice users who can draw on prior sensory-motor experiences to gain access to domains previously only accessible to specialists. As well as facilitating intuitive interaction, they recognise the potential of conceptual metaphors to be used to evaluate and enhance existing designs (Wilkie, Holland & Mulholland 2013).

The integration of embodied principles and metaphors in mapping performer movements to sound processes is growing in momentum (Antle, Corness & Droumeva 2009; Wilkie, Holland & Mulholland 2010; Roddy & Furlong 2013). Borrowing from established links and embodied understandings of physical phenomena increases the chances of developing a gestural system that makes sense and feels natural to the performer. Stephen Roddy and Dermot Furlong (2013) argue that embodied schemata — patterns that help us interpret out physical experience — offer a way to map performer actions to musical outcomes in live computer music intuitively (Roddy & Furlong 2013, p. 1).

Antle, Corness and Droumeva (2009) refer to links between abstract concepts and our physical way of relating to the world as embodied metaphors. When designing mappings, they suggest that tacit knowledge of a physical source domain can inform a conceptual metaphor to aid users in interacting with a more abstract conceptual target domain (Antle, Corness & Droumeva 2009, p. 240). These design principles are applied to an educational interactive audio system, the Sound Maker, which relies on bodily awareness and pre-reflective, automatic knowledge to structure musical learning experiences for children. Inspired by Dalcroze Eurhythmics (Jaques-Dalcroze 1930), the system encourages understanding of musical concepts through movement exercises. Evidence from an exploratory study comparing interaction with and without embodied metaphors reveals that the embodied metaphor interaction model is more intuitive for users (Antle, Corness & Droumeva 2009).

Donald A. Norman (2002) applies similar concepts in interaction design, emphasising that the mental model of the user must match the conceptual model of the system. Castagne and Cadoz (2002) reiterate this point by stressing the importance of a good mental model in leading the user to anticipate the results of their actions when using an interactive system, thus encouraging exploration. However, if the interaction becomes too predictable exploration potential can be compromised. This research continues to explore the potential benefits of applying conceptual metaphors in the design and refinement of mapping strategies that support intuitive interaction and understandings of movement in Chapter 5.

2.4.3 Feedback

Endeavours to complement auditory feedback with haptic or visual feedback within gestural interface design provides insights into the subject of how additional feedback can aid movement-based performance. The absence of haptic cues in open air gestural controllers has given rise to several solutions to tackle inconsistent control and ‘unrepeatability’:

> Because gestures are unconstrained, they are apt to be performed in an ambiguous or uninterruptable manner, in which case constructive feedback is required to allow the person to learn the appropriate manner of performance and to understand what was wrong with their action. (Norman 2010, p. 10)

Sile O’Modhrain’s doctoral research reveals that added feedback can assist beginners in learning and controlling air instruments (O’Modhrain 2000). O’Modhrain finds that theremins with introduced haptic feedback assist players in gaining a more concrete understanding of the instrument.

Rovan and Hayward (2000) have undertaken complementary work, extending an open-air glove controller with a tactile attenuator on the performer’s hand and feet “to explore the perceptual attributes of a simple vibrotactile vocabulary synthesised in response to a gesture” (Pedrosa & MacLean 2008, p. 24). More recently, Knutzen, Kvifte, and Wanderley (2014) have examined the possibilities of vibrotactile feedback for open-air music controllers. An informal user study indicates that vibrotactile stimuli can provide useful feedback and improve user experience (Knutzen, Kvifte & Wanderley 2014).

The tendency of designers to introduce tactile rather than visual feedback into systems may stem from the argument that traditional acoustic instrumentalists rely more on tactile feedback (Hunt & Kirk 2000). As discussed in Section 2.3.1, Non-tactile systems, Rovan and Hayward (2000, p. 7) warn against the implementation of visual feedback, citing difficulty in achieving repeatable results and the need for extensive training and specialised skills. They argue that when reaching for an absolute position in space, a performer will tend to adjust their movement gradually in response to feedback stimulus, resulting in lower accuracy.

However, tactile and haptic feedback can potentially restrict the physical movement of the user. Whether it be an open-air glove controller (Rovan & Hayward 2000), or Rodet, Gosselin and Mobuchon's (2005) PHASE project, which incorporates a force-feedback haptic arm, the performer must wear or manipulate an external object, potentially inhibiting their physical ability to perform other actions, such as play an augmented instrument with fine motor control or move freely about the stage.

2.4.3.1 Visual Feedback

In the absence of tangible and haptic feedback, added visual feedback can complement audio feedback in gestural systems. In Norman and Nielsen's (2011) general usability guidelines for gestural interfaces, they stress the importance of a graphical user interface (GUI) to promote discoverability. The absence of icons and menus can be problematic for gestural performers, who instead rely primarily on auditory and proprioceptive feedback. The presence of explicit visuals that reveal the system state may give the performer more freedom to explore, as they receive valuable information about how gestures are being interpreted during the interaction. By exploiting links between visual perception and proprioception (Gibson 1986), visual feedback can provide an opportunity to support the development of proprioceptive skills amongst musicians.

The importance of visual feedback in relation to DMI design is well established, particularly in the research of Sergi Jordà (2003a) and more recently, Perrotin and d'Alessandro's (2014) research, which indicates the usefulness of visual feedback in promoting performer expressivity and audience comprehension of mapping strategies in a gesture-based vocal performance, *Cantor Digitalis*. However the way in which visual feedback is designed in new interfaces for musical expression is still under theorised (Yang & Essl 2012).

James Gibson (1986) describes the centrality of movement in the act of visual perception, where locomotion, head-turning, eyeball movements and tiny, continuous adjustments to the lens, retina and related optical anatomy assist humans in perceiving and exploring their environment. Perception of self and environment thus go hand-in-hand. The way in which this link between visual perception and proprioception can be accentuated through the introduction of visual feedback, assisting the refinement of proprioceptive skills among musicians who perform with gestural interfaces, constitutes one of the themes of this thesis. The effectiveness of visual feedback as a design strategy is evaluated in an expert user case study in Chapter 6.

In addition to its functional aspects, visual feedback can also provide aesthetic enhancement to gestural performances. Video-enhanced musical performance can play a role in highlighting the physical actions and musical processes that result in sound (Brown 2006, p. 44). Visual feedback can become a way of exploring and emphasising sound and movement relationships while amplifying the physical presence of the performer, providing "an increased sensitivity to the role played by the eye in the perception of musical experience" (Brown 2006, 43).

Recent research has also demonstrated the effectiveness of visual feedback in assisting users to learn complex three-dimensional gestures through an interactive training system (Anderson 2014). Visual feedback offers the potential to "broaden the communication channel between the instrument and its player" by offering an illustrative, symbolic representation of system features that provides non-technical access to the interface (Jordà 2003a, p. 3). The capacity for visual feedback to present 'audio' feedback and movement data in visual form can encourage intuitive understanding and mastery of the interface, allowing simultaneous control of multiple parameters (Jordà et al. 2007, p. 3).

Visual feedback that reflects varying levels of intensity in a piece establishes multidimensional cues for the performer. This facilitates intuitive interaction and enjoyment for the musician. It also strengthens audience engagement by illuminating mapping strategies, helping observers understand the underlying musical processes behind a performance. The more unskilled the audience is, the more they rely on visual clues to understand musical intention and information (Davidson 1994), making it a potentially important feature in performances presenting new associations between movement and sound.

Another strength of visual feedback is amplifying the subtleties of movement that are sometimes lost in a passing performance. Visualising motion and audio data can magnify performer gestures during live performance, drawing out the details and character of existing visual cues for the audience. Sensors transform and simplify movement, making visualising a valuable exercise to depict this data in different ways to advance our understanding of how the machine interprets key movement qualities (Hansen 2013). Visual feedback thus becomes a way to nurture creative engagement, offering design tools to manipulate, repeat and rehearse aspects of gesture (Hansen 2013).

Creating digital tools to visualise movement data strengthens an artistic relationship to underlying ideas by bringing them to the surface (Hansen 2013, p. 144). Hansen (2013, p. 139) proposes that visualisations can expose the potentials contained in movement data. She sees visual feedback as a means of exploring digital embodiment through movement data and observing the impact of this process on interaction. Introducing a visual component to a gestural interface can thus be effective in teasing out selected elements and nuances of abstract movement data.

Abstracting movement data with technology began with the pioneering work of Eadweard Muybridge, renowned for his photographic studies of everyday human movement using stop-motion techniques with multiple cameras. Contemporary and collaborator Jules-Etienne Marey also focused on depicting the subtleties of human and animal motion with the chronophotographic gun, invented in 1882. His studies segmented movement into twelve individual frames, representing segmented motion in one photograph. The work of Muybridge and Marey represents the nuances of human motion by controlling and delineating time in such a way that its complexity is observable to the naked eye.

As mentioned previously, Krueger's (1983) artificial reality work, *VIDEOPLACE,* was the first interactive environment to incorporate gestural control with visual feedback through silhouette extraction of multiple users. Another influential designer of interactive environments exploring ways of connecting expressive human gestures and speech with audio-visual performance is Golan Levin (2000), whose meta-audio-visual instrument provides a basis for other artists and musicians to design their own customised instruments. The Audiovisual Environment Suite (AEVS] (Levin 2000) consists of six mouse-controlled artworks that enable artists and designers to generate and perform abstract animations in conjunction with synthesised sound (Levin 2005). The works aim to encourage personally expressive audio-visual performances that can be created, altered and deleted in a painterly manner.

Related works include performances that employ music visualisation techniques, including *Manual Input Sessions* (2004), a series of short audio-visual pieces that explore the expressive possibilities of hand gestures and finger movements through custom interactive software, and *Messa di Voce (*Levin et al. 2003) with Zachary Lieberman, Jaap Blonk and Joan La Barbara, which reconfigures every vocal nuance of two performers into interactive visualisations. The visuals depict the singers' voices and also serve as controls for their acoustic playback. The voice-generated graphics thus become an instrument with which the singers can perform body-based manipulations and additionally replay the sounds of their voices, creating a cycle of interaction that contributes to an atmosphere combining sound, virtual objects and real-time processing. Levin's works pursue infinitely variable creative possibilities, uniting technical and aesthetic design goals to explore the potentials inherent in audio-visual performance systems.

Another visual tool offered to digital artists is Sync (Hansen 2013), which visualises movement dynamics and isolates specific elements of continuous movement data to inform artistic explorations of movement and interaction design. Sync functions as an intermediary digital tool for engaging with transient and temporal movement data, making it more visible to the designer and artist: "For movement data, digital visualisations become a way of exploring material properties and particularities, such as velocity, repetition and so on" (Hansen 2013, p. 144).

In related work, Fraser Anderson (2014) presents the system, YouMove, which offers visual feedback that displays mirror representations and dynamic movement trajectory highlights to support gesture learning in HCI. System evaluations reveal that visual feedback provides an intuitive and natural guide for the user, thus lowering cognitive load.

Within the dance field, Shannon Cuykendall, Thecla Schiphorst and Jim Bizzocchi (2014) advocate the benefits of using images in performances to engage the audience more kinaesthetically, finding that iconic images can emphasise the subtleties of movement, potentially engaging a broader audience. This approach has also proven effective for Jordà (2003b) when projecting visual feedback of the Faust Music Online (FMOL) software onto a projector for the audience, in exposing the underlying musical processes to the audience without the need for program notes or extensive explanations.

To further improve the relationship between performer and audience in live computer-assisted music, Schloss (2003) argues that visual cues must be provided in order to highlight the relationship designed between gesture and sound. As discussed in Section 2.3, Gestural Systems for Musical Performance, he notes that visible effort is often associated with effective performances, as it illustrates performer engagement. Drawing on practical performance experiences with the Radio Drum in collaboration with composer David Jaffe, Schloss carefully considers the visual/corporeal aspects of performance, progressing gradually from simple to more complex modes of interaction to guide the observer through the performance in order to make it more convincing.

2.4.3.2 Kinaesthetic Feedback

As already mentioned, kinaesthetic feedback, an internal form of guidance directed by the felt sensation of one's own movement, is an important skill in non-tactile performance. This section examines the effect of conscious awareness on performer movements in gesturally augmented performance. The contribution of kinaesthetic awareness and maintaining conscious awareness of established movement patterns to the usability of gestural interfaces for musical performance is rarely considered in related design literature. However, these skills may offer a way of expanding levels of nuance available from gestural systems. To gain a greater understanding of this underexplored area, I draw insights from musical education approaches that encourage movement awareness and interaction design projects that emphasise self-awareness as a foundation for body-based interaction experiences (Nunez-Pacheo & Loke 2014).

Kinaesthetic awareness is regarded as an essential part of the experiential body of knowledge in the practice of dance or movement improvisation (Blom & Chaplin 1988). Lynne Anne Blom and L. Tarrin Chaplin (1998) describe the term as a primary perception and self-awareness of the body in motion. The body's proprioceptive system judges "spatial parameters, distances, sizes; monitors the positions of the parts of the body; and stores information about laterality, gravity, verticality, balance, tensions, movement dynamics" (Blom & Chaplin 1988, p. 18). They argue that awareness of movement grows through repetition and experience. Paying attention to and experimenting with different combinations of movement parameters through movement improvisation leads to increased sensitivity to felt sensations and an enhanced ability to produce and direct movement with greater subtlety and range (Loke 2009).

Noland (2009) also acknowledges the importance of kinaesthetic sensations that coexist with movement, which function on a different level from the meanings and functions of gesture in a cultural context. Within this kinaesthetic experience lies the capacity to transcend social conditioning, making way for new innovations in performance and cultural practice (Noland 2009, pp. 2-3). Noland views kinaesthetic awareness as a force that encourages experimentation and freedom from habitual socially acquired bodily practices (Noland 2009). She argues that kinaesthetic experience, or awareness of one's own movement, can foster experimentation, dismantling bodily habits and challenging cultural meanings through conscious behaviour modification. This focused attention reveals the agency involved in overcoming an established set of bodily practices (Noland 2009).

This sentiment is reiterated by dance therapist Mary Whitehouse (1995), who warns that individuals are prone to physical strains and distortions from a lifetime of "being assimilated to mental images of choice, necessity, value and inappropriateness" (Whitehouse 1995, p. 245). This danger can be avoided by moving in reaction to inner impulses rather than in ways that appear acceptable or aesthetically pleasing (Whitehouse 1995, p. 250). Danielle Wilde (2011) integrates this theme into the design of *hipDisk*, a wearable interactive device that deliberately induces experimental and awkward behaviour to encourage users' playfulness and hone their movement awareness.

Sheets-Johnstone also regards kinaesthetic awareness as a liberating creative force that is essential to the production and appreciation of performances (Sheets-Johnstone 2013, p. 3). This skill delivers greater understanding of movement dynamics characterised by qualitative features such as smoothness, intensity, swiftness and expansiveness (Sheets-Johnstone 2013, p. 21). Sheets-Johnstone emphasises the overall neglect of the experiential aspects of movement in research on embodiment and enaction, blocking a deeper understanding of movement (Sheets-Johnstone 2010, p. 217): “To attend in this deeper sense to the dynamics of our own movement is to be attuned to the qualitative character of our movement” (Sheets-Johnstone 2013, p. 21). The neglect of experiential qualities of movement is also evident in gestural interface design for music, where there is a tendency to overlook the proprioceptive and kinaesthetic senses of the performer.

Musicians, who have long relied on haptic feedback and the tactility of physical musical instruments, need to adopt more refined physical forms of musicianship to achieve more nuanced gestural control of sound. As previously outlined, visual feedback (Section 2.4.3.1, Visual Feedback) and embodied mapping models (Section 2.4.2.1, Embodied Mapping Metaphors) may contribute to an increased sense of internal movement awareness by assisting musicians to calibrate their actions in reaction to system responses. Another way to improve kinaesthetic feedback skills among musicians is to nurture new forms of musicianship by leveraging existing musical learning techniques and co-opting movement-based musical and dance education approaches that are discussed in the next section.

Movement-based approaches in music education and interaction design

Within vocal pedagogy, an emphasis on movement awareness is common, as physical awareness and mastery have a direct impact on a vocalist’s technique (Leigh-Post 2014). Another source of movement awareness education in the musical field is Dalcroze Eurhythmics, which employs physical exercises to facilitate understanding of musical concepts (Acitores 2011, p. 223). Teachers can, for example, sometimes assist students to understand the structure of a piece by involving them in a dance that enables them to feel the direction and pace of the piece directly through their own bodies (Acitores 2011, p. 223).

Dalcroze Eurhythmics emerged as a pedagogical method in early twentieth century performing arts, offering a series of exercises aimed at developing kinaesthetic awareness in musicians. Émile Jaques-Dalcroze (1965–1950), the founder of this educational approach, which links music and movement, offers techniques for visualising musical elements such as pitch, rhythm and intensity through physical movements (Mason 2012). Students are guided to physically express music while hearing it, by following rhythmic, melodic, form and phrasing contours. By experiencing music more holistically and physically, students are encouraged to become more creative and open.

Marilyn Wyers (2013) also employs movement exercises in musical workshops for performers. She discusses the initial self-consciousness that participants feel when undertaking physical musical exercises. When this feeling erodes over time, joyful engagement ensues. Wyers describes the concept of shaping sound, where workshop participants engage in:

> adjusting and adapting their movement to follow the dictates of the sounds on the piano's form establishing a bridge between themselves and the instrument, suggesting that the piano's form does not change during a performance but the form of a musician's body does. (Wyers 2013, p. 63)

Particularly during virtuosic passages, a pianist's body will morph according to pitch and rhythmic contours to master the technical difficulty of the section (Wyers 2013), or through tensing the muscles to make the performance appear effortless to the audience (Newland 2014). These transformations demonstrate the fluidity and deep level of physical engagement musicians feel during performance. Wyers endeavours to instil performers with more conscious awareness of these emerging patterns of movement.

Yet there are few educational guides for musicians to develop improved kinaesthetic imagination and motor control to aid in the control of gestural interfaces. There is little written on the subject of new musical skills required for gestural performance, with the exception of Jan Schacher's paper on hybrid musicianship (2013), which describes a course that aims to bridge existing instrumental practice with gestural musical interaction in a form of hybrid musicianship. Otherwise, most tertiary courses on digital music instruments tend to focus specifically on the basic concepts of design and building a customised system rather than on teaching musicianship skills for gestural performance (Schacher 2013).

The general lack of formal training opportunities and research dedicated to investigating musicians' sensorimotor skills and movement awareness in gestural performance indicates a gap that needs to be addressed in gestural interface design research for musical applications. The technical concerns of developing effective motion tracking, gesture recognition and mapping strategies tend to dominate the field, overshadowing requirements for the formulation of appropriate performance techniques to match rapid technical advances in the area.

The prevailing preoccupation with technical issues can lead to continual cycles of design iterations, where interface designs are rarely perfected and crafted into finished instruments. Waisvisz summarises the risks of this situation in terms of performance skills, experimentation and developing new repertoire:

> About my own experiences with gestural controllers I can only say that I fight with them most of the time. That's something that almost every

> instrumentalist will tell. But if you are in the position to be able to design and build your own instruments, and so many interesting technologies pop up almost weekly, you are tempted to change/improve your instrument all the time. This adds another conflict: you never get to master your instrument perfectly even though the instrument gets better (?) all the time. The only solution that worked for me is to freeze tech development for a period of sometimes nearly two years, and then exclusively compose, perform and explore/exploit its limits. (Buxton et al., 2000, p. 629)

The temptation to constantly refine designs can thus compromise creative development while also resulting in shallow systems that are often developed only for specific projects or performances. This issue is particularly prevalent for performer/designers of interactive systems, where conventional boundaries between instrument building, systems design and performance often overlap (Drummond 2009, p. 124), and where the creative process can become blurred with constant design improvements.

The embodied interaction design approach that frames this research considers a deeper understanding of the body's capacity and felt experience is central to decision making throughout gestural interface prototyping and application. This approach draws on dance and interaction design that privileges movement experience and awareness. Regarding the body as an instrument assists in targeting the essential criteria of greater sensitivity, nuance and subtlety in order to reflect the individual movement preferences and characteristics of performers.

Aaron Levisohn argues that prioritising the body is essential to advancing interactive design:

> By considering the body as a medium, developers of multimedia applications can begin to explore ways in which the kinaesthetic and

> proprioceptive senses can be manipulated to realise new modes of interaction. (Levisohn 2007, p. 4)

By looking to interaction design methods that encourage movement experimentation through improvisation, it may be possible to find ways for musicians to gain more ease and precision when venturing into more physical types of performance. Nunez-Pacheco and Loke (2014, p. 553) stress the capacity of self-awareness to shape interactive experiences that hinge on the body. They present a body-centred approach to wearable technology design informed by felt experience, emphasising the importance of self-perception in embodied interaction design.

The Bodybug system, which prioritises kinaesthetic awareness, is founded on Moen's kinaesthetic movement interaction (KMI) framework (Moen 2006). Rather than looking at the functions and actions of the body, attention is focused on understanding movement from an internal perspective and exploring its potential (Moen 2006, p. 20). The wearable device encourages the user to improvise and explore their movement potential, developing awareness of their movement patterns and preferences. Moen regards the lack of movement awareness as rife in our culture, arguing that "we need to gain knowledge of our body's limitations as well as possibilities in order to be able to experience and sense an embodied body" (Moen 2006, p. 21).

2.5 Performing with Gestural Systems

Funk and Coeckelbergh (2013, p. 125) identify three main areas of musical knowledge:

1. Theoretical knowledge, such as score reading and understanding harmonic structures and tablature;
2. Sensorimotor knowledge, or the ability to physically master instruments;

3. Perceptual knowledge, which involves embodied skills that facilitate sensory interpretation.

The second and third categories recognise the implicit knowledge inherent in a musician's performance of a piece beyond the details of a particular score. The close connection between these two types of knowledge is summarised in the acknowledgement that "when we know how to execute a movement, we usually also know how to realise a sensory perception that belongs to it" (Funk & Coeckelbergh 2013, p. 126).

Professional pianist Mine Doğantan-Dack (2011, p. 258) highlights the importance of investigating these kinaesthetic experiences and understandings. She undertakes a phenomenological investigation into how performers experience movement, their level of consciousness of this phenomenon, and the types of movements meaningful to the performer (Doğantan-Dack 2011, pp. 247-248).

In her analysis of live piano performance, Doğantan-Dack identifies links between the source of specific pianist movements and timbre. For pianists, the 'initiatory' gesture that precedes a key strike has the power to affect the timbre of that note. She recognises the gesture and tone as one and the same: "To be precise, it is not the attack that produces the sound, but the gesture bringing about the attack" (Doğantan-Dack 2011, p. 259). The hand anticipates the change, enacting kinaesthetic images and associated timbres ahead of time. This body memory and internal mind map of associations between gesture and sound directs a pianist's movement, reflecting the integration between formalised training and intuitive interpretation, commonly referred to as 'feel'. Through kinaesthetic sensations linked to different memorised tone colours, pianists develop a sense of 'touch' that distinguishes them from all other players (Doğantan-Dack 2011).

Leveraging these existing skills can be a valuable approach to ease the transition to gestural instruments. The use of internal imagery, a combination of kinaesthetic and auditory images that have been refined over years of practice and performance, is one technique musicians use to associate particular sounds with actions. This notion of imagery as a vital part of a musician's perception and development is echoed by Godøy's (2004) argument that musical imagery is reinforced by gestural imagery. The act of visualising or simulating gestures, Godøy claims, can support musicians in developing more movement mastery (Godøy 2004, p. 60). Godøy (2001, p. 241) defines musical or auditory imagery as a cross-modal combination of imagined auditory, visual and movement images.

The inner guidance evoked by these mental skills can be particularly useful when performing with non-tactile instruments. Drawing on motor cognition theory, Godøy associates gestural imagery in music with motor programmes, or mentally imagining an action or sequence of actions (Godøy 2004, p. 59). The potential of altering motor programmes has interesting potential in musical applications, where a performer can rehearse a sequence internally by focusing on different parts at various speeds, unrestricted by real-time reality (Godøy 2004, p. 59).

Within musical practice and learning, musical imagery is useful in reading, composing, expectation of sound and listening (Godøy & Jorgensen 2001; Saintilan 2008). It can form a bridge between sound and movement for the musician, similar to a technique dancers use when visualising the shapes their bodies form prior to executing the action, or when keyboard players perform at an imaginary keyboard on their desk to evoke established relationships between movement and internal sound in a written harmony exam (Odam 1995).

In a study of orchestral musicians, William Trusheim finds that:

> These mental representations are present for the majority of players in the form of auditory or kinaesthetic images, which have been painstakingly developed through years of practice and performance. (Rosenberg & Trusheim 1989, p. 64)

This method can aid in aligning the physical apparatus to the instrument during the warm up phase before a concert. In the case of wind players, this process involves the preparation and relaxation of the air column to produce a desired sonic result (Rosenberg & Trusheim1989).

Trusheim's study demonstrates that some musicians' mental representations of an ideal sound have visual, kinaesthetic or spatial elements (Rosenberg & Trusheim 1989, p. 65):

> These players have a very strong aural concept or image of the sound they wish to produce. This aural concept is important in guiding tone production and may be associated with sensations or perceptions of images in sense modalities other than auditory. (Rosenberg & Trusheim, 1989, p. 66)

The study reveals that this is an established technique for professional players:

> Many players begin by calling up an auditory image of a specific sound that they wish to produce and then strive to match that as they play. Others use a kinaesthetic image that guides them in achieving the proper "feel". (Rosenberg & Trusheim, 1989, p. 64)

This observation indicates the importance of incorporating kinaesthetic and spatial imagery into gestural instrument design to build on a technique that many musicians apply when envisaging actions in relation to sonic outcomes.

The development of internal imagery can assist a performer in developing a relationship with their instrument over time:

> It is no accident that musicians consider the “feel” of an instrument to be as important as its sound. What they describe in an instrument’s “feel” is how it responds to their actions, that is to say the consistency with which they can predict the relationship between actions they perform and the corresponding sounds that are produced. (O’Modhrain 2000, pp. 81-82)

Feel can be built up from a combination of muscle memory and visual imagery developed over many years of training and practice (O’Modhrain 2000). In her studies of theremin performance with introduced haptic feedback, O’Modhrain discovers that novice musicians rely on feedback to inform their interaction much more than expert performers, who have developed inbuilt mental representations and motor programs to guide their movements (O’Modhrain 2000, p. 31). This finding demonstrates the significance of introduced feedback during the early stages of gestural interaction and system learning.

I argue that another way to develop the feel of gestural systems is to focus on the musician’s physical and sensorimotor skills. Scientific research on sensorimotor integration, or the co-ordination of sensory information with motor behaviour, has largely focused on visuo-motor integration rather than audio-motor integration, which musicians tend to rely on:

> With a few important exceptions, research on the brain and music has focused on how we perceive and process music from the external perspective of the listener, rather than from the internal perspective of the performer, thereby overlooking the effect of one’s own voice when singing on spatial cognition (i.e. proprioceptive knowledge of one’s own place in

> space) and bodily kinaesthetic intelligence in general. (Leigh-Post 2014, p. xv)

Yet it is essential to gain a deeper bodily awareness, defined by Karen Leigh-Post (2014, p. xv) as “an ability to integrate sensations from the environment and ourselves with our immediate goals to guide behaviour”, in order to effectively utilise gestural systems for performance.

The deficit in kinaesthetic awareness amongst musicians is evident in the amount of injuries suffered by professional musicians from classical and rock backgrounds. This situation has prompted initiatives aimed at preventing physical problems in trained musicians early in their careers, such as the Australian National Academy of Music’s *Fit to Play* program (Smith 2014). When our kinaesthetic abilities as musicians increase, this drives more targeted design, which addresses evolving sensory skills.

One way of refining kinaesthetic awareness is through movement improvisation (Moen 2006, p. 29). Blom and Chaplin describe movement improvisation as a spontaneous and exploratory process unsuppressed by internal censorship (Blom & Chaplin 1988, p. 6). It is a process accessible to anybody, not only to trained dancers. Even with amateurs and reluctant movers, it can yield beneficial results according to Jin Moen, who argues that:

> it requires a kinaesthetic awareness and an ability to be one with the material from which you create, namely your own body and its movement. This ability and awareness is possible to train through physically experiencing dance improvisation, and thus gain an increased understanding of the aesthetic potential of dance and human movement. (Moen 2006, p. 30)

Blom and Chaplin consider the knowledge that emerges from dance to be intuitive. When discussed and shared, it moves to a conscious level (Blom & Chaplin 1988, p. 16). Participating in dance practice highlights the knowledge that can be gained from this physical discipline: "A trained dancer learns to circumvent everyday movements, to detach herself from them and to create new patterns and variations thereof" (Schacher & Stoecklin 2011, p. 293). This more deliberate and aesthetically-motivated approach to movement distinguishes dancers from other types of performers, constituting a valuable skill that can inform gesturally-controlled musical performance.

The benefit of involvement in dance improvisation for musicians and composers is also echoed by Karlheinz Stockhausen, who advises musicians to dance to music regularly without inhibition as part of their musical practice:

> [G]esture and dance are at the origin of music, and I certainly want to bring music back to that condition of ritual where everything you see is as important as what you hear, and not only the actions of producing sound, but also those creating the music-theatre. (Stockhausen, cited in Maconie 1989, p. 145)

Choreo-musical research forges such links between dance and musical theory (Jordan 2011). This area of study into the relationship between music and dance offers insights into connections between sound and movement in any performance genre (Mason 2012). The methodology behind Stephanie Jordan's (2011) choreo-musical analysis uses rhythm as the basis for comparing music and dance:

> Rhythm is an immediate point of contact between the two art forms. As a phenomenon, it can, after all, enter through both the eye and ear, and in both

> cases it reaches us in a part of the brain connected with motor function, at which point it is decoded as rhythm. (Jordan 2011, p. 52)

The unifying influence of rhythm poses implications for gestural composition and interface design, where parallels can be drawn to suggest potential associations between movement and sound. Analysing music and dance in conjunction offers powerful insights that enrich evolving corporeal understandings in music theory, according to Jordan, who finds that:

> embodiment through performance and somatic engagement, is an area where dance can offer something important to music, or at least reinforce the ideas about embodiment that increasingly interest musicologists. (Jordan 2011, pp. 56-57)

Dance research can help establish understandings of a performer's physical engagement in gestural interaction, particularly in the absence of a tangible musical instrument.

The choreo-musical approach is central to Newland's piano performances, providing choreographic inspiration for the performance, *Woman=Music=Desire* (Newland 2014). Although the variability of performance styles between musicians makes them difficult to quantify scientifically, these same differences make them ripe for creative interpretation (Newland 2014, p. 154). As discussed in Section 2.3.2, Body as Instrument, Newland's collaboration with dancers who transform her movements during piano performance into choreographic sequences leads to an extensive process of self-reflection. Newland (2014, p. 155) is able to observe her own movements reformulated and embodied by others with a detachment that helps to accentuate her physical relationship between music making and expression. This blending of choreographic and musical approaches can inform gestural interface design through cross-disciplinary research into movement-based art.

2.5.1 Design Considerations

When making sounds ‘in the air,’ proprioceptive and kinaesthetic skills are paramount. Although commonly discussed in dance and vocal training, these skills are not emphasised as strongly in the electro-acoustic music tradition.

When playing the theremin, phrasing is deliberately controlled by interrupting and lowering the amplitude with the left hand, leading to a constant interaction with the right hand, which regulates frequency. Phrasing is not influenced by physical elements like the fixed length of a string instrument or the breathing capacity of a wind performer or vocalist. This leads to the challenge of sensing the correct spatial position to attain a certain pitch, due to the absence of haptic feedback.

Precision and speed is required to avoid an unintended portamento effect. Therefore, theremin players need a heightened ability to detect position in space, or proprioception, and the kinaesthetic skill of controlling the weight, direction and magnitude of their movements (Mandancini & Sapir 2012, p. 2). Marcella Mandancini and Sylviane Sapir compare the theremin’s imaginary control surface with the Kinect interface, drawing on theremin playing technique to explain the new skills needed by users of such systems.

In *Method for the theremin*, Clara Rockmore (1998) suggests that a sense of delicacy be applied to performing in the air, likening the fingers to butterfly wings. Even the act of tuning the instrument relates directly to the body, with Rockmore recommending that the player “[t]une to your own body capacity”(Rockmore 1998, p. 13) which is defined by the individual’s vertical movement range.

To hit the correct note she suggests, “aiming not only for the **desired note**, but the very **centre of the note**” to avoid the glissandi effect produced by more inexperienced performers. Rockmore envisages the theremin as one long string of the violin, as mentioned in an interview with Robert Moog (1967), drawing on her instrumental background as a violin virtuoso.

These parallels between playing technique for the theremin and remote sensors such as the Kinect provide a useful context for design approaches that address the need for enhanced kinaesthetic awareness and improved motor skills among musicians in order to achieve sufficient nuance and subtlety during movement-controlled performance.

In a design context, experience of physically experimenting with movement and mappings between gesture and sound can provide a solid grounding for embodied and individualised interaction design. This notion of ‘thinking though the body’, prominent in Sheets-Johnstone’s (1999) work, is extended into the interaction design realm through collaborative design projects to re-sensitise the body through increased movement awareness (Loke et al. 2013). Similarly, in relation to gestural system design, this approach can stimulate new physically grounded design ideas and help solve persistent problems such as how to create intuitive mappings.

The implication for designers is to actively participate and experiment with movement and reflection at many stages in the design process: “It is important for designers to know whether first-hand motor involvement matters as much as common sense claims” (Kirsh 2013, p. 25). Advocates for direct physical interaction with designs as they evolve include Hummels, Overbeeke and Klooster (2006, p. 677), who argue that “one has to be an expert in movement, not just theoretically, by imagination or on paper, but by doing and experiencing while dancing”.

Musicians rely on certain techniques grounded in physical experience to master or develop a feel for an instrument — sometimes relying on mental imagery or metaphors, and at other times physically practicing specific aspects of a performance to master technically challenging elements in isolation. A similar technique called ‘marking’ exists in dance, which amounts to performing rough versions of choreographic sequences (Kirsh 2013). David Kirsh’s research into this common dance technique, which involves imperfect enactments of movement sequences during rehearsal to aid in learning new choreographic material, indicates the value of enacted movements in the learning and rehearsal phases of movement-based performance.

Imagined movements can also prove useful in these preparatory stages. With regard to using internal visualisations, “[m]ental images, just as gestures and simplified movements [are], are fast and flexible” (Kirsh 2013, p. 6). In certain contexts, internal visualisations can help a performer more than what Kirsh terms embodied models or pronounced movements; for example, when mentally preparing for a performance or helping achieve a particularly technically challenging and strenuous passage. Kirsh finds that expert dancers consider marking to be more effective than mentally simulating movement or practicing with overt, perfected movements. Dancers find this technique particularly useful for perfecting complex and detailed dance phrases.

Kirsh attributes this finding to dancers' feeling the movements kinaesthetically, demonstrating the effectiveness of cognition reinforced through bodily experience:

> because the act of creating an external movement provides a physical anchor for the dancers to project their full movement onto. This physical anchor carries some of the weight of imagination and helps dancers to think more effectively about the aspects of their movement that they are trying to improve, recall, or practice. (Kirsh 2013, p. 22)

This technique enables dancers to isolate and focus on different qualities of their movement, allowing them to systematically master more detailed tasks. The advantage of enacting movements, rather than learning through observing, is in the detail dancers can achieve through their embodied awareness:

> kinaesthetic perception reveals different properties than visual perception, and these kinaesthetic properties, because of the way they are encoded, make it easier to recognize the validity of inferences that would be near impossible to infer from vision alone, if one did not also move the body. (Kirsh 2013, p. 30)

Kirsh believes that the significance of overt movements can be applied to other creative practices and design contexts. Building on these understandings of the links between external and internal simulation can advance further design efforts incorporating physical movement (Kirsh 2013).

The inferiority of visual perception in capturing the depth of movement qualities compared to direct physical enactment, Kirsh asserts, is due to the absence of

> phenomenologically prominent features that arise when we interact with objects, or work with objects, or work with our bodies. But they are mostly invisible visually. We feel more than we show. And when as observers we see something subtle we may be misled. (Kirsh 2013, p. 26)

Kirsh's findings highlighting the importance of physically engaging in movement to refine choreographic mastery can also be applied to design methods for gestural music systems. These methods may include experiential approaches to mapping, in which performers physically experiment with rudimentary mappings between sound and movement during rehearsal and gestural system customisation to discover more coherent and meaningful mappings while refining their movement skills.

2.6 Conclusion

This chapter has explored the myriad of gestural interface design approaches for musical performance and the challenges performers face when entering into the field, particularly those with no prior programming or movement training. While there is much research into motion capture, gesture recognition and gesture–sound mapping techniques, less is known about how performers engage with gestural interfaces and the types of skills needed to achieve nuanced and fine-grained control with existing or adapted systems. To address this gap I consulted dance and body-centred interaction design perspectives (Moen 2006; Loke 2009; Larrsen et al. 2007; Schiphorst, 2009; Hansen, 2013) to discover movement exploration and self-awareness approaches that could be applied to improving the accessibility and viability of gestural systems for musical performance.

Chapter 3: Methodology

3.1 Research Influences and Questions

In this chapter I introduce the primary methods underlying this investigation into the influence of gestural interaction on musicians' experiences. The methodology of this practice-based research combines several interdisciplinary theoretical and analytical threads, including embodied cognition, phenomenology, and music and gesture theory. Within this framework, methods to examine the nature of musicians' experiences of gestural control are drawn from the related fields of interaction design within the HCI, arts and dance contexts.

This research is founded on first-hand experiential accounts of my own practice and that of practicing musicians. The research design encompasses qualitative methods, including interviews and participant observation. A central aspect of these activities involves creating a prototype gestural performance system to identify the creative applications and practical challenges of movement-based musical control. Through a series of works and performances, the system is developed and refined using an iterative design approach. The insights from my performance experiences contribute to an autoethnographic account that incorporates the principles of reflective practice and performance inquiry. To complement personal reflections as a performer and designer, an expert user case study provides additional insights into the experiences of musical experts in performance and production. This hybrid approach highlights the importance of diverse creative practitioner perspectives in understanding movement-based performance.

My primary research goal was to discover areas in which gestural systems designed for musical performance may be improved to ensure increased accessibility and longevity. In order to reach that goal, the research activities were structured according to the following aims:

- Explore the influence of gestural interaction on my own performance practice;
- Design a gestural performance system for the augmentation of voice, instruments and control of virtual instruments;
- Examine the ways in which expert users interact with the system.

The overall research questions framing this investigation are:

1. What are the main control features that characterise effective gestural systems for musical performance?
2. How do musicians integrate gestural interaction into their existing performance practice?
3. What design strategies can be applied to improving precision, explorability and nuance in gestural systems for musical performance?

The research aims were addressed in relation to three main research phases. First, a set of exploratory works was composed in conjunction with an initial gestural system prototyping stage. Second, an expert user case study was conducted to investigate users' experiences with the resulting system. Third, a new iteration of the system informed by this feedback was developed and evaluated through performances.

As Figure 5 shows, each research activity impacts upon the others through an iterative process inspired by reflective practice (Schön 1996). In a process of action, critical reflection and refinement, the research questions initiated the inquiry and influenced the selection of research methods. Developing a workable gestural system prototype played a significant role in shaping initial performances. The experiences gathered during the performances in turn influenced adjustments to the design, as did feedback from musicians during the expert user case study. This iterative approach is particularly relevant to practice-based research in art and design, contributing to a deeper understanding of the creative process through self-examination and reflection (Scrivener & Chapman 2004).

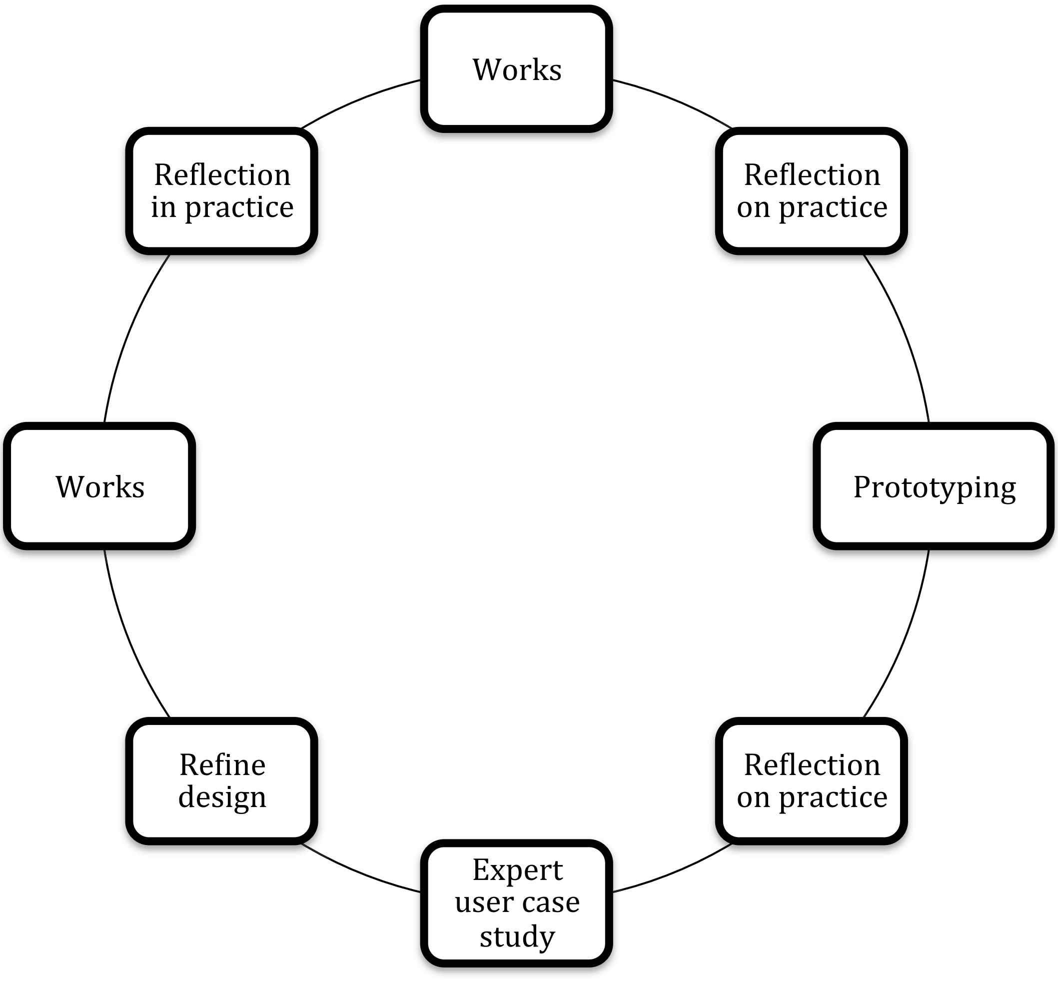

Figure 7: Summary of research activities

The following section outlines the rationale for the chosen theoretical framework and related research methods.

3.2 Theoretical Framework

As I am seeking information about the lived experience of gesture, the research methods chosen have a deliberate experiential focus. To research the temporal and transient subject of gestural interaction in performance, I examined my subjective first-hand experiences through gestural system design and performance before seeking broader insights from potential users within an embodied philosophical framework. These activities were conducted and analysed through the lens of phenomenology, embodiment and embodied interaction design, informed by critical reflection of movement experiences (Shusterman 2009).

3.2.1 Phenomenology

Phenomenology focuses on the study of human experience. In uniting mental processes with physical experiences, it offers a suitable framework for researching the potential of gestural control in performance. Phenomenology first emerged in the works by German philosopher Edmund Husserl, *Logical investigations* (1901) and *Ideas: general introduction to pure phenomenology* (1962). The theory of phenomenology seeks meaning from experience and intuition, favouring the subjective. It focuses on attaining a deeper insight into the nature or meaning of everyday experiences (Van Manen, 1990). Departing from previous philosophical traditions that pursued universal and objective truths, phenomenology regards sensory and intuitive attributes as the core of consciousness (Nelson 2009). This emphasis on sensory and highly individual approaches makes phenomenology a popular framework for creative researchers in music and performance (Nelson 2009, p. 58).

The notion that our understanding of the world emerges from our corporeal nature underpins Merleau-Ponty's work, *Phenomenology of perception* (1999). Extending Husserl's concept of lived experience, the world of immediate experience prior to reflective or critical thought, Merleau-Ponty regards perception as the means by which embodied beings are situated in the world. Rather than being an object of the world, the body forms the basis of our communication with it (Merleau-Ponty 1999).

Sheets-Johnstone builds on Merleau-Ponty's work by adopting a phenomenological analysis of movement. In her book, *The primacy of movement* (1999), Sheets-Johnstone highlights the felt qualities of human movement, which are perceived through the kinaesthetic sense. She argues that in becoming attuned to these qualities by performing free variations of habitual movements, a greater awareness can be gained of our movement patterns (Sheets-Johnstone 1999, p. 143). Attention to feelings associated with movement, "which include a bodily felt sense of the direction of our movement, its speed, its range, its tension" (Sheets-Johnston 1999, p. 56), can advance our understandings of our bodies and how we move in the world.

Another theorist who supports the extension of Merleau-Ponty's focus on "re-achieving direct and primitive contact with the world and endowing it with a philosophical status" (Merleau-Ponty 1999, p. vii) is the pioneer of somaesthetics, Richard Shusterman (2009). Somaesthetics is a pragmatic discipline that draws on somatic practices such as Feldenkrais and Alexander Technique to deliver more satisfying experiences through enhanced somatic functioning (Mullis 2006).

Shusterman promotes somatic awareness as a method for improving action and performance by reconstructing habits and embracing different types of bodily behaviour. He characterises 'soma' as "the living, sensing, dynamic, perceptive body that lies at the heart of the project of somaesthetics" (Shusterman 2009, p. 133). In opposition to Merleau-Ponty, who favours spontaneity as an effective and uninterrupted way of allowing the body to guide us through everyday life, Shusterman argues that spontaneity must be balanced with conscious awareness in order to overcome any repetitive behaviour that may hinder our experience (Shusterman 2009, p. 135).

Whereas Merleau-Ponty describes spontaneous and habitual behaviour as primal, based on the body's capacity that "guides us among things only on the condition that we stop analysing it and make use of it" (Merleau-Ponty 1964, p. 78), Shusterman (2009, p. 135) recognises that, without critical reflection, these same habits can result in a damaging misuse of the body if not executed in a manner that is harmonious with it.

Van Manen addresses the challenge of capturing the complexity of lived experience, relying on the concept of 'pathic knowledge' to describe aspects of professional knowledge that incorporate a felt sense of being in the world (Van Manen 2007, p. 20). His idea of pathic knowledge relates to a felt sense of being in the world or "aspects of knowledge that are in part prereflective, pre-theoretic, pre-linguistic" (Van Manen 2007, p. 20). Rather than reverting to calculative thought, sharing experiential stories can provide a means of reflecting on professional practices.

The pathic dimensions of practice exist in our bodies, preconceptual relations to the things of the world, our relations with others and our actions (Van Manen, 2007, 22):

> Even our gestures, the way we smile, the tone of our voice, the tilt of our head, and the way we look the other in the eye are expressive of the way we know our world and comport ourselves in this world. On the one hand, our actions are sedimented into habituations, routines, kinaesthetic memories. We do things in response to the rituals of the situation in which we find ourselves. On the other hand, our actions are sensitive to the contingencies, novelties, and expectancies of our world.

This concept links to the phenomenon of embodiment, characterising a type of knowledge that is inherent not only in the routines, habits and motor skills of the body, but also in the way we do things or the 'feel' we have for a certain place or experience (Van Manen 2007, p. 21). This pathic understanding provides access to "the experiential, moral and personal dimensions of professional life" (Van Manen 2007, p. 22), establishing a suitable framework for studying the subtleties of physical experiences in the area of gesturally-controlled musical performance.

Within this specific area, performer and researcher Doğantan-Dack (2011) addresses the phenomenological challenge of representing how performers experience bodily engagement during musical performance. Her quest to find methods to convey this embodied knowledge in written text is directly relevant to my own attempts to communicate insights derived from physical involvement in musical performance.

Through this approach, connections between bodily gestures, the kinaesthetic sensations associated with them, and resulting timbral and melodic shapes can highlight potential connections between performer actions and resulting sounds. Doğantan-Dack

(2011) notes that the feelings performers experience when making specific gestures are not commonly acknowledged in performance studies. Yet this somatic dimension is particularly important in the context of gestural interface design, where the documentation of performer experience can inform a new understanding of relationships between movement and music.

3.2.1.1 Embodied Interaction Design

The recognition that all human actions are embodied actions is central to recent trends in interaction design (Loke 2009) — sometimes considered the 'third wave' of HCI (Harrison, Tatar & Sengers 2007) — which incorporate aspects of ethnography, embodiment and phenomenology. Paul Dourish (2004) highlights the benefits of embodied interaction in leveraging innate human abilities to allow users to grasp an interaction without prior training. His comprehensive overview of embodied approaches in interaction design (Dourish 2004) is reflected in the research of movement practitioners in the field, including Larssen et al. (2007) and Schiphorst (2009). In related work, Loke (2009) draws on ethnographically-inspired and phenomenologically-informed design, emphasising the value of first-hand, first-person perspectives and experiential data in designing technology that incorporates human movement (Loke 2009).

Levisohn and Schiphorst (2011, p. 108) provide a compelling argument for embodied interaction approaches to designing computer systems, arguing that

> By better understanding theories of embodiment, designers of computer systems have the opportunity to transform interaction, increasing engagement, improving the fidelity of communication, and supporting human cognition and emotional well-being.

My research examines similar benefits, investigating the transformative impact of gestural interaction in musical performance from an embodied perspective, particularly in relation to the changing status of the body as it assumes the role of instrument in non-tactile interaction.

Research supporting the importance of movement awareness in somatics, dance and interactive dance is used to affirm the body's central role in gestural interface design. The field of somatics is primarily concerned with promoting movement awareness through an acknowledgement of related felt sensations within the body, stemming from a first-person perspective (Hanna 1988). A focus on using experiential accounts to inform gestural design improvements can thus add to understandings surrounding the movement experiences of musicians in interactive contexts.

3.3 Research Approaches

I am particularly interested in user experience, which makes the participant observations and interviews of the expert user case study an important aspect of gathering first-hand impressions of expert musicians encountering a sample gestural performance system for the first time. The qualitative approach of this research complements a performance ethnography component in which I document and analyse my own experience as a performer/designer performing with the system over a three-year period.

3.3.1 Performative Research

The research methodology is framed within two strands of performance-led approaches — performative inquiry and performance ethnography. Performative inquiry is a term first introduced by Lynn Fels (1999) to denote the spontaneous insights that emerge during performance. This form of investigation embodies a balance between critical and creative action, borrowing from the tradition of reflective practice, which is linked to a set of research practices including action research, self-study and autoethnography (Griffiths 2011, p. 184). Haseman (2007, p. 151) distinguishes performative research as a separate research paradigm to quantitative and qualitative research, differentiated by its reliance on symbolic data that includes material forms of practice, from music, images and sound to performance and software code.

The relatively new field of performative social science has emerged over the past two decades and is still in its developmental stages (Gergen & Gergen 2011). It provides a scientific context in which to investigate the complexities and subtleties of a range of art forms, including music, dance and multimedia applications (Gergen & Gergen 2011). Unlike traditional social science writing, performative branches of social research such as performance ethnography and autoethnography can accommodate a range of perspectives and individual artist orientations:

> Performance ethnography embraces the muddiness of multiple perspectives, idiosyncrasy, and competing truths, and pushes everyone present into an immediate confrontation with our beliefs and behaviour. (Jones 2006, p. 245)

Doğantan-Dack (2012, p. 34) argues that live performance constitutes a site of knowledge production. Discovering how this knowledge contributes to performer learning on stage, and the most appropriate methods for documenting and analysing it, are the two main issues she addresses in relation to live musical performance. Doğantan-Dack considers this an under-researched area of contemporary music performance studies, even though it is important that the perspective of performer-researcher is represented and contributes to the performer-oriented discourse on live music-making. In her view, psychological and quantitative studies of musical performance tend to depersonalise the performer’s voice, leaving little room for experiential insights generated during the live event:

> The insider’s view on what happens in a musical performance – and why – can be brought to light only through a discourse that takes account of and thrives on the situatedness and the very subjectivity of the aesthetic judgements made by the performer in relation to his or her performance. (Doğantan-Dack 2012, p. 37)

As live performance research is in its early stages, researchers are still discovering the most suitable research methods. Obtaining audio-visual documentation is a common starting point; however, the recorded event needs to be contextualised through multimodal methods to preserve its liveness (Doğantan-Dack 2012, p. 40). One method Doğantan-Dack advocates for capturing the performer’s claims to knowledge and associated feelings is narrative autoethnography, which is discussed in the next section.

When observing videos of performances, the performer acquires a new sense of distance, savouring the audience perspective. Internal thoughts and bodily sensations become secondary to the visible and aesthetic elements of the event. This provides material for reflection and a basis for evaluating the effectiveness of the performance in reaching aesthetic and conceptual goals. Combining these observations with autoethnographic writing allows both dimensions to inform one another.

The methodology for this thesis is structured according to reflections on process, facilitated by documentation to capture the first-person moment that can be used to interrogate practice (James 2003). Anne-Marie Forbes (2014, p. 271) asserts that "[t]he nexus between research and musical performance is built through reflective practice" as defined by Schön (1996). To keep expanding practice, Schön recommends engaging in reflection-in-action and reflection-on-action to:

> [s]urface and criticise the tacit understandings that have grown up around the repetitive experiences of a specialised practice, and can make new sense of the situations of uncertainty or uniqueness which he may allow himself to experience. (Schön 1996, p. 61)

In a case study illustrating performative research approaches, Brad Haseman (2007) outlines theatre director David Fenton's research relating to a creative work-in-progress that employs reflective methods such as improvisation, pre- and post-performance journalling, video recording and editing. My research incorporates similar documentation methods, including the use of artistic and design journals to record preparation for performances, design iterations, and phenomenological observations after performances (Van Manen 1990). The purpose of these journals is to capture immediate reflections and provide a central place to gather insights from reflections on unfolding actions (Schön 1996; Forbes 2014, p. 275).

Summaries of spontaneous insights during the compositional process were documented in an artistic journal; recording lyrics, ideas conceived during design and development, performance preparation and post-performance feelings combined with any feedback or comments offered afterwards by audience members.

A separate design journal was maintained for detailing creative work in progress and mapping ideas, all program patches, results of compositional exercises and recordings incorporating gestural experiments, to obtain insights into the types of mappings that promote precision and exploration. The journalling process eased the challenge of articulating this newly-evolving embodied knowledge, providing a context for exploring suitable language to explain physical, tacit and experiential insights (Stock 2014, p. 301).

To communicate the meaning or the temporal experiences of gestural interaction, beyond summarising a collection of body forms, postures and trajectories, it is necessary to develop a language that adequately depicts the depth of the experience:

> A performative orientation invites the writer to explore the potentials of the medium, including, for example, irony, metaphor, humour, and more. While traditional writing seeks to bring the full content into a logically coherent whole, a performative orientation invites explorations into ambiguity, subtle nuance, and contradiction. (Gergen & Gergen 2011, p. 295)

These details and blurred areas are not fully represented in traditional forms of scientific writing, Gergen and Gergen (2011) argue, paving the way for more creative and exploratory approaches where the act of writing itself becomes an inherent part of the investigation (Richardson 1994).

3.3.2 Autoethnography

Autoethnography, where personal feelings and experiences form a major contribution to written research, has become a significant path to researching wider social phenomena (Reed-Danahay 1997; Ellis 1999; Spry 2001; Ellis & Bochner 2000, 2006; Anderson 2006; Denzin 2006a; Chang 2008; Bartleet 2009; Bartleet & Ellis 2009). The personal experience of the researcher becomes a form of data that is analysed in relation to the cultural context in which the analysis and interpretation takes place. By linking personally-motivated research to wider social phenomena, the pitfall of lapsing into self-absorption (Geertz 1998) can potentially be avoided.

According to Ellis and Bartleet (2009, p. 9), “[m]usicians and autoethnographers grapple with the challenges of communicating and writing about their lived experiences”. Within the style of evocative autoethnography is the potential to produce dynamic writings that fully communicate the richness of musical experiences, beyond dry scholarly descriptions. The autoethnographic paradigm also enables a focus on the physicality of music-making and the centrality of the body. Like Ellis and Bartleet (2009, p. 12), I want the personal parts of music, including emotions, intuition and bodily sensations, to emerge in my writing and performances.

Leon Anderson (2006, p. 380) identifies multitasking challenges for the autoethnographer acting as a participant observer in a fieldwork setting. The act of constantly recording their actions can distance the autoethnographer from embodied phenomenological experience. This divided focus can inhibit full immersion in performance, creating a conflict between the need to document and experience the feeling of ‘flow’, a phenomenon examined in Mihaly Csikszentmihaly’s book, *Creativity: flow and the psychology of discovery and invention* (1996). It is important to be mindful of the impact this can have on interactive performance. Assuming a more analytic and self-conscious role can affect the level of involvement compared to other participants (Anderson 2006, p. 382). For this reason, I attempted to limit my observations to the end of performances, reserving note-taking for the pre-performance rehearsal stage and post-performance video analysis, where a degree of distance could be achieved from the creative event.

My work is also related to action research established by Schön (1996), where a focus on developing understandings as a practitioner is commonly called self-study (Bullough & Pinnegar 2001) or autoethnography (Reed-Danahay 1997; Bochner & Ellis 2002). In seeking insights that advance my performance practice, my research is a case study of practitioner learning in which insights are gained from different professional contexts (Herr & Anderson 2005). By reflecting on performance experiences, these insights inform iterative design cycles that shape and influence the application of gestural systems in my creative practice.

Studies investigating performance movements from a performer's perspective are rare (Doğantan-Dack 2011), though a number of autoethnographies documenting artist and artist/designer experiences in the field of live electronic music are relevant to this study. Of particular relevance are Jon Bowers' ethnographic account, involving a participant-observational study of a series of improvised electro-acoustic performances (2002), and Thor Magnusson's experiences as a live coder (2014).

Bowers (2002, p. 43) systematically reviews his performance experiences, providing detailed insights into the feelings of improvising with sometimes unpredictable machines and unexpected events, "negotiating the manifold contingencies of place, technology, programming and preparation". His observations of audience and collaborator responses evoke a sense of resonance in the reader, providing insights into the often hidden activities underlying the organisation and performance of electro-acoustic music (Bowers 2002, p. 52).

In the specific gestural performance field are Sarah Nicolls' (2010) documentation of extended piano performance and Doğantan-Dack's phenomenological approach to studying piano movements. These autoethnographic accounts demonstrate the contribution of reflective first-person accounts to in-depth understandings of performer experiences that are not as directly accessible through objective scientific methodologies (Magnusson 2014).

The implicit knowledge that emerges from personal insights (Polanyi 2009) can be made explicit within the autoethnographic method (Magnusson 2014). My decision to embrace this method was based on a desire to capture reflections on the creative process and associated physical experiences, drawing on rich, individualised accounts.

It is also important to complement and establish links between existing third-person accounts into performer gesture and musical interaction design (Varela & Shear 1999). As discussed in Chapter 2, a comprehensive range of motion tracking studies investigates the visual appearance and quantitative data derived from performer gestures. The findings from this research can be further enriched by creative practitioner perspectives, contributing to the first-hand performer and designer accounts with sensor-based instruments exemplified by the work of Waisvisz (1999) and Tanaka (2000).

The reflective journalling process that drives these accounts contributes to the formulation and refinement of evaluation criteria for the expert user case study in my research. Other autoethnographic methods I have used include recording and reflecting on performance and composition experiences with the aid of videos, sound recordings and photographs (Bartleet 2009).

Musical and video analysis of recorded performances is conducted to ascertain the effectiveness of specific mapping strategies in achieving desired sonic results and interaction experiences, and in highlighting direct correlations between movement and sound in real-time performance situations. The reliance on recorded material keeps the data ‘fresh’, facilitating recall of performance memories with sufficient detail and a lack of distortion (Bartleet 2009).

Finding ways to articulate first-person insights derived from emerging embodied knowledge forms a significant part of Doğantan-Dack's (2011) research. It is also an important part of dance ethnography and performance studies. This challenge is prevalent in structuring my activities and articulating insights from practice-based research. Discovering appropriate terminology and language to categorise and analyse my movement experiences became a constant challenge throughout the research process.

Jin Kjölberg (2004) stresses the importance of exploring first-hand experience within dance practice for designers of movement-based interfaces. She sees direct involvement in artistic dance movement as a distinct advantage in making designers more aware of the potential of bodily communication. Kjölberg's research offers one example of the various dance-based studies that provide common terms and concepts for comprehensively describing and analysing interactive movement experiences. Research that embraces first person methods to investigate embodied interaction and experiential design within the dance field is highly influential in the language and approaches I have adopted throughout this research (Schiphorst & Anderson 2004; Moen 2006; Loke 2009; Wilde 2011).

3.3.3 Prototyping Methods/Iterative Design

The prototyping that underlies this research is part of an iterative design process that evolves in conjunction with artistic development. Iterative design relies on prototyping to advance designs in a cyclical way, so that each cycle contributes to refining the design's development (Elblaus, Hansen & Unander-Scharin 2012).

The work of Bau, Tanaka and Mackay (2008) provides methods for exploring sound and interaction through the processes of participatory design and technology probes. Their work also draws on the instrument-building approach common in NIME, where open-ended instruments are developed to enable the realisation of single or multiple compositions.

Ferguson and Wanderley (2010) present further insight into prototyping in an interdisciplinary context. Complementing the large body of research on the technical aspects of DMIs, they seek to advance the musical application of DMIs through the McGill Digital Orchestra project, exploring the impact of adequate rehearsal time with stable versions of software. Their approach draws on the combined skills of an interdisciplinary team of composers, performers and instrument designers to promote viability and longevity in design.

Ferguson and Wanderley (2010, p. 22) note the significant gap that exists between the relative ease and speed associated with developing a proof-of-concept prototype and designing a viable instrument that can function effectively in a range of concert situations. They identify a number of issues related to improving a prototype, from ergonomics to technical sensor considerations. For example, sensors behave in different ways in lab environments compared with concert venues. Camera and infrared sensors are particularly sensitive to varied light conditions. To address the issues that can arise, a series of design iterations are recommended to design a stable and robust DMI (Ferguson and Wanderley 2010, p. 23). Technical considerations are supplemented with artistic requirements, directed at achieving more dynamic and engaging live performances.

3.4 Research Design

This research is arranged into three interrelated phases. In the first phase, initial compositions formed the basis for exploring a range of sensor technologies and designing basic prototypes in Max/MSP.[13] Emerging impressions informed the development of a more robust gestural performance system that was then used in a series of semi-improvised performances. In the second phase, the system was tested with expert users. In the third phase, the feedback from this case study was analysed, culminating in the development of new compositions and a revised gestural instrument for performance.

3.4.1 Works and Performances

An orchestral piece, *Concentric Motion*, and a suite of *Gestural Études* provided the starting point from which to explore ideas of more physically-oriented performance and investigate potential links between gesture and sound. These works featured as semi-improvised performances that offered opportunities to ascertain the effectiveness of gestural prototypes in reaching artistic and design goals. Prioritising composition and performance reinforces an emerging belief in the literature that the longevity of an instrument relies on a repertoire of works that encourages future performances (Ferguson & Wanderley 2010).

3.4.1.1 Performances

A series of performances conducted over a three-year period became the basis for testing initial mappings and developing physical confidence with gestural control. Rehearsals offered an opportunity to conceive and refine initial mappings between gesture and sound. This process echoes the body-centric mapping approach of Bencina, Wilde and Langley (2008, p. 198), which is underpinned by a belief that "interweaving the development of sound and movement would open up new ways of thinking about gestural sound performance and lead to gestural sound

[13] Max, Cycling'74. n.d., *Max 7*, viewed 16 August 2015 <https://cycling74.com/products/max>.

synchresis”. Using similar experiential mapping methods, I engaged in a series of movement improvisation sessions with a preliminary set of Max/MSP gesture processing patches. These sessions offered a direct way to explore associations between sound and movement, by enabling simultaneous experimentation with a range of gestures types and sound processes to discover the most effective combinations for performances.

This experiential approach became an iterative process, in which I developed my kinaesthetic awareness and a deeper physical understanding of my body’s capacity through direct experience of gestural control during composition and early prototyping.

3.4.1.2 Data collected

The data collected during the composition and performance process take the form of software patches, journals documenting performance preparation and field notes, audio-visual recordings of performances and improvisations and scores. These methods are summarised in Table 1.

Table 1: Data collection methods

Research Method	**Description**
Composition	Artistic works exploring possibilities in gestural composition. Two major works are discussed in terms of their contribution to illustrating a gestural design strategy and achieving aesthetic intentions.
Prototyping	Design of a gestural performance system to explore selected mapping strategies, input gestures, and their effect on performance experiences.
Performance/ design Diary	- Documenting shifting kinaesthetic awareness in response to performances and experimentations. - Outlining key design developments and patches. - Recording comments from audience members and post-performance reflections.

Research Method	Description
Performance	- Reflections of observations as a 'participant-observer', recording spontaneous insights and bodily experiences during performances. - Collecting sound recordings of performances.
Audio recording	- Audio recordings of selected improvisations and ensemble rehearsals. - Audio recordings of performances and expert user case study sessions.
Video recording	- Video recordings of expert user case study sessions. - Video recordings of piano, vocal and gestural performances.
Interview	Interviews with expert users during expert user case study.

3.4.1.3 Documentation

I documented rehearsal sessions, mapping experiments and performances as video or audio recordings, drawing on the events captured to reflect on turning points and influential moments in my performance and design processes (Bartleet 2009). Photographic images also enabled me to revisit experiences from an external, distanced perspective.

Organising accumulated audio-visual data and writing a coherent autoethnographic narrative "that points to the commonalities as well as the particularities of our lives" (Ellis 2004, p. 200) became a challenge of combining personal insights that emerged from performances with other musician experiences to reflect on prevalent themes in the gestural interaction field.

3.4.2 Experiential Prototyping

A central component of my research design involved creating a prototype gestural performance system to investigate the creative applications and practical challenges of movement-based musical control. A series of performances formed part of a practical exploration into the influence of gestural interaction on my own practice, while an expert user case study examined experiences of expert musicians using the system for the first time. This hybrid approach allowed me to incorporate broader creative practitioner perspectives to form a more in-depth understanding of movement-based performance.

This focus aligns with other artistically and musically driven approaches to prototyping (Jordà 2005; Elblaus, Hansen & Unander-Scharin 2012), which are concerned not only with technical functionality but also with the harder to quantify area of user experience. A prototype used in musical performance can offer insights into an interaction scenario that then informs further refinements, as argued by Elblaus, Hansen and Unander-Scharin (2012, p. 380), who believe that direct engagement with a prototype can yield valuable information to guide the design process. Performer involvement in the early prototyping stages provides information about the physical fit of a novel interface to their body type and skills, as well as uncovering the unique ways they may utilise it, rather than guessing how it will work in practice (McNutt 2003, p. 299).

Direct physical experiences with a gestural prototype during performance and composition drove the iterative design process. This approach draws on research that imports experiential processes from the dance field to interactive art and design (Schiphorst & Anderson 2004; Loke, 2009; Schiphorst 2009). Movement awareness disciplines such as dance, Tai Chi, Alexander Technique, and Feldenkrais offer insights into first-person methodologies, which intersect disciplines spanning performance, psychology, philosophy and somatics (Schiphorst, 2009). These influences are harnessed in Loke's design of targeted movement exercises aimed at developing skills for working with different movement parameters such as space and time to inform movement-based interaction design (Loke 2009).

The documentation of personal movement-based exercises formed an essential part of deepening my sense of movement awareness and understanding my body's individual movement signature. To capture these insights in a way that preserved the original embodied nature of these experiences was a challenge that I addressed by constructing narratives that embrace the complexity of bodily experience.

The customised gestural system, Gestate, was designed to explore the nature of gestural control in live performance contexts and its influence on musicians' experiences. The system was developed iteratively over a series of performances, rehearsals and during the composition process. Initially, Gestate was used to augment instrumental and vocal performance by mapping performer gestures to digital signal processing. Subsequent applications enabled the control of virtual instruments and mixing parameters with free air gestures, using an interaction paradigm reminiscent of the theremin.

Insights that emerged from the iterative design process and public performances were recorded in a design and performance journal, as mentioned in Section 3.3.2, Autoethnography. The journal documented physical sensations and evolving impressions within the autoethnographic tradition, where data is sourced from personal experience. These impressions, informed by continual physical engagement with the system, formed the basis for regular design enhancements.

Adopting an experimental and experiential approach to developing mappings enabled direct body experiences to shape mapping and overall design strategies. My research adopts similar design methods to interactive artists' approaches (Bencina, Wilde & Langley 2008; Wilson-Bokowiec and Bokowiec 2006; Loke et al. 2013), where design is influenced by first-hand experiences and reflections. An unexpected side effect of this experiential prototyping process was to develop a heightened sense of kinaesthetic awareness and sensitivity to my own spatial potential and movement patterns. Like Chris Salter (2012, p. 182) and collaborators in the creation of the *Just Noticeable Difference (JND)* movement-controlled installation, direct bodily engagement played a vital role in the programming and refinement of the system. These tasks could not be undertaken from a distance given the physical nature of the interaction. Adopting a similar approach assisted me to formulate design goals and guidelines to shape the design process that were in accordance with my artistic and pragmatic performance aims.

3.4.3 Expert User Case Study

The primary goal of the expert user case study was to develop deeper understandings of how expert musicians engage with gestural systems in order to identify key areas for improvement. This research phase involved shifting my focus from that of direct participant to an observer, to complement and advance my personal insights in the performance area. Analysing how users experience the interaction was fundamental to refining the prototype presented.

3.4.3.1 Research Design

In line with ethnographically-inspired design methods, semi-structured interviews were conducted with expert users after their improvisation sessions with the system. The study was intended to inform the future development of the system, expanding the scope of the design beyond the performer/designer's perspective. Participant observation occurred in addition to video recording of sessions. Notes were recorded and extracts of the videos were analysed by myself. I analysed selected segments of the video, rather than transcribing the entire session, to identify core control movements and patterns that emerge with different users.

A small group of participants was chosen to facilitate insights into musicians' experiences with an example gestural system, and to provide anecdotal feedback and in-depth qualitative data. The participants were selected on the basis of their professional expertise in the musical field and represented a range of relevant career areas, including vocal and instrumental performance, production and instrument design, in order to examine the system's applicability across a range of musical activities. Rather than emphasising the functionality or utility of the gestural system, the data probed the experiences of musicians to discover what musical ideas and approaches they sought to express, and any physical sensations that emerged, when using the system.

The feedback gathered reflected a mixture of feelings and perceptions on expression from participants exposed to the system for the first time. The outcomes of the study informed the next design iteration of the system, expanding the scope of the design beyond the performer/designer's perspective.

The aims of the case study were to:

- Investigate the experiences of expert users interacting with a gestural performance system;
- Determine a core set of control features required by expert users;
- Discover how effective the system is in meeting user needs and preferences.

In relation to the primary research goal — identifying areas in which gestural systems may be improved to become more viable and accessible — these aims were directed at identifying the key characteristics of effective performance systems controlled by physical gesture. Users' experiences were investigated through semi-structured interviews after an improvisation phase to gain an understanding of levels of satisfaction with the prototype system and gather suggestions for improvement. This feedback also provided insights into the effectiveness of the design strategies that evolved during the course of the design process, and their effect on user satisfaction. Open-ended questions enabled participants to provide in-depth answers and explore areas outside the main topics represented in the questionnaire.

Investigating these questions assisted in the refinement of design criteria aimed at improving musicians' experiences and willingness to experiment with gestural performance systems for live work.

3.4.3.2 System

Gestate utilises a Microsoft Kinect depth camera as a sensor and visual feedback projected on either the computer or a projection screen in front of the performer. The hardware, software and rationale behind the design are explained fully in Chapter 5.

A simplified version of the system was presented to participants, incorporating three contrasting applications that represented the range of the system and were controlled by upper body motion. The first example, an arpeggiator application, mimics the direct mapping of the theremin. Right arm movements control pitch, while the left arm regulates the intensity of effects. The second application, the Cube, is an audio-visual instrument that requires the user to punch forwards, backwards and sideways with their right arm to trigger chord changes of a virtual physical mallet model. These triggers are visualised as rotations of a three-dimensional cube. The third application, a virtual mixer, allows the user to control the amplitude of pre-composed MIDI parts, controlling sound levels of individual tracks by expanding and contracting the movement range of the limbs.

3.5 Data Analysis Methods

Phenomenological analysis of design and artistic journals was undertaken to extract prominent themes and generate in-depth descriptions that reflected the essence of feelings associated with performance and design experiences. These themes became the basis for constructing an autoethnographic narrative linking all stages of the research and isolating pivotal moments in my creative and design processes.

Video analysis of performances and improvisation sessions involved multiple viewings to gain full immersion in the data and revisit the intricacies of the embodied experience. Rather than transcribing each video recording in its entirety, selected segments were analysed to identify dominant movement patterns and characterise the relationship between particular movements and specific musical outcomes.

Feedback from experienced musicians during the expert user case study provided a broader perspective that complemented the strong personal narrative framing the first half of the research. Each session was recorded in digital video format for future transcription, noting both verbal and non-verbal communication during the interview. This freed me to record spontaneous observations of participants during the session. Prominent sections of the recorded improvisation sessions were analysed to record the key gestures that emerged during the improvisations.

3.5.1 Analysing Movement

Various analytic approaches were used to analyse the video documentation from the study and my performances. I undertook coding similar to that of Davidson (2007) to study the types of gestures I produce. However, observing the motions in isolation was not sufficient to understand the expression behind a performance; for this I needed to understand the nuances and intentions behind movement.

Aided by Sheets-Johnstone's (1999) work on dynamic movement qualities, with reference to Laban Movement Analysis (LMA) (Laban 1998), I observed the movement characteristics associated with particular gestures. Sheets-Johnstone has three primary ways to distinguish how a movement is performed: *tension*, or the amount of effort or force that is prepared in anticipation of performing a movement, leading to minute adjustments in muscular tension to carry out a range of everyday tasks; *linearity*, the path or trajectory that a movement follows, whether it be a curved or straight line; and *amplitude*, or the scale of a gesture. Different cultural settings and socialisation will dictate how expansive or contracted gestures will be, a topic explored by Iris Marion Young in her essay, "Throwing like a girl" (1980), in which she observes societal influences on the restricted amount of space that girls occupy, compared with boys.

I adapted the concept of movement qualities to analysing movement in video recordings of performances and improvisations, in order to define gestural vocabularies for the system and to inform gesture capture and mapping strategies.

3.6 Conclusion

This chapter outlined mapping and design approaches in the field of gestural performance. A literature and contextual review influenced the selection of initial mapping strategies that contributed to developments of a prototype gestural performance system. Using a practice-based methodology, the main research activities of data collection, analysis and the initial research questions were continually reflected upon, leading to cyclical stages of refinement. The research design was described and justified in relation to a theoretical framework rooted in phenomenological principles.

The methodology chosen has its foundations in theories of embodiment, and specifically, embodied music cognition, placing performer experience at the forefront of the investigation.

Chapter 4: Exploratory Works

> *I dream of instruments obedient to my thought and which with their contribution of a whole new world of unexpected sounds, will lend themselves to the exigencies of my inner rhythm.*
>
> Edgard Varèse (1917/1966)

4.1 Introduction

This chapter details the performances of works that were formative in refining the questions that underpin this research. Examining the potential of gestural composition and performance in shaping my creative process constituted the main component of the performative inquiry approach, as outlined in Chapter 3. In guidelines for designing computer music controllers, Perry Cook (2001, p. 3), advises DMI designers to "make a piece, not an instrument or controller", reminding them of the need to prioritise artistic goals over technical considerations. Rehearsing and performing music thus becomes an important stage in the testing and refinement of DMI projects (Malloch 2008).

During the composition, rehearsal and performance stages of each piece, I reflected on the interplay of my dominant motion patterns, inclinations and the sound processes I chose to experiment with. I aimed to explore various performance practices, including extended vocal techniques and augmented instrument design, within the context of audio-visual performance. The outcomes of these performances formed the basis for the design criteria and strategies of a customised gestural performance system, Gestate*,* presented in Chapter 5.

As part of my exploration into the possibilities of movement-generated and -controlled music, I composed a suite of *Gestural Études,* in which I experimented with a range of control gestures, sound synthesis and processing methods, and an orchestral work: *Concentric Motion: Concerto for Voice, Piano and Gestural Controller*. Each étude focused on a different form of gestural control and audio-visual environment. The composition process, which overlaps with interface design, examined methods for channelling my movements as a performer into digital signal processing and virtual instrument control parameters during electro-acoustic performance. The overarching aim behind the pieces was to develop improvisational techniques integrating my expressive gestures. The following section describes the motivations and aesthetic choices behind this collection of works.

Composing and performing the pieces aided in identifying key technical and practical aspects of configuring and applying gesture–sound relationships. These semi-improvised works became instrumental in the development of my research question and main areas of inquiry. They reflect an experiential approach to gestural interface design, grounded in observations of my existing movement patterns and personal physical experiments with movement. Insights gained from performing each piece informed the design of Gestate, a gestural system that bridges existing practice with gestural control methods.

In addition to describing the planning and rehearsal of the pieces, I discuss insights drawn from pivotal performances. Section 4.2 describes the composition of *Concentric Motion,* summarising key artistic and design understandings that emerged from the composition, rehearsal and performance stages. Section 4.3

describes the *Gestural Études,* a collection of pieces focusing on open air or free gestures and augmented voice.

My creative process is organised into three phases:

- Developing a deeper understanding of my existing movement patterns by identifying common movements in audio and video recordings of solo improvisation sessions and rehearsals;
- Reframing these movements by using them as a control input for digital signal processing;
- Creating a series of sound–movement associations through exploratory movement improvisations.

The first two phases are relevant to the augmented piano and vocal works, while the third phase pertains to works that employ free air gestures to control virtual instruments. The common theme uniting these pieces is the desire to depict my signature gestural patterns in order to incorporate the idiosyncrasies of my movement style, providing a basis for exploring potential associations between movement and sound.

4.2 *Concentric Motion: Concerto for Voice, Piano and Gestural Controller*

Following a series of improvised gestural performances, the first major work for this research, *Concentric Motion: Concerto for Voice, Piano and Gestural Controller*, was composed for the innovative category of the 2012 International Space-time Concerto Competition hosted by the Newcastle Conservatorium, Newcastle, New South Wales, Australia. The eight-minute piece incorporated both vocal and piano augmentation and digital signal processing of the overall sound. As a soloist, I alternately processed the input of the acoustic piano, voice and orchestra with my movements. A particle system, visualising audio input levels and joint positions, was projected onto two screens positioned at either end of the stage.

Acceleration derived from my performance gestures controlled the digital signal processing, reflecting fluctuating energy levels that increased in intensity as I became more immersed in the work. Positional samples of selected joints were captured at the 30 Hz frame-rate of the Kinect infrared motion sensor. The change in position was then calculated and velocity and acceleration derived from these measurements.

4.2.1 Background

Revisiting the motivations discussed in Chapter 1, the main aim of this work was to investigate methods for accessing digital audio software parameter controls remotely, using large-scale gestures to gain greater breadth of movement than that afforded by laptops or audio hardware devices. As a performer in the live electronic genre, I have long searched for a stronger sense of ‘liveness’ or interactivity in my performances. I sought more animated and active connections with the audio hardware and software I commonly used through increased physical involvement in electronic manipulation. This process led me to explore embodied approaches to electronic music that blended harmoniously with my existing performance skills and movement patterns.

As discussed in Chapter 2, the disassociation between sound control and production in electronic input devices can inhibit the feel related to producing a particular type of sound (Roads 1996). Several designers have confronted this challenge by introducing haptic and vibrotactile feedback to improve the overall feel of digital musical instruments (Marshall 2008), gestural controllers (Bongers

1998; O’Modhrain 2000; Rovan & Hayward 2000), and augmented instruments (Berdahl, Niemeyer & Smith 2009). I also examined the potential of introduced feedback, focusing on the visual modality and strengthening kinaesthetic awareness to deliver new performer-centred strategies of directing energy and effort when playing non-tactile interfaces.

The decision to augment the acoustic piano was based on a desire to harness my existing gestural language and the expressive capacity I had developed over many years of playing the instrument. This strong relationship and development of expressive ‘touch’ was never attainable with the electronic keyboard, where I lacked the ability to translate nuanced physical expression to sound effectively, even after an extensive history of performing with electronic keyboards such as synthesisers and organs. Given my background as a piano and keyboard player, the choice of working with my main instrument provided a familiar grounding to assist in designing the gestural system for this work. By integrating my current practice into the interaction design, I could leverage my existing technique and patterns of movement. The additional benefit of tactile feedback afforded by the piano keyboard enabled me to experience tactile feedback in association with spatial movement.

I also wanted to overcome the sonic limitations of the piano, to implement more continuous, sustained control, extending its acoustic properties through digital signal processing and the continuous timbral shaping capacity of synthesis techniques. Performing with effects processing already constituted a large part of my vocal performances, leading me to consider how I could shape this technique through my gestural inflections and nuances. Similarly, I aimed to use movement qualities derived from my common performance gestures to modify the acoustic properties of the voice.

4.2.2 Preparation

The preparation for this work involved a number of stages, including assembling the composition, producing a score, designing a gesturally augmented piano and vocal application, iteratively refining the design, and rehearsals.

The first step in transforming my performance gestures into interactive control was for me to become conscious of my existing movement patterns. Like British composer Neil March (2009) whose solo piano piece *Diversions* aims to reflect the form of ordinary gestures, I became interested in investigating my own movement patterns to identify the most common gestures performed both intentionally and unconsciously during performance. This process involved selecting a non-invasive sensor and designing a software configuration for capturing and channelling movement data to a range of sound-processing applications. The Kinect was chosen as it enables skeleton tracking with minimal programming, and interferes less with vocal and instrumental performance than a wearable or hand-held sensor.

A principle aim was to achieve a sense of fluidity by blending gestural control seamlessly with my existing instrumental and expressive gestures: I wanted to perform in a way that followed the natural lines of my movements. For this reason, I initially decided against a predefined gestural vocabulary, as I felt it would anchor me to predetermined gestures that could prevent movement from evolving in subtle ways. In this early phase, I opted not to train a gesture-recognition system, as the gesture library would be based on gestures that were indicative of a past style of performance. The need to conform to gestures recorded in the past could lead to feelings of awkwardness or artificiality, potentially impacting my usual performance movement style.

Instead I chose to focus on identifying general patterns in my body language, by reflecting on extracts from audio and video recordings of solo improvisation sessions with and without the Max/MSP gesture processing patch and rehearsals[14]. A similar approach to observing and documenting performers' body movements to understand how they produce expressivity is evident in Ward et al.'s (2008) study of historic film recordings of two theremenists, Clara Rockmore and Lydia Kavina. Laban Movement Analysis is adopted as an interpretative framework for the study. Their conclusion, from analysing and comparing the effort phrasing of both performers, is that each individual exercises a distinct movement approach to meeting the technical demands of playing the instrument (Ward et al. 2008, p. 120). Even though the theremin places restrictions on the performer to retain overall stillness so as not to interfere with the pitch and volume control performed by the arms and hands, both players are able to develop unique expressive techniques in response to the instrument's constraints, demonstrating highly idiosyncratic movement styles.

A first-hand investigation into performer movement is the self-reflective movement study undertaken by singer Jane Ginsborg (2010), who conducts a questionnaire for herself and her duet partner, enquiring about the types of movements she uses most in practice, rehearsal and performance in order to discover the role of kinaesthetic learning in the development of mental

[14] Video recordings of example improvisation sessions are available at the following link, viewed 20 August 2015: <http://www.mainsbridge.com/improvisations/>.

representations for music. Through an analysis of key movement repetitions from individual practice and ensemble rehearsal sessions, she identifies four main types of movement:

1. Pulse-beating;
2. Conducting;
3. Gesturing;
4. Periods where little or no movement occurred. (Ginsborg 2010, p. 123)

Ginsborg found that gesturing occurs mainly in relation to conveying the semantic meaning of musical elements and text, whereas the first two types of movements assist in achieving rhythmic accuracy, co-ordinating timing between performers, and also memory retention of the piece.

Ginsborg's is the first study to explore body movements in relation to a singer's preparation for performance, providing a valuable template for this research. Previous studies detailed in Section 2.2.2 focus on audience perception of performer movements or on physical communication between ensemble players. Ginsborg's study involves detailed coding of the performer's movements in an interpretation of *Ricercar I*, a solo soprano and instrumental ensemble movement of Stravinsky's *Cantata* for two solo singers, women's choir and small instrumental ensemble. The following questions frame Ginsborg's process of self-observation:

- *What* movements did I use?
- *When* did I use them during the course of four weeks practice and rehearsal?
- *Where* did I use them, in relation to the musical features and performance cues identified in the music after the performance? (Ginsborg 2010, p. 123)

Adapting these questions to my first-hand account of movement in relation to musical features, the main movements that I observed in my piano performance varied according to their position in a phrase. Merging Ginsborg's (2010) and Davidson's (2001, 2007, 2012) methods of studying body movements during performance, I identified three main types of movements that occurred in relation to each phrase of a piano performance, including preparatory, rhythmic and concluding movements. Table 2 lists these movements.

Table 2: Common piano performance movements

Movement Types	**Description/Key Features**
1. Preparatory movements before a phrase.	• Arm lifts • Postural adjustment • Head lifts • Bowing head
2. Movements types during a phrase: - Rhythmic - Flowing and continuous - Emphatic	• Torso sway and rocking • Elbows fanning out • Shoulder lifts • Head lifts • Rhythmic
3. Concluding movements after a phrase.	• Posture shifting • Arm lifts • Head lifts

Video recordings of piano improvisations revealed that my movements coincided with the occurrence of phrases. In contrast to the discrete gestures I performed at the start and end of each phrase, I exhibited more flowing and rhythmic movements during the middle sections of the phrases. At times I emphasised accents and downbeats in the music with head bowing motions. Alternately, head lifts signalled an anacrusis or syncopated rhythm. Elbow fanning gestures frequently coincided with acceleration and crescendo at the peak expressive point of a melody. Torso sway or rocking motions contributed to establishing an internal pulse during the improvisation.

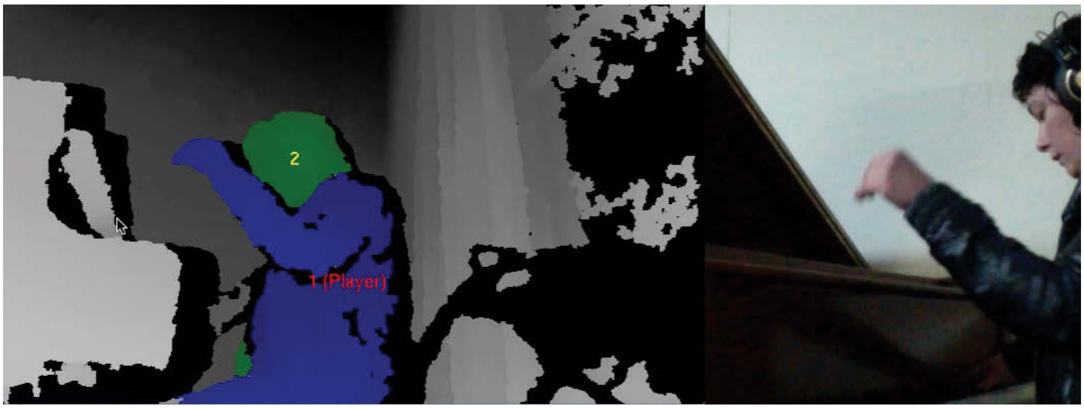

Figure 8: Piano improvisation with Kinect and web camera view

Figure 8 is a screenshot taken from a solo piano improvisation that was captured with the Kinect camera (Kinect view shown on the left side of the screen) and a web camera (webcam view shown on the left side of the screen). It features a preparatory movement made before a phrase. The joint data was also captured through Max/MSP and compared to the video data to discern the scale and range of my movements.

4.2.2.1 Movement Qualities

In addition to identifying the types of movements that typified my performance practice, it became equally important to understand *how* these movements were being performed. The definition of movement qualities in gesture and bodily expressivity analysis is commonly used to identify expressive aspects of movement. Examples of frameworks in the musical realm include the work by Camurri et al. (2004) and Jessop Nattinger (2014). In the interactive dance field, Fdili Alaoui et al. (2013) define movement qualities for interactive applications based on LMA.

Of particular relevance is Jessop Nattinger's (2014) Expressive Performance Extension Framework, which includes an example set of six expressive parameters that relates both to body movements and vocal performance, including energy, rate, fluidity, scale, intensity and complexity. This set incorporates many expressivity parameters classified in related literature by Eirini Kalatha and George Caridakis (2013), including:

- Quantity of gestures;
- Spatial extent of gestures;
- Temporality (speed of movement);
- Fluidity (smoothness of abruptness of movements);
- Power/energy (dynamic qualities of movement);
- Repetivity (rhythmic repetition of movement). (Kalatha & George Caridakis 2013, p. 100).

To use movement qualities, an established aspect of dance practice (Laban 1963; Blom & Chaplin 1988), musicians designing gestural systems and performance must first define a glossary of relevant movement qualities. I undertook this process in the early stages of gesture-sound mapping and while developing an interaction design for the piece.

As part of my gesture capture strategy, I focused on extracting the following movement features:

- Magnitude/scale of gestures;
- Speed (velocity);
- Force = mass x acceleration.

These movement qualities formed the basic building blocks for the Max/MSP patch used for *Concentric Motion*, as they mirror the fundamental components of the laws of motion in physics: displacement, distance, velocity and acceleration. The features I selected bear some similarities to Jessop Nattinger's framework (2014) and the expressivity parameters outlined by Kalatha and Caridakis (2013). However these authors' comprehensive typologies are reduced to three core qualities that provide access to a range of valuable expressive information.

By measuring the magnitude and velocity of movements, it was possible to derive information about their spatial extent and intensity. My decision to adopt the magnitude or scale of gestures was based on research that links the scale or openness of gestures to the emotional intensity of musical sound production (Davidson, 1994; Camurri et al., 2004). The speed or velocity of movement was selected on the basis of past movement studies that identify velocity as a significant cue for expressive movement (Camurri, Mazzarino & Volpe 2004; Camurri et al. 2004, Leman 2010). Force was chosen because it offers insight into the amount of effort and energy behind actions, providing another representation of intensity and engagement in a work.

In addition to interpreting movement in physical, quantitative or anatomical terms, LMA provides a qualitative framework for describing how effort is directed and performed. Laban regards effort as the inner source of all movement:

> Every human movement is indissolubly linked with an effort, which is, indeed, its origin and inner aspect. Effort and its resulting action may be both unconscious and involuntary, but they are always present in any bodily movement; otherwise they could not be perceived by others, or become effectual in the external surroundings of the moving person. (Laban 1988, pp. 20-21)

As Figure 9 demonstrates, eight effort elements reveal the inner attitude of the performer before or during the execution of actions: bound or free; sudden or sustained; light or strong; and direct or flexible. These elements account for not only the visual aspects of a gesture but also the feelings associated with their execution, offering potential insight into the expressive style of the performer.

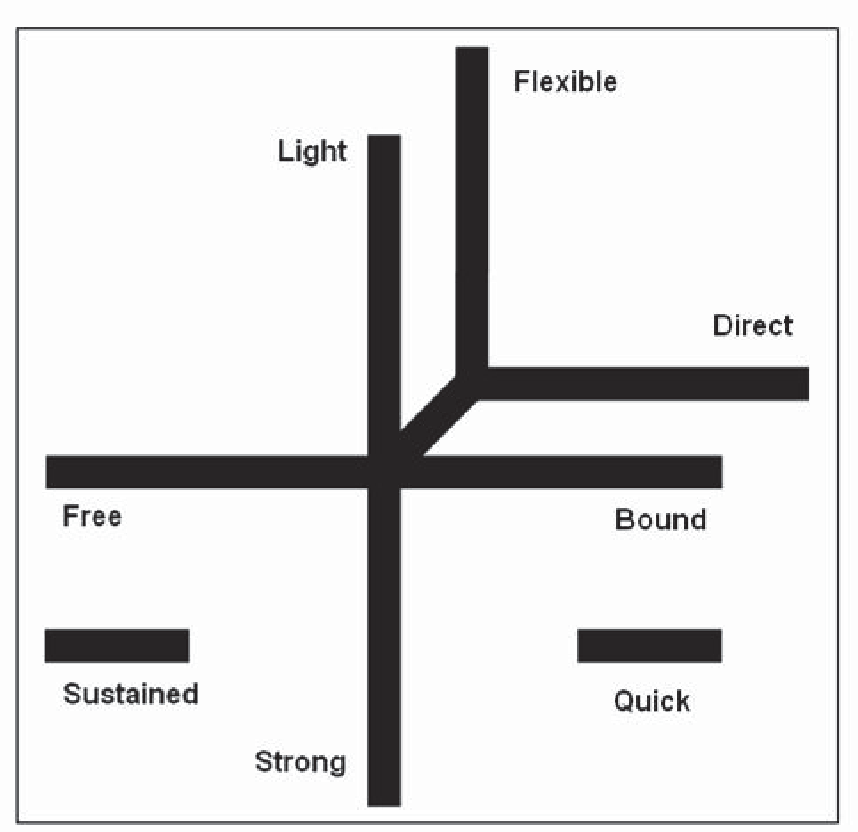

Figure 9: Laban effort graph

Of all the four basic elements that form the basis of LMA, including Body, Space, Effort and Shape, Charles L. Gambetta (2010, p. 17) regards effort as the most useful aspect available to conductors to convey their musical intentions and the inner expressive essence of the music to the orchestra. His proposition hints at the potential significance of representing effort as a key feature of the experiments described in the next section.

4.2.2.2 Experiential Mapping

In addition to observing distinctive movements and qualities associated with my performance, I engaged in a series of movement experiments to explore associations between gesture and sound, similar to the collaboration between Bencina, Langley and Wilde (2008) documented in Wilde's exegesis:

> The overarching aim of the *experiments* was to extend the body with sound so as to mesh gestural/physical and sonic composition in such a way that sound production would seem to be an inherent and unavoidable consequence of moving the body. (Wilde 2011, p. 34)

This exploratory approach contrasts with the more common technology-led practice of creating mapping strategies prior to implementing them physically. In order to develop mappings that suited my body type and artistic aims, I engaged in a series of improvisations to design initial mappings for the piece. I adapted the primary aim of the *Gesture≈sound experiments* (Bencina, Langley & Wilde 2008) to facilitate explorations of movement and sound interdependently, drawing out the dynamic relationships and complexities of the interconnected modalities (Wilde 2011, p. 34). Relying on a similar methodology, I simultaneously combined movement development with designing sound processes and algorithms.

Wilde, whose background in movement stems from physical theatre, observes that her fellow collaborators on the project, both electro-acoustic composers, adopt a less physically oriented stance and ignore the expressive capacity of their movements:

> Musicians and technologists do not typically have highly developed skills in expressive movement exploration. While there was no desire to privilege the physical, short-circuiting Bencina and Langley's tendency to de-prioritise their body's expressive range afforded a different mindset from which to investigate. (Wilde 2011, p. 35)

Similarly, as I have no formal movement training, apart from casual yoga practice, movement improvisations offered an opportunity to become more consciously aware of my own movement tendencies and patterns in performance.

First, I experimented with channelling positional and velocity data from the main joints that appeared active during piano performance. Positional data was initially obtained from a distance of my left hand, right hand, left elbow, right elbow and head from my torso. The acceleration of these combined measurements was mapped to a range of audio parameters, including tempo and digital signal processing controls, through a Max/MSP patch. At the same time I observed the type of data entering the patch, in order to refine the scaling to attain the appropriate level of control sensitivity.

The screenshot in Figure 10 shows that the software that captured movement data is controlling playback and record in a looper plugin, tempo and additional effects plugins within an Ableton Live[15] session. I experimented with controlling the tempo of MIDI sequences and also affecting the tempo of the looper playback to produce timbral variations of the piano sound, captured by a stereo pair of condenser microphones.

---

[15] Ableton n.d., *Ableton Live*, versions 8-9, viewed 16 August 2015 <https://www.ableton.com/en/live/new-in-9/>.

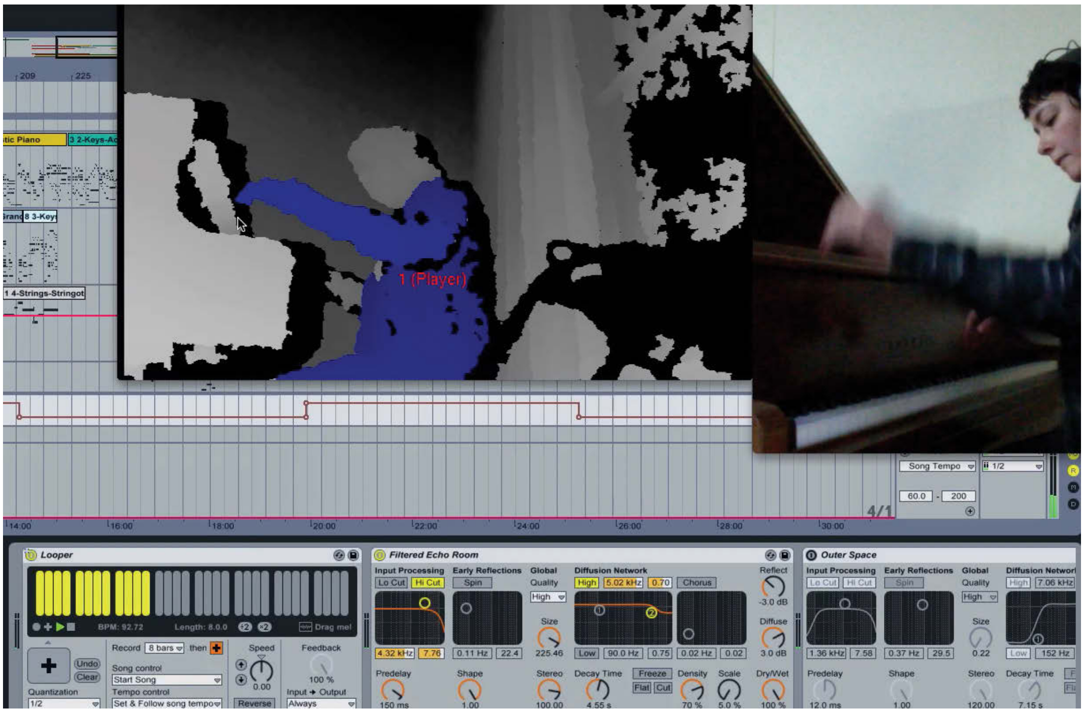

Figure 10: Screenshot showing joints controlling looper and effects

Figure 11 displays the Ableton Live looper plugin. By varying the tempo of the session, I was simultaneously able to alter the speed of looped sections, enabling me to alter the piano's acoustic properties, producing tone colours ranging from deep cavernous effects to high, wispy notes.

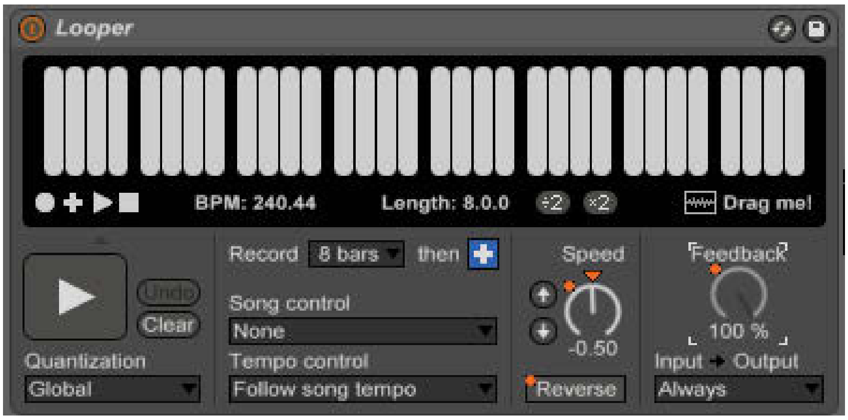

Figure 11: Ableton Live looper plugin

I documented and reflected on these sessions with the aid of video recordings and recorded sensor output to gain a deeper understanding of my personal movement language. This process enabled me to identify emerging patterns and ranges in the streams of numbers entering the patch that were then compared with the video data from each session. These combined movement–sound improvisations formed the basis for formalising gestural design criteria and approaches outlined in the Chapter 5.

A performer's capacity to understand the mappings that form part of an instrument's design leads to increased consistency, coherence and refined performances: "Listeners perceive the result in the range, accuracy and speed of performed gestures" (Goudeseune 2003, p. 85). Rather than pursue implicit mapping, which relies on machine learning techniques such as neural networks or Hidden Markov Models (HMMs) to perform high-level analysis of gesture, I chose to exclusively explore explicitly-designed mapping (Rovan et al. 1997; Hunt & Kirk 2000; Van Nort, Wanderley & Depalle 2004). The reasons behind this decision stemmed from a desire to simplify the mapping process by lowering the amount of tasks the system must perform in real-time to minimise latency and to aid audience comprehension of the implemented mapping strategies.

In line with my artistic goals to represent human idiosyncrasies and comprehensive, detailed control of a system by the performer, the ability to explicitly define mappings allowed me to influence every aspect of the relationship between individual instrument controls (input parameters) and the output of a sound synthesiser (synthesis parameters) or audio software. This option ensured a detailed level of control by making it easier to alter mappings in real-time in order to create different modes of behaviour for a system (Wright et al. 2001). Explicit mapping also decreases dependence on pre-recorded gestures, which enabled me to vary my movements without needing to conform to predefined gestures.

The next step was to match the types of physical movements identified to specific sound generation and manipulation processes, shifting the focus from technical considerations towards musical composition (Winkler 1995). I decided to concentrate my efforts on digital signal processing, as this allowed me to build on previous live work in which electronic and vocal sources were modified with audio effects.

Digital audio effects have been less favoured in gestural control applications than sound synthesis methods, where digital sounds are generated from scratch (Verfaille, Wanderley & Depalle 2006). A reason for this could be that manipulating effects is viewed as simplistic due to the small amount of variables needed to control an audio effect. Also, audio effects may not be considered as performable as sound synthesis (Verfaille, Wanderley & Depalle 2006). The notion of performing effects is a key aspect in the augmented vocal and piano performances described in the following sections.

4.2.3 Audio-visual Environment

A non-invasive camera method that could function effectively in low-light conditions was required for capturing movement data. For this reason, the motion sensing device selected for this piece was the Kinect.

I considered a range of existing mapping software applications; however, many confine the user to predetermined setups. EyesWeb, which facilitates expressive feature extraction from movement, restricts flexibility due to its reliance on predefined expressive categories.

Early experiments of operating the record and playback functions of a looper with clockwise and anti-clockwise circular movements of the hand using

Gesture Follower[16] allowed me to create a small repertoire of repetitive gestures. However, I found it difficult to perform these movements precisely and consistently, leading to some unpredictable sonic results.

Initial experiments were conducted with Max/MSP visual programming software, where movement data was routed to digital signal processing parameters in Ableton Live, as outlined in Section 4.2.2.2, Experiential Mapping. Max/MSP offers flexible real-time manipulation of movement data. For me, this program offered the ability to undertake rapid prototyping and adapt mapping connections quickly during rehearsals. To be able to access a range of patches simultaneously, they were converted to Max for Live instruments that were embedded in individual tracks within Ableton Live for convenient access.

Figure 12 shows a video still of an experiment in which my overall energy score calculated from upper body joint motion was used to power stereo effects send amount and tempo for pre-recorded MIDI parts in Ableton Live. From the associated video[17], it is possible to see the knob controlling the effects send move in response to the level and intensity of my movements. By altering the effects and tempo simultaneously, I was able to achieve a range of timbres from selected effects. The visualisation on the left hand side of the screen displays a smoke-like particle system that is mapped to the audio output of the piano and upper body joint position data.

---

[16] Gesture Follower, n.d. *Gesture Follower*, Ircam, Paris, France, viewed 16 August 2015, <http://imtr.ircam.fr/imtr/Gesture_Follower>.

[17] The video of the augmented piano experiment is available for viewing at http://www.mainsbridge.com/improvisations/, viewed 2 February 2016, <https://vimeo.com/153590602>.

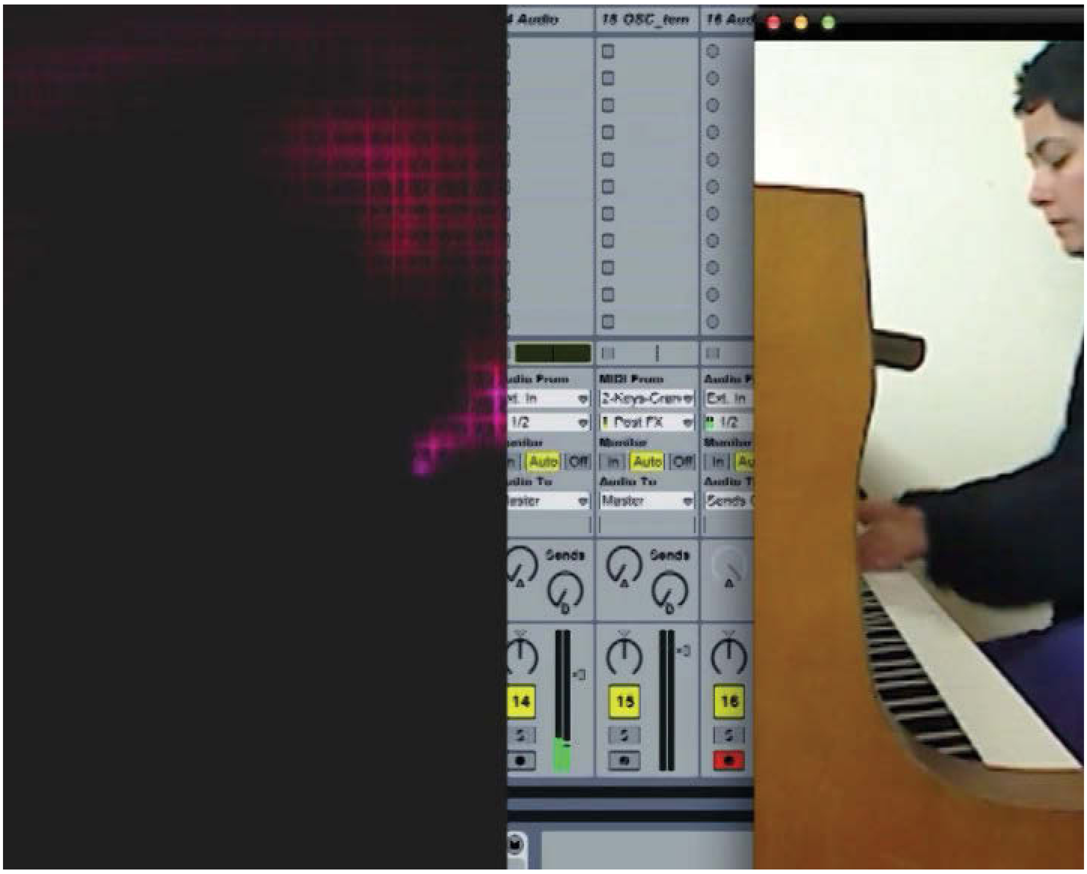

Figure 12: Video still from early experiment with Smokescreen visualisation

The modular process displayed in Figure 13 reveals the four stages of capturing gesture and mapping gesture, providing a flexible framework that enables the system to be adapted to different users, creative applications, gestures and sonification and visualisation techniques. These gestures were then scaled according to my physical dimensions and gestural style to produce maximum sensitivity in controlling digital audio effects processing and virtual instruments or tempo.

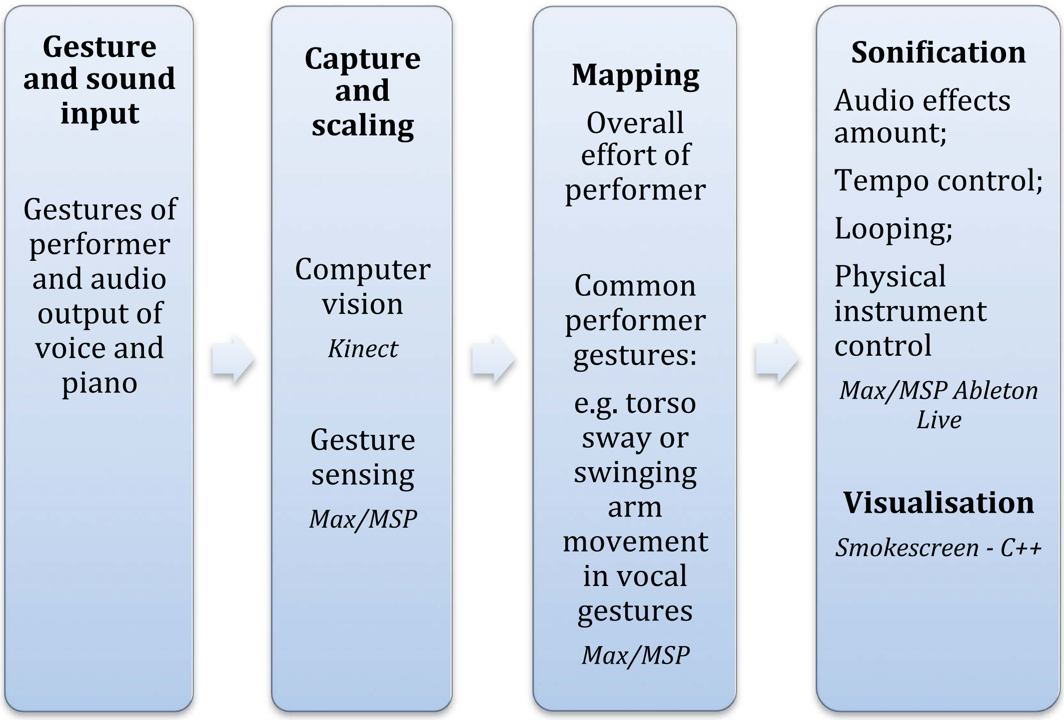

Figure 13: Modular process for capturing and processing gestures

As a result of the gesture categories identified in the self-observation phase in Section 4.2.2, Preparation, I used a range of Synapse[18] parameters to capture relevant body movement information through the Max/MSP patch. The selected joints, listed in Table 3, were considered the most representative of my upper-body performance gestures. Shoulder movements were initially considered as significant but in my personal playing style the elbows tended to convey more expressive information, as observed in video recordings of piano improvisations that illustrate prominent fanning motions during expressive peaks in the middle of phrases.

---

[18] Challinor, R. n.d., *Synapse*, viewed 20 August 2015 <http://synapsekinect.tumblr.com>.

Table 3: Synapse parameters available in the Max/MSP patch

Parameter	Type of Motion Data Captured
Lefthand pos body	Distance of the left hand from the torso.
Righthand pos body	Distance of the right hand from the torso.
Left elbow pos body	Distance of the left elbow from the torso.
Right elbow pos body	Distance of the right elbow from the torso.
Head pos world	Head position in relation to surrounding space.

In Synapse, 'Body Mode' was chosen in preference to the other main options of 'Screen Mode' and 'Real-World Mode', which capture skeleton data relative to the Kinect camera and user's position within surrounding space. Instead, 'Body Mode' represents incoming joint data in relation to torso position coordinates. This provides data about body movement within peripersonal space or the kinesphere (Laban and Lawrence 1974): the area surrounding the body measured by the full extension of the upper limbs. This decision rested on past empirical research suggesting that music intuitively induces movement in peripersonal space (Eitan & Granot 2006) and that upper body motion is linked to expressive and affective communication (Kleinsmith, Fushimi & Bianchi-Berthouze 2005). An extension of this phenomenon is the notion of expansion and contraction as a conveyer of musical expressiveness, represented in the dynamic patterns of the upper limbs (Maes et al. 2010).

The position of the limbs away from the body was selected over global joint position within space to highlight the important expressive indicator of limb motion in relation to the body, recognised in previous gesture research (Davidson 1994; Camurri et al. 2004), and that features as an expressive cue in gestural processing environments like EyesWeb, which associate motion size and openness with the emotional intensity of musical performance (Maes et al. 2010). The position of the limbs away from the body indicates how demonstrative the performer is and how much physical involvement and engagement they exhibit, and acts as an indicator of the overall amount of energy exerted by the performer.

The sitting position at the piano regulates movement expression (Davidson, 2007). Therefore, the torso became a pivot and reference point for all other upper-body motion in this patch. This design decision was founded on empirical studies investigating piano performance, notably Davidson's (2007) identification of a link between motion shapes formed by the head and torso and expressively significant parts of a piece. The torso, Davidson argues, communicates general expressive intent while the hands convey more local information, explaining why they do not always deliver a similar level of clear expressive information to larger-scale gestures in her study (Davidson 2007, p. 386). For this reason, the hands were not represented in the patch I implemented for this work; instead the torso provided a context for interpreting all other more localised body movements.

Davidson acknowledges the global swinging movement of the torso in relation to the 'centre of moment' concept, where the centre of the body acts as a physical core from which expressive content can be spread to the rest of the body. This repetitive movement pattern is prevalent in my own piano performance, observable in video recordings of my piano improvisations, revealing the importance of the torso as a reference point from which other gestures of the upper body radiate.

In related work, Buck, MacRitchie and Bailey (2013, p. 110) uncover that patterns of phrasing motion are highly idiosyncratic, varying significantly between performers. Like Davidson, they also identify repeated curved motions in the upper-body movements of pianists that radiate from the body's centre. This discovery emphasises the importance of relating positional data of the limbs to the torso, rather than simply representing absolute position coordinates. Their quantitative study reveals that individual performers execute idiosyncratic versions of motion pattern shapes, acting as important indicators of individual performer expression (Buck, MacRitchie & Bailey 2013). This identification of unique movement styles distinguishing performers suggests that each performance is imprinted with a musician's individual movement style, a hypothesis I explored throughout the works described in this chapter.

In addition to selecting key joints that convey expressive information, I used acceleration data to represent the intensity and magnitude of combined movements. Position co-ordinates on the x, y and z axis were used to calculate the velocity and acceleration of selected joints. Within the patch, velocity was calculated by subtracting past position from current position. This decision is supported by related work involving the Kinect that finds velocity data to be more effective than positional data alone in allowing users to alter sound more intuitively with a movement-based controller (Yoo, Beak & Lee 2011).

A 'many-to-one' mapping was chosen, in which the combined acceleration of the left and right hands was calculated into an overall energy score within the designated Max/MSP patch. The energy score was mapped directly to the effects bus amount. This allowed me to link the overall intensity of my movements to the level of audio effects processing. The formula used for acceleration was *Current velocity – Past velocity / time*.

The combined energy output of the instrumental gestures controlled two effects buses within an Ableton Live session, one for each limb. As shown in Table 4, the effects on both buses included a resonant filter, formant shifting with Formant +5 plug-in in Ableton; the Six seconds delay; Ultra Grain (a granular effects plug-in) and a filter delay. Panning from left to right was achieved through upper-limb motion on the horizontal plane. The main effects in the effects chain are displayed in Figure 14.

Figure 14: Effects chain for *Concentric Motion*

During rehearsals and early improvisations with the software I also experimented with controlling a looper, applying time and pitch shifting to selected phrases. However, I decided to reserve this effect for future performances with more sparse instrumentation, as I was concerned about altering the pitch and rhythm while playing with acoustic orchestral instruments.

Table 4: Movement–sound mapping for *Concentric Motion*

Movement Data	**Mapped to:**
Combined acceleration of • left hand • right hand • left elbow • right elbow • head	Overall level of effects bus amount in A & B - • Formant modification • Delay • Granular delay • Resonators
Horizontal hand motion	Stereo panning

Acceleration or inertial sensing has become a viable technique for gestural interaction with mobile devices (Strachan, Murray-Smith & O'Modhrain, 2007). As a movement feature, it has also proven effective in triggering discrete free air gestures accurately and reliably, indicating that detecting peaks in acceleration could contribute to more naturally responsive gestural instruments (Dahl 2014).

In a study of air drummers performing discrete hits, Luke Dahl (2014) demonstrates the benefits of measuring acceleration peaks, as they occur on average before an audio event, offering a way of increasing real-time performance that can be applied to the improvement of gestural systems. This finding suggests that acceleration provides an effective way of detecting preparatory and concluding movements that occur before and after sound-producing gestures.

This technique also allows the performer to feel a natural sense of timing through the system, reducing the amount of perceived latency. The choice of acceleration to activate effects in this piece, which sometimes requires discrete movements to trigger rhythmic delays that synchronise with the overall tempo of the piece, is supported by this work on capturing air drumming hits successfully through acceleration peak detection.

The hardware setup for the augmented piano involved mounting the Kinect to recognise my side profile, leading to a degree of occlusion and jitter in the motion tracking, as a frontal view delivers more accurate joint recognition. However, a frontal perspective becomes problematic when the bulk of the piano obscures the camera's accurate detection of the body. I experimented with different mounting positions, including suspending the camera above the keyboard, but this had the effect of emphasising the fingers and hands at the expense of the rest of the upper body. Finally, the side position was decided upon, as the tracking resulted in the most desirable sonic effects. Unlike an engineering exercise, which strives for technical correctness, the sensing position was influenced mostly by aesthetic considerations.

In terms of audio setup, two condenser microphones were positioned above the soundboard of the piano. The microphone output was directed to a stereo channel in Ableton Live. For the augmented vocal, a wireless headset microphone was used to capture the sound of the voice. The full list of connections is displayed in Figure 15.

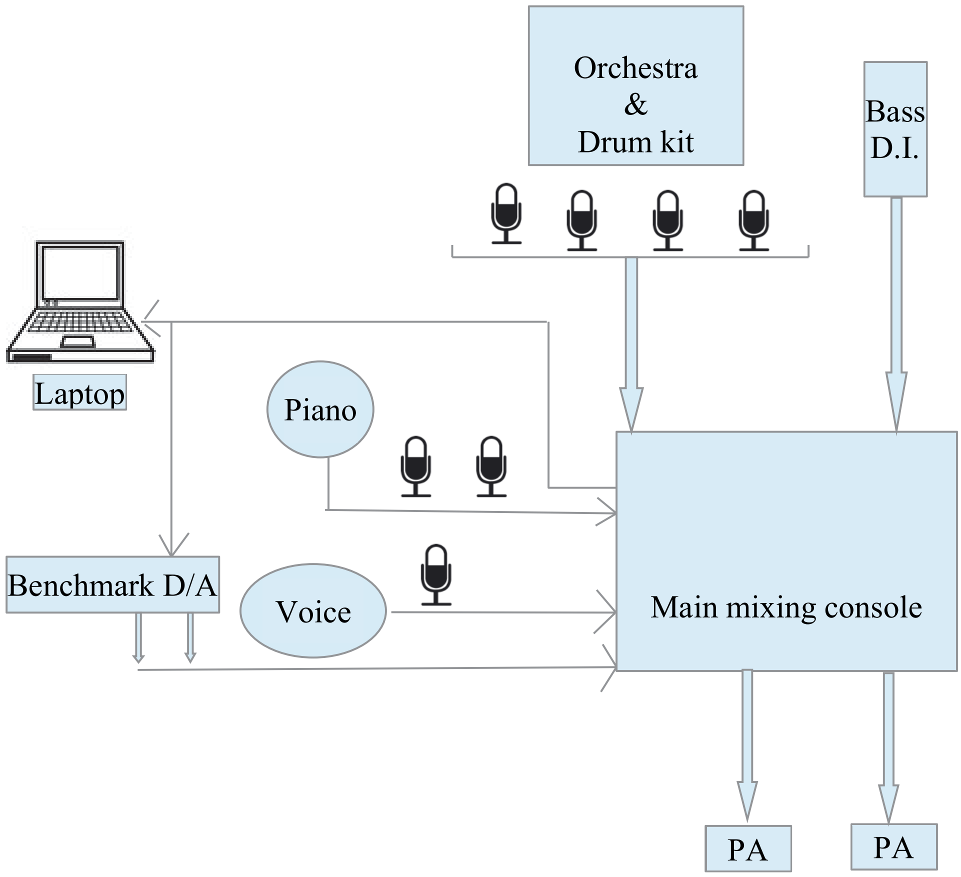

Figure 15: Schematic diagram: *Concentric Motion*

4.2.4 Video Projections

The initial aim of including a visual component for the work was to highlight relationships between performer movement and sound control while also adding to the visual spectacle of the performance. The projections were designed to amplify my movements and display the rationale behind the gesture-sound mappings for the audience. Stills from the projections are shown in Figure 16. A video recording of the work is also available for viewing.[19]

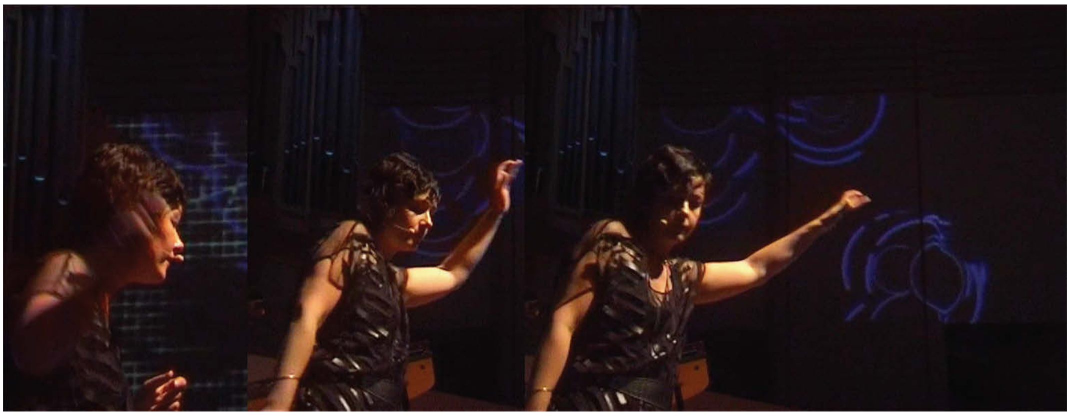

Figure 16: Video projections for *Concentric Motion*: vocal movements

The visuals were created in Quartz Composer.[20] A two-dimensional particle system responded to the amplitude of the line input from the piano and vocals, while the position of the particles related directly to the *x* and *y* position of the head and limbs. The particles were layered onto a subtly changing video grid-like background that formed a contrast to the size-shifting circles. The visualisation was projected onto two elevated screens on either side of the stage.

Portraying audio effects processing visually is not a straightforward process. Furthermore, when expressive gestures are reconfigured as control gestures, this becomes a murky area where the audience must reconsider the commonly-held perception of causality between action and sound in performance. Therefore, I limited the visual representation to mapping overall amplitude levels of incoming audio signal to the size of individual particles. Apart from the program notes, the

---

[19] A video extract and full video recording and score of *Concentric Motion* are playable or downloadable at the following link, viewed 20 August 2015, <http://www.mainsbridge.com/concentric-motion/>.

[20] Apple Inc. n.d. *Quartz Composer*, viewed 20 August 2015, <https://developer.apple.com/library/prerelease/watchos/documentation/GraphicsImaging/Conceptual/QuartzComposerUserGuide/qc_intro/qc_intro.html >.

audience did not receive any other information about the mappings, so I kept the projections deliberately simple in an effort to display a clear relationship between sonic output and the visualisation.

4.2.5 Composition and Performance

Concentric Motion is constructed around a rhythm section consisting of acoustic drum kit and electric bass, inspired by the rhythms of the body and the expression of rhythm through musical components that include phrasing, repetition and the application of force through accents.

Rhythm to me is a form of directed energy. Internal rhythms of breathing and circulation underpin our existence, such as the natural rhythm of wakefulness and sleep, which establishes a constant ebb and flow throughout our lives (Sheets-Johnstone 2010). As Michael Young (1998, p. 20) observes, “the bodies of human beings, and almost all other organisms, are composed of multiple rhythms, time locked ones at that”. These in-built rhythms converge with broader social rhythms, regulating our patterns of activity, providing vital links for understanding the idiosyncratic nature of movement and analysing how it can translate into musical rhythms.

The connection between movement rhythms and musical rhythm, explored in the choreo-musical field (Jordan 2011, p. 44), became a key aspect to organising the structure and interaction design of *Concentric Motion*. In a musical context, wind players have a keen sense of rhythm shaped by breathing and lung capacity, as do singers. This physical capacity influences the length of musical phrases, a connection that informs the mapping underlying this piece.

The work is divided into three movements — first a piano movement and then two vocal movements connected by an instrumental interlude. The subtle effects manipulations produced by piano movements contrast with the increasingly pronounced digital signal processing generated by the more expansive gestures that accompany vocal performance. Delays and resonators, triggered by sweeping arc-like movements specific to my vocal performance style, intensify selected phrases.

At the start of the performance, my movements were deliberately minimal and contained, ensuring that the acoustic piano sound could feature in isolation and highlighting the initial percussive chord progression introducing the piece. As my movements became more exaggerated, the rhythmic piano chords were punctuated by splashes of resonant filter and delay effects, emphasising key phrases. The acoustic drum kit and electric bass were then introduced, followed by the orchestra's string section.

The immediacy and tactility of the piano performance established a contrast to the non-tangible gestures of vocal performance, which occur later in the piece. At the conclusion of the first section, I rose from the piano, capturing the last phrase 'in the air', where it lingered in anticipation of the vocal performance in the following two sections.

In the middle instrumental section I controlled the sound of the orchestral instruments, applying counter rhythms with delays triggered by free air gestures. These movements appeared similar to conducting gestures (see Figure 17), functioning as a more exaggerated and dance-like extension of my expressive vocal gestures. The instrumental section was sonically dense, as it combined digital signal processing with the full orchestra. Therefore I had to carefully balance the processing amount with the 'liveness' of the highly reverberant concert venue.

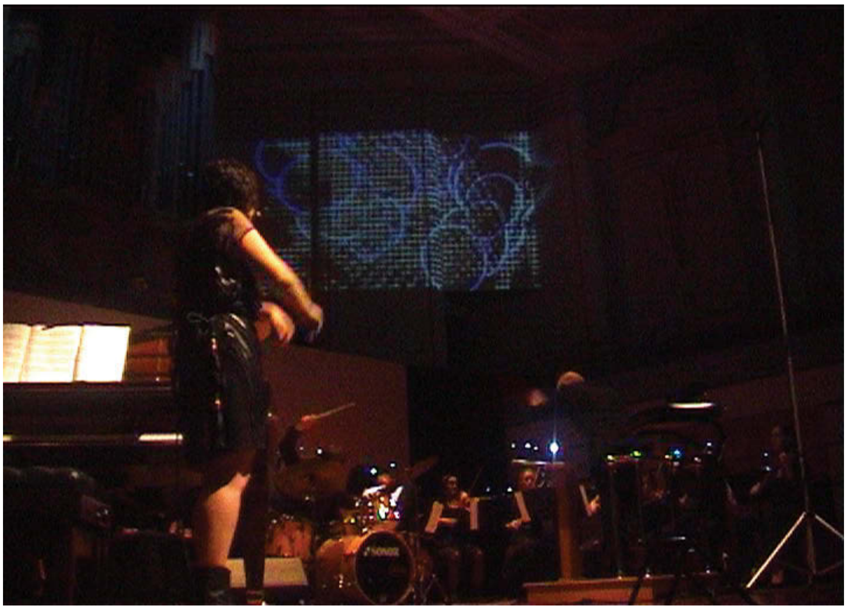

Figure 17: ***Concentric Motion*** **performance: conducting gestures**

4.2.6 Phrasing

The link between phrasing structure and movement observed in Section 4.2.2, Preparation, had a direct influence on the construction of the gestural processing patch for this piece. Ward et al. (2008) highlight the link between movement phrasing and sonic phrasing as a key to understanding effortful musical expression, which, they argue, can inform mappings of new DMIs. Drawing parallels between Laban's theory of movement phrasing and musical phrasing, they argue that musicianship hinges on sequences of movement that incorporate phases of preparation, action and recuperation. This is particularly relevant to vocal and wind instrument performance, where the need to take a breath regulates the length of phrases:

> For the designer of a new instrument a consideration of movement phrasing in the context of musical outcomes could form the basis for a new design

> that leverages the enjoyment of expressive movement rather than seeks simply to minimise effort. (Ward et al. 2008, p. 120)

The link between phrasing and effort is an important one, directly applicable to *Concentric Motion*, forming a unit of action linking energy levels with processing intensity.

During my past performances, effects, particularly delays, were usually activated during the concluding part of a phrase, affecting only one or two notes or beats to preserve clarity. In this piece I could take advantage of my concluding movements during the tail end of a phrase to initiate processing. In the case of piano performance, this usually included torso sway and an arm lift in preparation for the next phrase.

Similar patterns are observed in related empirical motion studies of instrumentalists, as summarised in Section 2.2.2, Expressive Gestures. A recent study of clarinettists demonstrates that briefer movements occur at the start and end of phrases, compared to more elongated and extended motions in the middle sections (Caramiaux 2012).

This distinction was utilised within my augmented instrument design by channelling longer, smoother movements during a phrase to produce more subtle effects control, and relating shorter, more energetic movements, characterised by increased acceleration, to increased levels of processing. By capitalising on the performance gestures occurring in the initial and final part of a phrase, I was able to create fluctuations in effects that mirrored the energy and intensity of my usual movement style. This pattern is reflective of Laban's notion that a movement phrase is divided into three phases that include an initiation or preparation stage, main action and recuperation (Ward et al. 2008, p. 119).

As Figure 18 demonstrates, the phrase of one vocal line is characterised by a preparatory gesture signalled by the arms positioned on either the side of the torso. The movement pattern then evolved into continuous, flowing arm gestures that create subtle audio effects. The phrase ends with a cyclical flowing upward movement of the left arm that extends above the head to activate maximum effects processing. This movement corresponds with the occurrence of the last syllable in the lyrical line, allowing the final note to be emphasised and extended through a combination of grain delay and resonant filter effects and additional compression. There is then a period of recuperation or recovery before the next phrase, in which no effects are activated to leave space for the repetitious effects to subside.

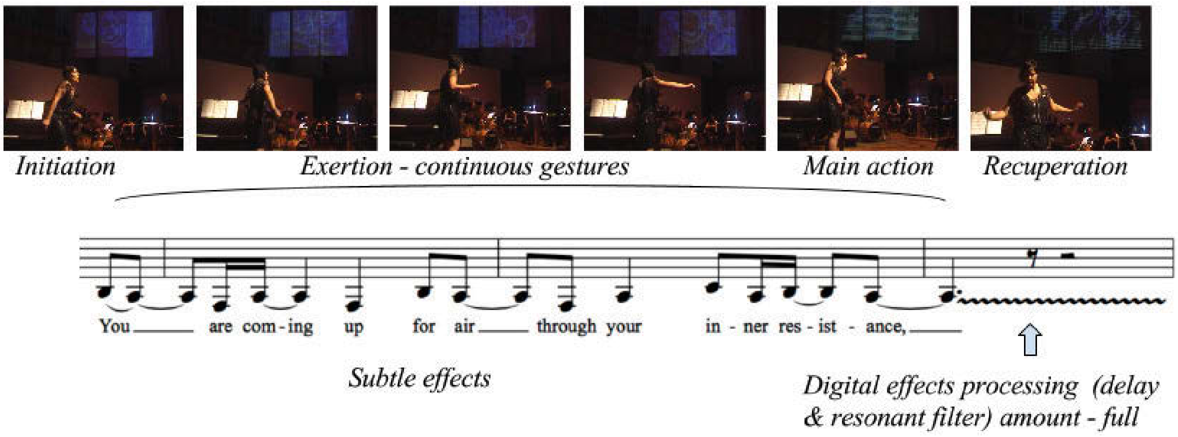

Figure 18: Phases of a vocal phrase in *Concentric Motion*

During initial practice sessions and rehearsals, the processing occurred at an almost subconscious level as I engaged with the gesture processing patch. My original aim was not to intentionally control effects but rather to arrive at unexpected sonic outcomes initiated by spontaneous movements. However, as rehearsals progressed, I found myself becoming increasingly deliberate in activating effects by exaggerating my usual movements, to make the sonic impact more pronounced. By the time of the concert, my movements had acquired an almost theatrical quality as I sought to not only increase the intensity of the effects but also to highlight the link between my expressive gestures and the electronic augmentation of the acoustic sound sources for the audience.

The overall result was the ability to accentuate the conclusion of phrases, producing resonances and delays that diffused into the gaps or 'breaths' between phrases. Similar to pressing the sustain pedal on a piano, the timing of effects activation often related to phrase introductions and endings. Throughout the piece, this gesturally-actuated processing capacity extended the percussive quality of the piano with more variation than a sustain pedal. The effects chosen accentuated the harmonic overtones of the struck strings, temporarily transforming the original tone of the piano that was heard alongside the unaffected acoustic signal.

Polyrhythms began to occur between the acoustic and processed signals when the delays coincided with the start of the next phrase. This rhythmic effect linked with another theme of the piece based on exploring the association between physical and musical motion, which I discuss in the next section.

4.2.7 Body Rhythms

In *Concentric Motion* I chose to evoke the inherent rhythms that emerge from the moving body. In the lead-up to the performance, I became increasingly attuned to basic bodily rhythms, including breathing, walking, resting and the timing of pauses between actions. I wished to explore how the delays within the effects sends could be varied by consciously altering a range of gestural phrasing patterns to produce deliberate syncopations and polyrhythms. I experimented with activating processing of vocal phrases and utterances on different accents, not just at the conclusion of a phrase, in order to produce subtly shifting counter-rhythms.

As outlined in Section 2.3.4, Augmented Instruments, rhythm can provide a common basis for understanding how music and dance intersect (Jordan 2011). This connection establishes a focal point for exploring possible sound–movement associations. Correspondences between rhythm in speech and gesture also emerge in Daniel Loehr's (2007) discovery of associations between speech stresses and hand gestures. In related work, Mewburn's (2009) study of the role of gesture in architectural design studio practice reveals a coupling between gesture and the rhythm of a drawing performance: "The timing of the drawing, speech and gesture helps tie the two modes together" (Mewburn 2009, p. 157).

The link between physical timing and musical components is explored in the work of Eitan and Granot (2006, p. 227), who argue: "Pace is the most direct link between music and motion and has been shown to strongly affect both music perception and production". A comprehensive overview of the interrelationships between rhythms in dance and musical motion is also available in Carlos Geudes' (2005) doctoral thesis, 'Mapping movement to musical rhythm: A study in interactive dance'.

In relation to vocal performance, I decided to focus on the link between hand and body gestures and my vocal phrasing, to gain an understanding of the rhythmic character of the connection. The vocal movements of *Concentric Motion* draw on theories relating speech to accompanying gestures, as presented in the work of Kendon (2004), McNeill (2005) and Goldin-Meadow (2003). The association between vocal and arm movements, head tilting and other common speech-related gestures provides fertile ground for experimentation, suggesting a range of mappings similar to the speech-gesture experiments pursued in Beller's

(2014) Synekine project, which is summarised in Section 2.3.3, Gestural Systems for the Voice.

In the first movement, I was restricted to instrumental gestures based around piano performance. In the vocal movement, however, the absence of a tangible instrument or the physical prop of a microphone stand automatically encouraged experimentation with more varied and expansive gestures. Exploring the rhythm of these movements became another reference point for me to help structure and frame my gestures.

The freedom of performing without an external prop prompted me to gain a greater awareness of the movement patterns I usually exhibit when I sing. I had never considered my performance gestures in isolation before this exercise, and at times found the process confronting and daunting. Like many musicians, I do not systematically reflect on my movements, unless I am in an educational setting where the aim is to improve my technical proficiency and minimise injuries from accumulated tensions in particular muscular areas. The last time I did this was when my shoulder rose spontaneously during technically challenging musical passages. My piano teacher at the time, a follower of the Alexander Technique,[21] made me aware of this extraneous motion and encouraged me to abandon this damaging habit in the interests of smooth energy flow and economy of movement.

Reflecting on this experience prompted me to reflect on the role of rhythm in other pedagogies that highlight self-awareness in order to explore the link between bodily movement and musical rhythm.

---

[21] Alexander Technique n.d., *Alexander technique*, viewed 20 August 2015 <http://alexandertechnique.com>.

A notable example is Dalcroze Eurhythmics, a practice:

> that awakens the possibility of experiencing music and movement in a sensitive way by attuning the body's sensitivity towards the qualities of its movements and that of music. (Juntunen & Hyvönen 2004, p. 211)

Of particular relevance to music education is the application of rhythmic movement exercises to illustrate rhythmic and musical concepts to enhance musicianship. These can include enacting a challenging rhythm by walking or clapping it out. The emphasis on increased awareness of kinaesthetic sensations guides the musician through this movement-based training (Juntunen & Hyvönen 2004, p. 203). I informally applied these techniques to gaining a greater understanding of my own movements and emerging rhythmic patterns, which I had previously never focused on in a considered way.

4.2.8 Discussion

The work *Concentric Motion: Concerto for Piano, Voice and Gestural Controller* was written early in my research journey. The central theme of the piece hinged on translating my common performance gestures into control inputs for digital audio effects processing. This approach subsequently became the template for future pieces and the inspiration for the *Gestate* system presented in Chapter 5.

Concentric Motion was performed at the Harold Lobb concert hall at the Newcastle Conservatorium in Newcastle, New South Wales, Australia. In such a reverberant venue originally designed for acoustic performance, the clarity of the digital audio effects were tempered by overall mixing balance considerations. Within my in-ear monitoring, I sometimes did not hear the effects adequately, resulting in a sense of disconnection from the overall sound. This affected my ability to control the digital effects processing with the level of precision intended.

This is evident in the video recording of the performance, where the dry vocal signal is far more prominent than the effected version, causing the effects to have less impact. Without direct communication with the sound engineer at the front of house, I was unable to rectify this situation during the performance.

The issue of controlling effects from the stage opens up the problem of not hearing a true stereo balance and the reverberations of the room sound that the audience hears. In-ear monitoring presents a compressed sound that does not reliably represent the mix the audience is hearing, making the achievement of an appropriate balance challenging. Although it is liberating to control the effects independently, this requires reliable foldback and extensive rehearsal time in the designated venue, to ensure that the appropriate balance can be achieved.

Another issue that emerged related to the cognitive demands of performing with augmented piano and voice. The performance necessitated a high degree of multitasking, resulting in a tendency to adhere more to the score than in my other semi-improvised performances. As I managed the simultaneous requirements of listening, vocalising, playing and maintaining an awareness of gesturing, I found myself reverting to pre-rehearsed melodic lines and lyrics.

Usually I improvise more, using the score of the soloist lyrics and parts as an indication of the recommended placement, key and rhythm of each phrase. However on this occasion I often lapsed into the safety of performing the parts as they were written, in order to concentrate on the gestural processing and the skilful delivery of instrumental and vocal phrases. This had the opposite effect to my original intention of performing spontaneously and maintaining a sense of flow and immersion.

Once the performance started, I found myself altering my usual behaviour by exaggerating each gesture to achieve more pronounced effects. This added theatricality emerged as a new and unexpected dimension to the work, the result of a feedback loop between my playing and hearing the results of gestural processing. It also highlighted the contradiction of using intuitive gestures to control processing. The unconscious suddenly becomes conscious and controllable.

As described in Section 4.1, Introduction, the second phase of the creative organisation underlying the works in this chapter represents the reframing of original performance gestures as control gestures. When expressive gestures are used as control data, their original meaning is disrupted.[22] In performance, extra-musical gestures may acquire a dramatic character, becoming exaggerated or drawn out, as the performer reacts to the digitally-altered sound and responds accordingly. In my case, I adapted my usual movement style to produce broad, sweeping gestures at the end of vocal phrases where I intended to intensify effects. Alternatively, I minimised my movement to return to the dry, unaffected vocal signal and bring the original sound to the forefront. I also used punctuated movements to capture a particular note or fragment of sound to delay or filter it in isolation.

Davidson (2006) identifies expressive gestural repertoires that are common in pop vocalist performance. These movements can emphasise lyrical content, similar to speech accompanying gestures, or occur subconsciously, as demonstrated in her expressive movement coding of influential pop vocal performances (Davidson 2007, p. 391). Similar to Donna Hewitt's work with the eMic and Cathy

[22] Van Eck, C. n.d., *Song no 3 - singing through gestures*, viewed 20 August 2015, <http://www.cathyvaneck.net/gallery/song-no-3/>.

van Eck's performance of *Song no 3*,[23] I appropriated several of these common upper-body gestures to process my voice. However, I ensured that they reflected my own movement style, as observed in video recordings of improvisations. Van Eck uses head and arm movements to control electronic sound in her performance of *Song no 3*. For me, spontaneous gestures made to the rhythm of the piece and around vocal phrasing were significant and therefore featured in the performance. These once-incidental performance gestures assumed a central role in the music production, even when they were originally accompanist in nature.

In the mapping strategy for *Song no 3*, van Eck highlights the alteration of gestural intention when a common vocalist gesture of moving the microphone to the mouth in anticipation of singing a phrase is transformed into a sound shaping gesture.[24] Unlike Hewitt and van Eck however, I did not include a hand-held microphone in the system. Instead I opted for a headset microphone, so as not to interrupt the skeleton tracking of the Kinect. This opened up increased freedom to experiment with creating new free air gestures, coupled with the need to create a whole new movement style borne from transforming usual patterns of movement, or at the very least, simplifying and abstracting existing movement to emphasise its essence. This process led me to delve further into channelling gestures associated with vocal performance for virtual instrument control.

4.3 *Gestural Études*

After composing several experimental pieces that augmented piano and vocal performance with expressive gestures, I created a collection of semi-improvised

---

[23] ibid.
[24] ibid.

studies that featured different virtual instruments controlled by free air gestures, concentrating specifically on upper-body motion. These multi-purpose instruments served as a form of vocal accompaniment using sound synthesis, and also as a means of extending my vocal sound with digital audio effects.

The studies built on my existing performance practice and skill set, facilitating the development of a broader gestural vocabulary and further experimentation with various mapping strategies. The process of composing, rehearsing and performing the pieces enabled me to reflect on the interplay of my motion patterns, inclinations and desired mappings to sound.

The performances explored various threads, including extended vocal techniques and the gestural control of virtual instruments based on physical models within audio-visual performance. The gestures used drew on my usual movement vocabulary as a vocalist, combined with a range of deliberate gestures to activate discrete controls. Through these works I aimed to blend existing technique with my acquired body language as a performer. The *Gestural Études* were performed at the Electrofringe Festival (2013) at Newcastle, New South Wales, Australia with drummer Robbie Mudrazija. A video of the performance is available for viewing.[25]

I combined a range of audio-visual environments to maintain audience interest during the one-hour performance. Each piece was arranged as a separate

---

[25] *Gestural Études* performance, Electrofringe Festival 2013, viewed 20 August 2015, <http://www.mainsbridge.com/gestural-etudes/>. Poor lighting conditions affected the quality of the video projections. The visualisation can be more clearly seen in a video excerpt of the Diffuse performance on 24 October 2013, on the same page, which features an improvisation with virtual instrument, the Arpeggiator.

scene with distinct visual feedback in the mapping software Isadora Core.[26] These audio-visual scenes featured a different interaction environment and aesthetic. The works were organised according to three main virtual instruments with distinct functions — Mixer, Arpeggiator and Cube.

Movement information was processed through the pre-existing Max/MSP patch designed for *Concentric Motion*. The OSC data was converted to MIDI information within Isadora Core to trigger note and visual effect changes. The MIDI messages were used to control the following virtual instruments in Ableton Live:

- Arpeggiator;
- Cube;
- Mixer.

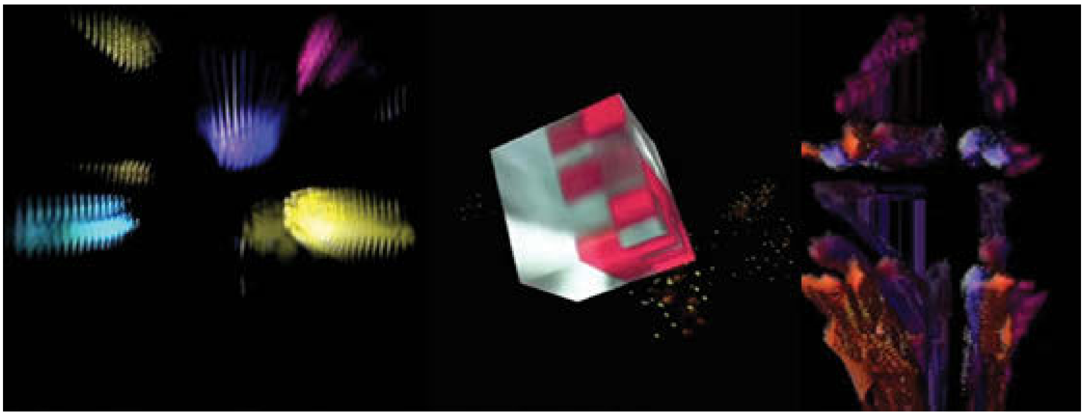

Figure 19: Arpeggiator, Cube and Mixer visual feedback

Visual feedback was projected onto a semi-transparent scrim erected at the front of the stage. The scrim performed the dual function of providing me with direct visual feedback and displaying a visualisation of my movements, body

[26] Coniglio, M. n.d., *Isadora Core*, version 2.0.5, viewed 20 August 2015, <http://troikatronix.com/isadora/about/>.

position and audio control processes. The visuals were deliberately abstract and conveyed aesthetic intentions rather than directive, explanatory information about the mappings. The projections drew out details from my performance gestures, using saturated colour and subtly shifting geometric patterns to emphasise their shifting dynamics. Positioned at the front of the stage, as shown in the stage layout diagram in Figure 20, the scrim projections were designed to provide an additional dynamic layer that emphasised my temporal actions.

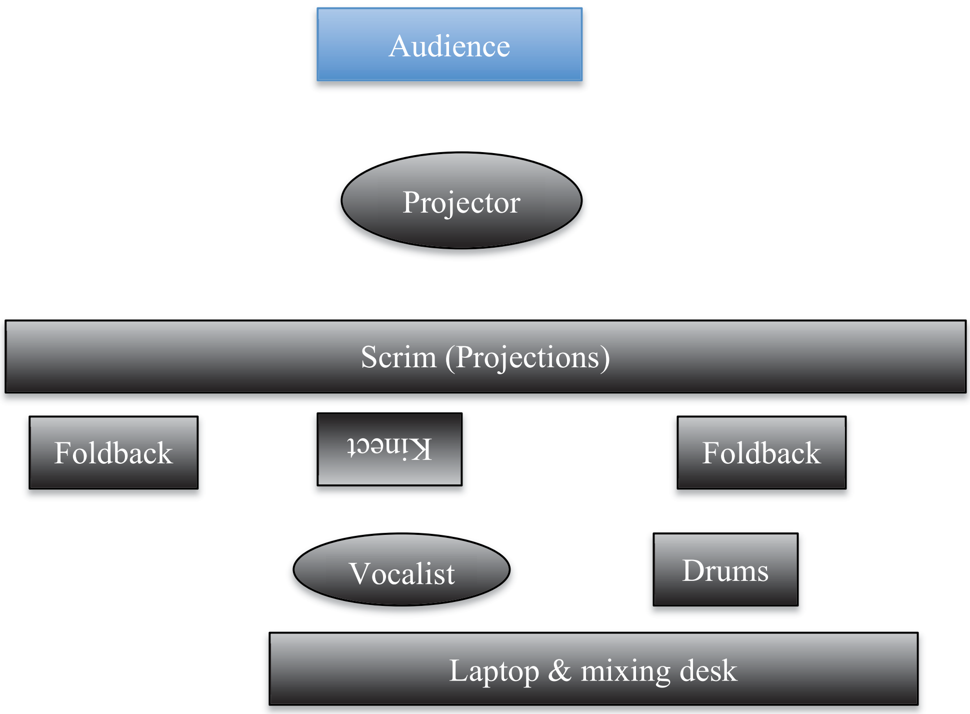

Figure 20: Stage layout – 2013 Electrofringe Festival

Projections have long been a part of my performances, presented in collaboration with a number of video artists, each of whom has contributed their unique aesthetic and musical interpretation. However, in this case I aimed to create visual components that echoed and amplified my actions, conveying the essence of the movement in an abstracted and simplified manner. I was interested in exploring how the ephemeral and immaterial nature of the video medium could offer a way to draw out the passing details of a gestural performance, reinforcing the links between performer actions and sonic outcomes for the audience.

Whereas in past performances I had mainly employed video projections to increase the sense of dynamism and visual spectacle of my primarily stationary electro-acoustic performances, I now wondered whether they could assist in calibrating my gestures. With the screen in front of me, I envisaged it as a virtual control surface, providing information about mode changes, position, detection of gestures and an altered view of my movements to aid proprioception. For example, I could clearly see if my movements were symmetrical, or visually observe their inertia through trailing particle systems that depicted the acceleration data being processed by the Max/MSP patch.

This calibrating function has been observed in other movement systems with visual feedback, including Wilde's work *Light Arrays*, which magnifies the augmented moving body to deliver a type of "observable synaesthesia for the viewer" (Wilde 2011, p. 75). Experiments with three artists possessing movement skills reveal that an array of LEDs and lasers embedded in a garment projecting lights onto the surrounding environment serve to augment their proprioception during the interaction. The participants find that the feedback offered by "the lights allow them to individually explore the different qualities of their physical presence in space" (Wilde 2011, p. 79), encouraging them to explore and move beyond their movement capacity.

This effect is also observable in a novel interactive dance system that visualises abstract physical models to draw out key movement characteristics (Fdili Alaoui et al. 2012). This targeted form of feedback is designed to educate the dancer on how to focus on and improve the execution of selected movement qualities.

Recent research into gesture learning confirms that dynamic visual feedback contributes to motor skill acquisition of two-dimensional gestures (Anderson 2014). An evaluation of an augmented reality mirror setup that forms part of Anderson's system, YouMove, reveals that visual feedback facilitates movement training for full body interaction, supporting both memorability and accurate reproduction of gestures.

Without training in full-body movement, which is available through areas such as dance and sports, acquiring advanced motor skills can necessitate extensive training and repetitive practice, requiring a prolonged time investment (Ward et al. 2004). As I do not possess specialist movement training or experience, the addition of visual feedback was intended to assist me in becoming more aware of my position in space, to recognise the state of the system and to stimulate a greater understanding of how I move in relation to the system. Through this process I hoped to gain more familiarity and nuanced mastery of movement-based musical control. Like a dancer who uses a floor-to-ceiling mirror to guide their movements, this altered visual representation of my actions offered another dimension to my virtual instrument performances by allowing me to focus on movement aspects drawn out by the system.

4.3.1 *Étude 1* — Audio-visual instrument study using set gestures

Étude 1, which features the Cube application, provided an opportunity to experiment with set gestures activated by punching movements of the right hand. The intention of the piece was to provide a transparent mapping that would enable the audience to recognise a clear and direct connection between gesture and sound before progressing to more complex mappings later in the performance.

4.3.1.1 Preparation

As the *Gestural Études* mark a departure from using instrumental gestures, it was necessary to configure new movements that were sympathetic with vocal performance and could be used to control virtual instruments in solo or ensemble formats. This formed the start of creating a deliberate gestural vocabulary, inspired by movements that emerged during improvisation sessions. Figure 21 shows a screenshot of the first piece's visualisation, created with the Cube application.

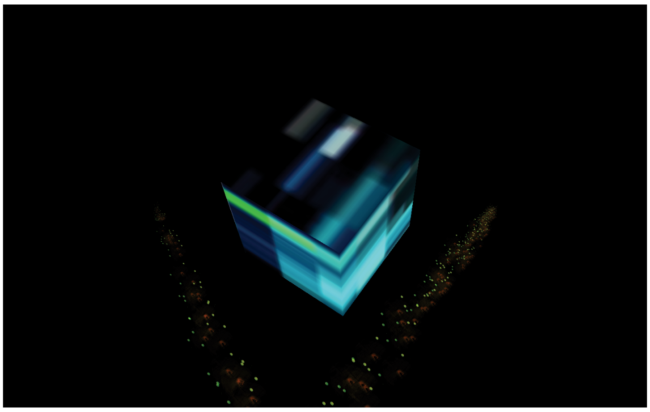

Figure 21: Cube application: screenshot

4.3.1.2 Mapping

Mapping that clearly links movement, sound and visuals was employed. This link elucidated the mapping for the audience, creating a sonic metaphor that draws on prior experiential knowing. The sound was generated through physical modelling synthesis, using a physical mallet model. The percussiveness of the sound was matched to swift input actions. I activated a range of chords through forward, backward and sideward punches with the right arm.

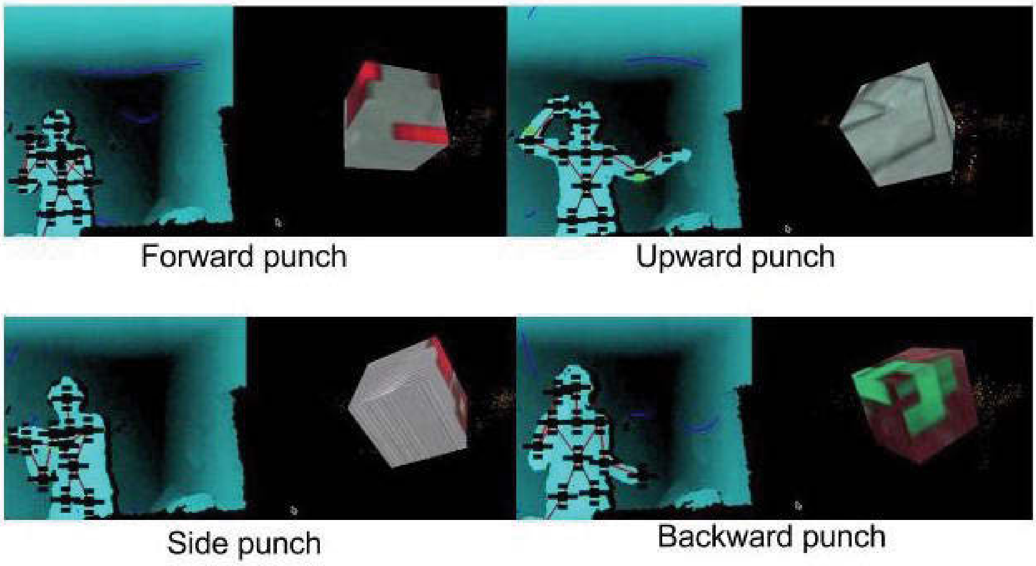

Figure 22: Gesture vocabulary for the Cube

In Figure 22 the main types of punches are shown with the corresponding rotating cube visualisation. In terms of the eight basic Laban formulated to characterise the human movement efforts (Figure 23), punching or thrusting are quick and direct movements that can be executed with bound or free flow, according to the basic effort elements illustrated in Figure 8 (Newlove and Dalby 2004, p. 138):

> When punching the air, rather than a target, the counter-tension of the antagonistic muscles will be strongly felt. As a *basic effort*, punching is direct, sudden and strong and its essential characteristics involve overcoming Weight, Space and Time, therefore, there is no indulgence in this action, no yielding to lightness or flexibility and no yielding to sustainment of the movement.

Figure 23: The Dynamosphere by Laban illustrating the eight basic efforts[27]

These motion qualities made the punch a suitable movement to trigger a physical mallet model, which requires an accurate percussive attack to be triggered at the intended time. The contrast between direct punching gestures and the flowing movement style of my previous augmented vocal and piano performances, enabled the system to reliably differentiate these discrete trigger gestures from common performance gestures, resulting in less false positive triggers. More flowing movements could then be reserved for digital signal processing of the voice and the physical model itself.

The visual feedback, demonstrated in Figure 24, featured a three-dimensional cube that completed one rotation each time a punch was executed in either a forward, upward, sideward or backward direction. Each side of the cube represented a different arpeggiated chord in a preset sequence. The aim was to appear to be rotating a virtual physical object in space, giving the overall mapping a sense of tangibility for the audience. This first mapping was deliberately simple, with clear correspondences between action, sound and visuals in order to introduce

---

[27] Georgia Robotics and InTelligent Systems Laboratory, viewed 3 February 2016, <http://gritslab.gatech.edu/home/2011/07/dancing/>.

direct causal links between the three elements to the audience before introducing more abstract mappings later in the set.

Once a sound was triggered in the right hand, the left hand could capture the audio output and feed it into the effects chain, using continuous, flowing motions. A particle system represented the presence of effects and also traced the *x*, *y* and *z* positions of both arms. With rapid and fluid movements between the left and right arms, complex alterations to the arpeggio could be achieved. The difference between continuous flowing and discrete punching gestures is demonstrated in Figure 24 during the performance of this piece at the Electrofringe Festival in 2013, in which the virtual instrument featured as a solo part and also as a form of accompaniment for the voice. Acceleration of selected joints, using the same algorithm that formed the basis for the augmented piano and vocal applications previously outlined was again used to drive effects on the virtual instrument and voice.

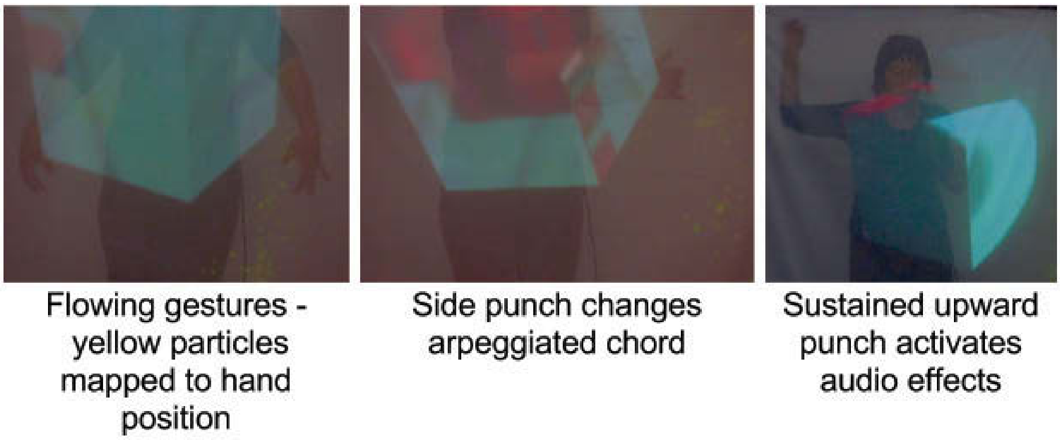

Figure 24: ***Gestural Études*: *Étude 1* mapping**

One undesirable effect of using predefined punching gestures was to contradict my original aim of achieving varied movement expression. Although I enjoyed having some constraints to operate within in order to guide my movements, I found that the repetitive punching overly restricted my behaviour. If I had based the mapping more on my usual movements, I may have been able to attain a more fluid approach to manipulating the virtual object.

4.3.2 *Étude 2* — Study with virtual mixer

In this piece I explored the scope and range of my movements. I began observing the outer reaches of my movement range and discovering the zones I felt most comfortable in. I wanted to extend my movement repertoire beyond these zones by experimenting with a mixing metaphor, using expansion and contraction of the upper limbs to control the amplitude of a multitrack composition comprised of sustained synthesiser chords. I experimented with slow arm stretches and long, sustained movements to gain a stronger feeling of control when mixing sounds spatially. I noted the mental and emotional states I reached after each of these improvisations, and used these impressions to compose the piece based on a slow-moving chord progression.

Throughout the work, I controlled six pre-composed MIDI parts with my hands, altering the levels of each channel with my arms. This instrument allowed me to control the amplitude of multiple sounds by tracking the position of both arms as they moved horizontally away from the torso, constructing six-part harmonies.

Figure 25: Representative gliding control gestures of the Mixer application

Employing the pitch to verticality metaphor, higher parts were located above the head, mid-range parts next to the torso, and bass parts below the pelvis, as indicated in Figure 26.

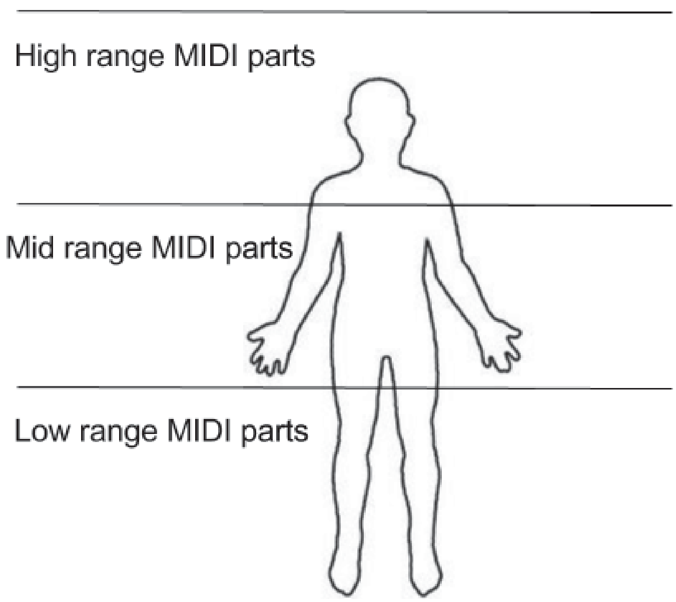

Figure 26: Control zones of the Mixer application

Extending the arms out resulted in maximum sound level, whereas keeping the arms close to the torso lowered the sound level. The choice of sustained synthesiser chords with slow attack encouraged gradual and fluid gestures, visible in Figure 25.

The qualities of these movements correspond to gliding in Laban's basic efforts classification.

4.3.2.1 Mapping

In developing this piece, I explored the contrast between the body being contained, resulting in little or no sound, to full expansion and maximum amplitude. I originally thought of the constrained ways in which we move during our everyday lives, limiting our movements to the bare minimum required by our daily activities while staying closely within our imagined circle of interpersonal space. When we move in crowded urban spaces, we shrink further into our personally defined space.

Similarly, when creating music on the computer I often feel my posture collapsing until I become conscious of it due to feelings of tightness and discomfort. I then correct it before forgetting and slumping into the chair again. With stationary and restricted movements, the body becomes stiff and stilted. I am constantly resisting this tendency in my own movement patterns. The sedentary nature of computer use has long dominated my creative process as an electronic musician, a state I actively resisted through these compositions.

Authors such as Antonio Camurri have associated expanded limb movements with joyful feelings and contracted movements with sadness (Camurri et al. 2004). This expressive indicator is incorporated as an independent module known as the Contraction Index (CI) in gestural processing software, EyesWeb. When expanding my posture I felt a sense of openness that did alter my mood somewhat. I felt less inward looking, but I also enjoyed the balance of contracting to achieve dramatic contrasts between subdued, quiet sounds and thick, loud sounds, where more sonic detail could be heard. I relished mixing in this way, by exploring the space around me, offering the opportunity to mix sounds with a greater degree of detail, compared to mixing with linear faders of a fixed length on a hardware mixer.

Throughout the Electrofringe performance of this piece, I found the experience of mixing with increased movement range preferable to controlling knobs or sliders, partially because it enabled me to maintain an open, upright posture, observing the visual feedback and audience through the screen, and partly due to the physically expanded degree of control. This enabled me to invest my whole body in the control process and to develop a more embodied feel compared to operating conventional controllers with small finger movements.

However, achieving precisely calibrated movements was challenging in such an exacting task as mixing. If I moved too quickly or jerkily, sudden jumps in amplitude would interrupt the smoothness of transitions between peaks and controlled fade-outs. As there were two parts for each of the bass, mid-range and high frequencies, there were also sometimes unexpected overlaps between channels that caused confusion over which part I was actually controlling.

The piece therefore became a useful exercise in learning how to achieve smooth, measured physical control of sound by slowing down my movements and learning to navigate around peripersonal space without the benefit of tangible reference points.

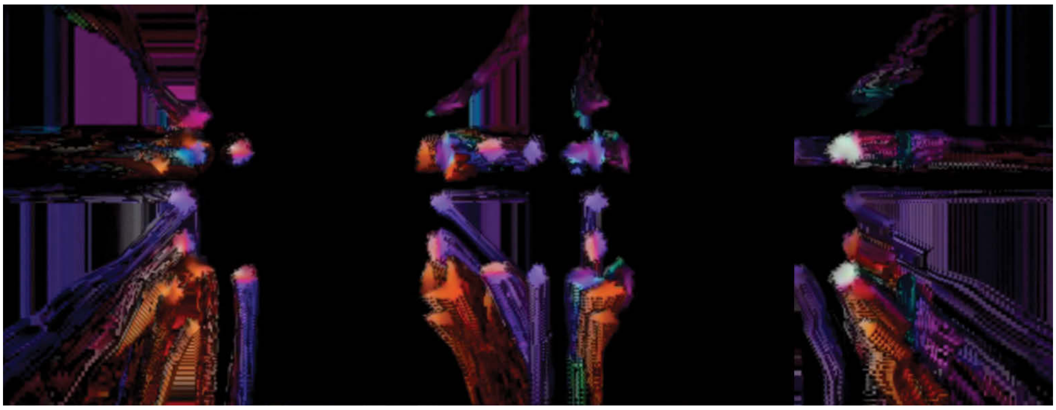

Figure 27: *Étude 2* visualisation screenshots

4.3.2.2 Visual Feedback

The visual feedback represented the positional data of the hands, head and torso. A short animation consisting of four rotating blocks of colour were spread to the far edges of the screen with expansive movements of the head and limbs, tracing the path of these motions. This smearing effect was created with a feedback plugin in Isadora Core, and was designed to visualise the correlation between the scale of overall motion and amplitude levels. The slowly evolving effect also accentuated the gradual pace of my movements and slow attack of the sustained synthesiser parts.

At times during the performance I found myself becoming distracted from the audio output, instead directing my focus on creating aesthetically pleasing images. However, I also found that the visual effect sometimes contributed to a more refined focus on the pace and regulation of my movements, which assisted me in achieving more precise and fluid control over audio levels.

4.3.3 *Étude 3* — Study for arpeggiator controlled by continuous gestures

The final piece featured the Arpeggiator, a synthesiser controlled by free air gestures. I found that it encouraged the most freedom of movement of all the virtual instruments described so far. Arpeggiated notes were controlled with the right hand,

and pitch was mapped to vertical motion. Apart from this constraint, any movements could be used, encouraging more extensive movement experimentation than the other applications and inspiring a number of other compositions.

The Arpeggiator allowed me to explore variations in the speed, direction and flow of my movements to achieve subtle or more exaggerated effects. It functioned more like an instrument than the other applications, allowing greater depth of expression and ongoing exploration than the Cube and Mixer, which served more as controllers for pre-composed musical elements.

As with the Mixer application, I could access different pitch zones by activating high, mid-range and bass frequencies in corresponding vertical spaces alongside the body. Joint position data from both arms was translated into MIDI messages that triggered notes in an arpeggiator plugin in Ableton Live. In a few-to-many mapping, sweeping acceleration movements triggered feedback and resonant delay effects. The mallet physical model used for the instrument, Timbulara, is a Collision instrument in Ableton Live.

Figure 28: Video stills from *Étude 3* Electrofringe 2013 performance

Figure 28 highlights an expanded gestural vocabulary to the previous Gestural Études. As well as performing continuous and free flowing motions with both hands, I also became more mobile in the torso. As the final still shows, I began contracting and expanding my overall posture to intensify dynamic transitions.

I could also prolong a phrase with feedback delay by suspending one arm in the air to provide a type of drone to support my singing, as seen in the first still of Figure 28. Gesturing frantically resulted in a concentrated cacophony of sound, which could then be reduced to a small bass rumble with minimal movement, followed by complete silence when I placed my hands over my chest.

I found this virtual instrument the most satisfying of all three because it encouraged exploration and the development of new movement patterns. It could function as either a solo or an ensemble instrument. However, I did not think it had the depth of sonic manipulation to be featured in a longer piece, unless I started feeding the live input of the voice or an audio file through it.

4.3.3.1 Visualisation: Triangle Feedback

A pre-made video clip supplied a subtly vibrating virtual energetic force field of triangle shapes composed of neon colours (see Figure 29). I could disrupt the force field by moving through it with upper-body motion. The *x* and *y* positions of the arms affected the amount of columns and rows in a three-dimensional mosaic effect within Isadora Core, sporadically disrupting the smoothness of the projection. When the hands were drawn close to the heart, the sound ceased and the screen returned to black.

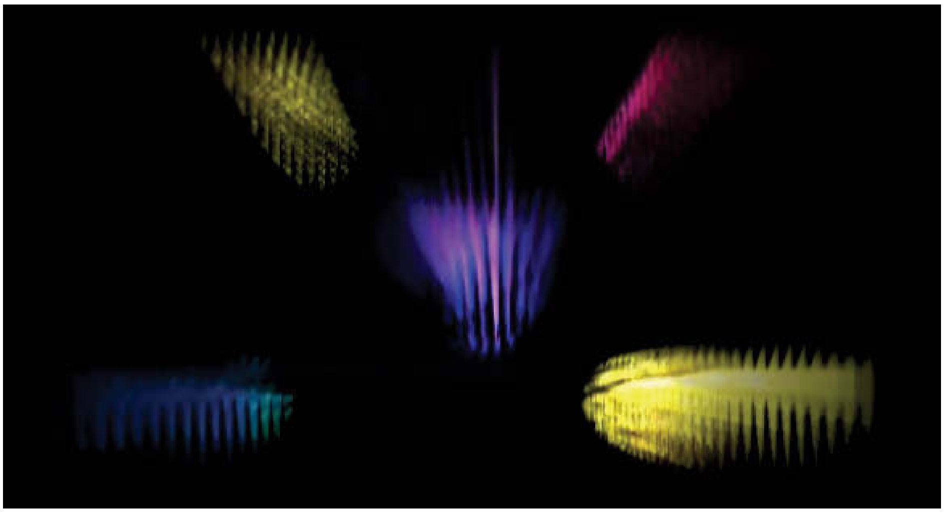

Figure 29: *Étude 3* visual feedback: screenshot

4.4 Post-performance Reflections

Controlling the virtual instruments with free air gestures for the first time in a performance was a completely new style of performance for me. With no specific instrument design to conform to or microphone stand to use as a prop, I felt a new sense of exposure and vulnerability before the audience, even with the shielding presence of the screen.

For vocalists, the freedom of movement offered by non-tactile controllers, paired with wireless microphones, can seem equally liberating and daunting. In these situations, performers need to invent new ways of performing, perhaps even extending or exaggerating their movements to create more dramatic sonic results or visual impact. For vocalists accustomed to performing with a microphone and stand, this novel way of working with the body may only become comfortable after many rehearsals and performances. I observed this transition to more physically expansive modes of performing as I progressed through the improvisations and rehearsals of the *Gestural Études*, increasingly becoming more willing to experiment with movement beyond my usual vocabulary.

Of all the applications discussed in this chapter, the augmented piano offered the most familiarity in terms of being able to leverage common instrumental gestures and technique. As I moved towards vocal and virtual instrument control, my usual movement language progressively expanded in response to the interaction. Feeling at ease with movement experimentation, I believe, plays a significant role in conveying a convincing movement-based performance and achieving alignment between actions and intended sounds.

4.4.1 Mapping Transparency

A continual challenge that emerged from the performances was the clear communication of mapping connections and interaction to the audience. Anecdotal feedback from several audience members revealed a lack of clarity regarding the relationships between movements, resulting sounds and the visualisation. My intention was always to make the processes behind the works transparent and understandable to the audience, stemming from my original motivation of incorporating greater physicality and visible effort into electronic performances. Yet this area required the most improvement, prompting further exploration in future works and informing the refinement of initial design decisions.

The need to draw out the physical presence of the performer within the interaction in a transparent way for the audience is also a priority for pianist Sarah Nicolls, who experiments with electronic enhancement of the instrument. She argues that "if physicality is being used to control something then it *must* make sense in some way, it must have a relationship that can be comprehended by the audience" (Nicolls 2010, p. 54). This essential prerequisite does not necessarily entail a reduction to simplistic one-to-one mappings that compromise the performer's engagement and interest, but a continual pursuit of connections that intuitively make sense by designing mappings based on familiar physical associations for the audience, such as the association between vertical and gravitational forces drawn from embodied metaphor theory (Antle, Corness & Bevans 2013). I continue to discuss the potential for these understandings to be reinforced with sympathetic visual amplification in Chapter 7.

4.4.2 Multi-tasking

Performing with gesturally controlled virtual instruments in the *Gestural Études* and augmented instruments in *Concentric Motion* presented multitasking challenges that led to some physical stiffness and self-consciousness as I became preoccupied with managing a range of processes. The concerto performance yielded many valuable lessons regarding the importance of balancing the cognitive demands of gestural control with instrumental and vocal performance. The event also offered the opportunity to combine innovative forms of presentation with the traditional concerto form, posing the challenge of finding an appropriate blend between the orchestral sound palette and gestural processing.

Reflecting on the video of the Electrofringe Festival performance, I observed a degree of physical restraint, demonstrated by a fixed facial expression and constrained movements. The lower half of my body barely moved. I stayed in a stationary position for most of the show, partly due to the smallness of the stage and the size of the makeshift scrim. The concentration on achieving precise pitch and amplitude control with my arms, like a theremin player, may also have contributed to this lack of physical expression.

The video footage confirmed my feelings of self-consciousness during the performance, associated with adapting to a completely new style of performance and learning to play a recently developed suite of instruments to which I was still becoming accustomed. The movements associated with these instruments were still emerging and I had not yet developed a movement language that reflected many years of engagement and practice, like I did with the piano.

Personal insights that emerged from these performances are in line with well-documented issues in the field of gestural and augmented instrument performance, particularly the issue of cognitive overload (Lähdeoja, Wanderley & Malloch 2009). When performing with effects controllers, the responsibility of maintaining constant audio levels and sonic clarity can preoccupy the performer by adding an additional control layer to existing vocal or instrumental technique. As discussed in Section 2.2 4, Augmented Instruments, Lähdeoja, Wanderley and Malloch's proposed solution is to introduce non-direct gesture–sound links through a multi-layered mapping strategy that frees the user from full conscious control over effects (Lähdeoja, Wanderley & Malloch 2009). However, in order to maintain a transparent mapping that is easily understandable by the audience and performer, I chose to adopt a mapping strategy that enabled me to exercise complete control over every aspect of the audio processing, rather than introduce an extra hidden layer that could obscure the connection between movement and sound.

Repeated practice is another method that may assist in reducing cognitive overload. When gestural controllers are used extensively as the main instrument throughout a performer's career, a deeper sense of mastery can develop (Hewitt 2013). The temptation to undertake last-minute instrument redesigns is common with interactive systems, leading to possible unresolved technical issues and a steep learning phase for the musician before a performance. The benefit of moving away from the cycles of constant refinement by 'freezing' development allows the performer to explore the system thoroughly, promoting confidence and the multitasking skills that such interfaces require.

4.4.3 Simplicity

One of the dangers of designing interactive systems is to overload the system by capturing too many movement parameters and mapping them to an endless array of sonic parameters. This problem, identified by Rokeby (1998) in relation to his installation work, illustrates the fact that users can become overwhelmed quickly when faced with a plethora of choices in an interactive system.

In the early stages of the *Very Nervous System*, Rokeby (1998, p. 41) attempted to translate user actions to countless parameters of system behaviour:

> I worked out ways to map velocity, gestural quality, acceleration, dynamics, and direction onto as many parameters of sound synthesis as I could. Every movement they made affected several aspects of the sound simultaneously, in different ways. Ironically, the system was interactive on so many levels that the interaction became indigestible.

This unexpected level of complication caused early users of *Very Nervous System* to regard the installation as a playback device and not interactive at all. Therefore, a designer must always temper their desire to explore the many exciting possibilities of movement-based control with a consideration of the performer's attention levels and cognitive threshold.

The call for simplicity is also evident in Puckette's (2012) warning against the temptation to become a 'one-man band' with interactive technology — controlling all of the instruments, visuals and lighting in a multisensory circus-like display. He also issues a caution about controlling too many modalities, which can lead to feelings of incomprehension amongst the audience. Because the technological means are available, he argues that the capacity to control too many parameters simultaneously can overwhelm the performer and make the connections between movement and sound processes opaque for the audience.

I consider this challenge in my own work. I initially planned to simultaneously combine looping, conducting, virtual instrument and augmented instrumental performance, aiming to achieve as much independence as possible through gestural control. However I also needed to balance this desire with aesthetic and usability considerations. I did not want to be overtaken by the management of multiple sound processes that would impede my ability to express myself physically and artistically.

Controlling too many simultaneous parameters can also affect how the audience perceives this type of performance. A high degree of overlapping gesture-sound relationships can lead to confusion and disassociation from the performance. I therefore deliberately chose to restrict the amount of gestural control applications used, or vary them at different times throughout longer performances containing several separate pieces.

Another area in which I exercised restraint was in relation to the notes themselves. I balanced the melodies to ensure definite pauses between each to allow sufficient space for processing. This resulted in simpler and sparser arrangements to leave adequate time for effects such as delays to be heard. Like Nicolls' experience of constructing an augmented piano performance (2010, p. 55), the aesthetic choice to produce simpler musical language was as much about conveying clear movement-sound associations to the audience as conserving cognitive space to perform multiple performance and processing tasks. Nicolls achieves this by "balancing the triangle of variables: the musical characteristics of the live input, the complexity of the processing controlled and the way the control happens" (Nicolls 2010, p. 55).

4.4.4 Improvisation

Through conscious reflection, I realised which movements were in harmony with my body and which movements were hindering fluid, effective movement (Shusterman 2009). I also developed a greater sensitivity to sensations relating to specific movements and movement qualities, and a capacity to vary and expand the scope of these movements. These insights align with other experiential interaction design approaches such as Loke's (2009, p. 57), confirming that "[t]he awareness of the experience of movement grows through repetition and experience."

The process prompted me to consider the use of improvisation in unlocking intuition, which I believe resides in the body. When designing discrete, functional gestures, I was keen to discover new types of movements that could be distinguished from my usual movement style and thus recognised adequately by the system. Improvisation sessions during practice and rehearsals facilitated this process. Improvisations during performance revealed the importance of expanding movement range in a dance-like or theatrical way to extract more nuance and variation from the system, demonstrating the influence of gestural control on my usual performance style.

4.5 Conclusions

This chapter presented the early movement improvisations and works that helped develop a practical understanding of the potential and limitations of existing movement-sound mapping strategies in my performances. These strategies drew on common DMI mapping methods, including few-to-many and explicit mapping, combined with basic embodied metaphors including pitch to verticality, expansion to amplitude levels and effort to intensity.

This performative inquiry has produced gesturally augmented vocal and piano performances controlled by expressive gestures and a set of *Gestural Études* that explored virtual instrument control with free air gestures. The pieces were informed by self-observation to identify the types of movements and movement qualities to use for the featured gestural control applications. To formulate mappings and discrete gestures for functional controls, I engaged in a series of sound–movement improvisations, emphasising the importance of direct experiential involvement and reflection throughout the mapping design process.

The transition from common instrumental and vocal gestures to a more deliberate gestural language influenced the usual ways in which I moved during performances, inspiring further movement exploration and adventurousness that was sometimes tempered by the self-consciousness of performing with minimal physical constraints in public.

In the next chapter I discuss how the insights from these embryonic works and performances influenced the development of a gestural performance system that served as a template for future pieces.

Chapter 5: Gestate System

5.1 Introduction

Drawing on insights from the performances and installations discussed in the previous chapter, I designed a flexible, adaptable system that could suit a range of performances. This chapter describes the rationale, design strategy and applications of Gestate, a gestural system developed to extend vocal and instrumental performance. Gestate was designed to facilitate the exploration of relationships between movement and sound. The prototyping process was directly informed by physical engagement with the interface.

Throughout a series of rehearsals and performances, I experienced the gradual evolution of new movement skills in response to continuous interaction with motion tracking sensor technology. This experiential knowledge evolved through the development of the works and movement improvisations described in Chapter 4, in which I explored and observed my own movement potential and the way in which it could best be translated into sonic form. This artist-led approach prioritises the acquisition and refinement of motor skills and kinaesthetic awareness, aligning the system with a range of experience-based approaches to movement interaction design (Kjölberg 2004; Moen 2006; Hummels, Overbeeke & Klooster 2007; Loke et al. 2013).

Initial mapping strategies and design criteria were adapted from existing gestural systems and theories identified in the literature and contextual review, which were then refined through further interactive compositions and performances that were discussed in the previous chapter. Iterative prototyping uncovered which of the chosen strategies proved most effective in the context of my performance practice.

Acting in the dual role of performer and designer, my primary intention was to develop an interface that functions as a seamless extension of the body, clearly demonstrating that the performer's moving physical form is the source of the sounds produced. The need to create a system that offered detailed and nuanced control was another significant design consideration in promoting the exploration and expression of new ideas that sonify the movement range, patterns and energy that flows through the body. The framework underlying the system was designed to be adaptable to a broad range of performers' needs, allowing for movements and gestures to be mapped to a range of continuous sound parameters.

The Gestate system provides both auditory and visual feedback. The desire to explore the strength of visualising motion and audio data to enhance user experience, precision and accuracy is a further dimension to the research presented in this chapter. The following sections examine how the main design criteria are addressed.

5.2 Design Criteria

Widely varying approaches to gestural interface design reflect diverse design priorities and criteria. This section outlines common design goals, based on guidelines drawn from the HCI and DMI design fields that focus specifically on usability and acknowledge the unique movement styles of individual performers.

In the general HCI field, Norman and Nielsen (2011) propose that usability guidelines meet the need for greater standardisation of gestural interfaces. Norman (2010) believes more time is required to make gestural interfaces viable alternatives to other interaction types, as the development of gesture as an interaction style is still in its infancy. He argues that further research is needed to decide how best to utilise gestures in interaction design and formalise conventions defining a standard set of gestures that retain the same meaning across a range of systems.

Norman and Nielsen (2011) outline how abiding by fundamental principles of interaction design, independent of technology, can improve the usability of gestural interfaces. Although referring primarily to touch-based phone systems, their guidelines are also relevant to musical performance contexts, listing adequate feedback, discoverability and reliability among the key requirements for effective gestural interfaces.

However, general guidelines from the HCI field must be adapted in relation to digital musical instruments (O'Modhrain 2011). Design criteria can vary according to the needs of a range of stakeholders, including performers, designers, composers, manufacturers and audiences (O'Modhrain 2011). Within the DMI field, there are several recurring design requirements. Evaluation guidelines proposed by Wanderley and Orio (2002) present learnability, explorability and controllability as essential prerequisites.

Human factors researchers investigating human–computer interaction have assessed systems on the basis of 'naturalness', referring to the consistency and adaptability of the interface to the user's preferences. In general gestural interface design, the incorporation of natural, uninhibited gestures ensures that people with a range of abilities, body types and skills can use them without over-exertion.

Within musical performance, this adaptability to individual body types and inclinations is often referred to as 'feel', or the fit of an instrument to a performer's body: "The 'how it feels' consideration is part of a critical feedback loop between action and instrument response" (Paine 2015, p. 84). Marshall and Wanderley (2011) evaluate the feel of an instrument according to the following characteristics: controllability, engagement, entertainment and potential for future performance.

The feel of a gestural system influences discoverability and ease-of-use. Although it is an important criterion for general gestural interaction, in DMI research ease-of-use has been found to interfere with expressive potential because it does not push performance boundaries and challenge the performer to produce richer sonic results. David Wessel and Matthew Wright (2002) stress the need for an adequate balance between ease-of-use during early adoption and strategies that stimulate ongoing interest and musical expressivity, a goal they describe as a "low entry fee with no ceiling on virtuosity" (Wessel & Wright 2002, p. 12). Similar musical requirements guide the development of Steven Gelineck's physical modelling instruments, including balancing simplicity of controls with infinite creative possibilities to achieve precision, expression and explorability (Gelineck 2012, p. 37).

A starting point for some designers is to adopt traditional acoustic instruments as a model or inspiration (Dobrian & Koppelman 2006; Kvifte & Jensenius 2006). Jensenius relates the laws governing acoustic instrument design to future instrument design (Jensenius 2013). Similarly, Tanaka (2000, p. 403) regards a successful sensor-based instrument as one that combines computer-human interface design with acoustic digital lutherie. Turning to classical models of a performer's relationship with an acoustic instrument, he lists fluency, coherence and clarity as essential design characteristics. I also draw on acoustic instrument design principles and existing musicianship to guide the design of Gestate, as I believe this approach is potentially accessible to a broader range of musicians, offering familiar frames of reference to guide early learning.

However, acoustic instrument design differs from gestural interface design in one significant area — conventional instruments are usually designed to conform to average body measurements, making them less adaptable to people with different physical requirements:

> It follows that there is a need for musical instruments with gestural interfaces that can adapt by themselves, through "learning" capabilities, or be adapted by the performer, without specific technical expertise, to the gestures and movements of the performer. (Mulder, 2000, p. 326)

Therefore, potential design criteria directed at improving performer engagement and satisfaction with gestural systems must also identify ways to make the instrument adaptable to varying performer needs and body types.

By leveraging existing musicianship, design strategies can be shaped to capitalise on established techniques musicians apply to learning and mastery. To achieve this goal, I apply insights from research into how musicians' body schema is shaped by instrumental performance. Nijs, Lesaffre and Leman (2009) pursue a greater understanding of the ways in which acoustic musicians relate to their instruments when performing classical music repertoire, particularly where the:

> symbiosis between musician and musical instrument results from a growing integration of instrumental and interpretative movements into a coherent whole that is compatible with the body of the musician and with the movement repertoire of daily life. Such integration leads to the transparency of the musical instrument that just like "natural" body parts disappears from consciousness. (Nijs, Lessafre & Leman 2009, p. 132)

To ensure that the musical instrument does not interrupt direct engagement with music, they argue that is necessary for it to be integrated into the performer's body schema.

The way that the body adapts to an instrument contributes to experiencing flow (Csikszentmihalyi 1996), which Nijs, Lesaffre and Leman (2009) consider a prerequisite of the instrument becoming a natural extension of the body. Their work is influential in the formulation of the following design goals that focus on the notion of the musician and instrument becoming one:

1. Intuitive interaction;
2. Nuance;
3. Explorability;
4. Consistency;
5. Flexibility.

These criteria address similar themes to related design research in the NIME community. Andrew Johnston (2009) identifies consistency, naturalness, complexity, flexibility and engagement among his prerequisites for virtual instruments, while Dan Overholt (2009) lists the wide range of expression, perceptibility of gestures and well-behaved synthesis algorithms among the criteria for Musical Interface Technology Design Space (MITDS), a framework for the design of expressive musical instruments.

In the following sections, I discuss each of these criteria guiding the Gestate design in further detail.

5.2.1 Intuitive Interaction

A common goal of gestural interface design is to provide users with the means to intuitively interact with an interface, so that no gestural vocabulary needs to be learned and gesture/action mappings are self-evident (Malizia & Belucci 2012, p. 37). In other words, the interface needs to be easily *discoverable* (Saffer 2008), a key guideline also set out by Norman and Nielsen (2011). The term 'intuitive interaction' generally relates to interfaces that a user can immediately utilise successfully (Antle, Corness & Droumeva 2009, p. 236) and that behave in a way that people expect (Spool 2005). Unlike a GUI, which enables every function to be discovered through the progressive exploration of menus, gestures cannot be easily represented in this type of visual format (Norman and Nielsen, 2011), and thus a gestural system relies on other techniques to promote intuitiveness.

Gestural interfaces are often referred to as 'natural user interfaces' (NUIs), based on the assumption that they are controlled by everyday gestures and therefore require no prior learning (Malizia & Belucci 2012, p. 36). Yet many gestural vocabularies fail to represent users' true behaviour, as they are created in laboratory contexts (Malizia and Belucci, 2012, p. 37). Alessio Malizia and Andrea Belucci (2012) call for a high degree of personalisation and customisation in gestural interface design, enabling end users to define their own gestural vocabularies in order to integrate the cultural, human and contextual variations inherent in gestures. Perhaps unconscious gestures, not involving hand movements, are more natural than the types usually used in interaction, they argue.

Malizia and Belucci (2012, p. 38) claim that current designs reflect a 'natural artificiality' where a set of gestures are imposed by a designer, when they should instead:

> break down the technology-driven approach to interaction and provide users with gestures they are more used to, taking into account their habits, backgrounds, and cultural aspects.

Similarly, Norman (2010, p. 6) disputes the tendency to label gestural interaction as natural, arguing that “gestures are neither natural nor easy to learn and remember. Few are innate or readily predisposed to rapid and easy learning”. The notion of natural gesture in music is also contentious, as any well-practised habit can become automatic (Sloboda 2005, p. 268). Through practice or rehearsal, a performer’s own expressive repertoires can become intuitive or semi-automatic.

In Alan Wexelbat’s (1995, p. 180) interpretation, ‘natural’ “means that the computer system adapts to the abilities and limitations of the human being, rather than the other way around”. Levels of intuitiveness in a musical interface are also measured by how natural the control gestures feel (Overholt 2009). Yet gestural systems often enforce a behavioural code that the performer must conform to, in the interests of discoverability.

Several dance and somatic theorists regard the body as an important access point for intuitive expression. Whitehouse (1995, p. 245) reflects that:

> the kinaesthetic sense or the sensation which accompanies or informs us of bodily movement which is developed in athletes, dancers, and actors if never developed or seldom used becomes unconscious and leads to distortions and a cutting off from instinctual functionality.

She regards the body as a central point for storing memories and emotions, possessing a unique type of intelligence (Kossak 2015, p. 37). Like body-centred psychotherapists who encourage spontaneous and improvised movement as a way of accessing this ‘embodied intelligence’ (Kossak 2015), movement-based systems have the potential to encourage this intuitive sense of connection.

American dancer and choreographer Martha Graham often commented that “[m]ovement never lies” (Graham, cited in Foster 1986, p. 28). This observation characterises the search for natural ways of moving, a natural body, and natural choreography — ideas prevalent in American concert dance throughout the twentieth century, where dance became "an outlet for intuitive and unconscious feelings inaccessible to verbal (intellectual) expression" (Foster 1986, p. xiv).

Dance-influenced interaction designers such as Moen (2006) prioritise the recognition of natural or intuitive movements:

> In movement-based interaction we should provide possibilities for people to make use of their natural movements for communication and to create a dialogue with the system or application. When people can move freely and make use of their natural and spontaneous movement patterns, they can choose to use movements that feel good in the body and that correspond to the personal movement qualities. (Moen 2006, p. 14)

By focusing on spontaneous movement patterns, designers can equip users with an entry point into an interaction scenario that promotes an early sense of confidence, encouraging them to explore the interface further.

Moen's (2006) research has implications for the construction of intuitive connections between gestures and sounds through a gestural system's mapping strategy. Intuitive interaction has an impact not only on performer understanding of a gestural system but also on audience perceptions: "Straying even a little from what seems intuitive in terms of mapping — what *makes sense* on a feeling level — will result in a piece for which the outsider loses all perception of interactivity" (Wechsler 2006, p. 67).

The mapping strategies for Gestate apply image schemas and embodied metaphors, tapping into tacit domains to increase levels of intuitiveness, where ample "opportunity for exploration remains for going beyond simple one to one physical mappings into the realm of abstract data manipulation" (Hurtienne &

Israel 2007, p. 134). The mapping therefore does not need to be over-simplified in order to make it understandable and easily learnable, but rather leverages familiar experiential knowledge to enable more complex interaction.

5.2.2 Nuance

Nuance refers to the level of sensitivity and subtlety achievable when controlling a gestural system. Ferguson and Wanderley (2010, p. 25) highlight the necessity of a DMI to extract information about subtle and fine details of performance gestures. They attribute the expressive potential of an instrument to both its design and well-honed performance practice. To evaluate this criterion, they consider a performer's feedback to be most relevant, based on comparisons with past performance experiences using other instruments.

To achieve this goal requires careful attention to mapping and gesture detection strategies to ensure that they do not limit the capacity for nuanced performance. As discussed in Section 2.4.2, Mapping, one-to-one mapping in musical controller design has been criticised for constraining expression. In the field of tangible interaction, Hornecker and Buur (2006, p. 440) echo this sentiment, observing that "too many tangible interfaces aim for direct one-to-one mappings, remaining literal and missing out opportunities". To avoid these limitations, "[t]he interface should be sensed in a holistic fashion encouraging a complex mapping with nuanced control of acoustic properties" (Malloch 2011). It is therefore necessary to create mappings that allow detailed control of multiple variables such as pitch, amplitude and timbre.

Evaluation measures set out for the MITDS by Overholt (2009) are relevant in this regard. Overholt emphasises the need for a sufficiently rich mapping methodology that accommodates the widest possible range of expression. This involves deepening the sensitivity of mapping and synthesis algorithms to allow a virtuoso precise control so that they can get the most out of a sound — placing the responsibility on the *human* performer, not the interface, to achieve expressivity.

The MITDS aims towards augmentation of human capabilities through high, mid and low-level controls. Higher-level interfaces controlling musical attributes such as tempo, spatialisation and volume do not offer as much detailed control. Expert musicians may prefer low-level interfaces controlling timbre, individual notes and even more fine-grained qualities (Overholt 2009, p. 220). Overholt believes that it is possible to combine both of these levels to create a more versatile interface. Designs that provide access to these different levels of control can thus reflect the needs of a broader range of musicians.

5.2.3 Explorability

By their hands-on nature, gestural systems encourage play and exploration (Saffer 2008, p. 19). Gelineck (2012) argues for the necessity of digital musical instruments to facilitate the exploration of new musical ideas. This is essential for sustaining a musician's interest in a new interface, as exploration prompts more advanced levels of use, ensuring the longevity of an instrument. The potential for highly variable musical outcomes is important for stimulating a musician's engagement and involvement throughout their career, and also for providing the ability to produce dynamic performances and highly original, diverse compositions.

A suitable environment must be constructed to embrace the opportunity for infinite play, following similar principles to game design. For a musician, interaction needs to be rewarding to encourage deeper levels of engagement and control (Overholt 2009). Achieving an appropriate balance between initial ease-of-use and explorability remains a significant challenge for designers, to ensure user satisfaction and to attract continued interest from musicians.

An effective gestural system for musical performance should stimulate ideas that could otherwise not be reached through other methods. In an open-ended form of creativity, the user can employ the system to explore the effect of their physical movement on sound, forging their own associations between the two and feeding these discoveries back into their work. The system also needs to capture the performer's attention during early and more advanced stages of use, enabling them to develop increased mastery with each performance.

5.2.4 Consistency

Under this category is latency, precision, repeatability and reliability. Immediacy relates to latency: the system should be plug-and-play and not require endless hours of adjustment. In a live performance situation, the robustness of a system is necessary to achieve convincing performances while remaining 'in the flow'. As Norman and Nielsen (2011) emphasise, there is no excuse for system operations not to work. Stability is essential in performance contexts, where a crash can ruin a performance and unpredictability can erode the player's confidence (Murray-Browne & Plumbley 2014).

Recapturing spontaneity and immediacy when physicality is compromised through the use of digital electronics is a primary consideration when designing new musical instruments, argues Joel Ryan (1991). It is up to the designer to inject physicality in an instrument if there is no existing physical component (Ryan 1991, p. 6). Achieving adequate responsiveness from a musical controller hinges on attaining the expected "feel" (Ryan 1991) or fit between the device and the musician.

In the area of HCI, Norman and Nielsen (2011) include standardisation as part of this criterion. Norman (2010) predicts that gestures will one day be standardised so that specific movements are linked to common functions across interfaces, such as an upward action relating to an increase in sound, action or amplitude. The cultural and contextual variables of gesture add to the challenge of constructing universal gestural vocabularies. However, incorporating familiar metaphoric associations in designs to guide users through a system may provide one step towards attaining this aim.

Despite the increasing affordability of sensors and the steady rise in commercial, academic and artistic gestural applications, lack of standardisation in the field of gestural interface design means artists are confronted with seemingly endless possibilities when incorporating gestural interaction into their work. The majority of gestural instruments are developed for specific projects and research applications. The lack of cross-purpose applications may contribute in part to explaining why more musicians do not consider gestural control to be a viable alternative to acoustic instruments and DMIs modelled on conventional instruments.

5.2.5 Flexibility

One of the most important goals is to design gestural systems that are accessible to musicians without formal computer programming skills, so that a wider range of users can participate in the design and development of audio-visual applications (Taylor, Boulanger & Torres 2006) and easily customise system variables such as input gestures, mapping and sound banks to suit their own needs and preferences. This includes being able to enter into and make necessary changes to hardware and software elements, influencing the expressive potential of the system independent of the designer (Wilson-Bokowiec & Bokowiec 2006).

The capacity to adapt gestural systems to performer physical needs and stylistic preferences is also paramount. Gestural design needs to accommodate different body types (Saffer 2008). Within a musical context, designer and performer Axel Mulder (2000) sets out an agenda to improve compatibility between performers and new instruments by addressing the physical variations among users in a variety of contexts. He draws on Richard Moore's concept of "control intimacy" to describe this match between the skills of an experienced performer and the desirable musical outcomes available from an instrument (Moore, 1998). Moore considers the human voice to exhibit the most control intimacy, alongside instruments such as the violin, sitar and flute, where "micro-gestural movements of the performer's body are translated into sound in ways that allow the performer to evoke a wide range of affective quality in musical sound" (Moore 1998, p. 22).

This knowledge is highly relevant to gestural interface design. It features in the design requirements presented by Wessel and Wright (2002, p. 2), who believe that control intimacy can be achieved with appropriate control metaphors and low latency systems, encouraging users of new instruments to further develop their skills and personal style.

In the next section I present a description of Gestate, which employs similar design strategies to meet the goal of flexibility, through the inclusion of mappings based on embodied metaphor theory and visual feedback to promote exploration and learning amongst musicians.

5.3 System Overview

Gestate is a gestural control system that draws on the performer's movement language to augment vocal or instrumental performance with virtual instruments, effects and visualisation. The system provides an environment that promotes the gradual evolution of creative ideas through unconstrained and exploratory physical movement. It offers a framework to improvise with the temporal and spatial aspects of gestural control in a way that suits live performance.

Table 5: Summary of Gestate system

Hardware/Software	• Sensor to track upper body motion — **Kinect** • Real-time programming environments — **Max/MSP** and **Isadora Core** • Audio engine — **Ableton Live**
Gestures Used	• Common performer gestures for augmented piano and voice. • Deliberate functional gestures — continuous/discrete.
Mapping	• Continuous gestures of performer drive effects. • Discrete gestures trigger on/off events; e.g. looper record/play. • Acceleration of combined joints drive audio effects processing — effort linked to intensity. • Virtual instrument control - right hand position controls pitch and MIDI note generation.

Gestate can be used in a non-inhibitive way to augment acoustic instrumental performance with virtual instruments, effects and visualisation. It gives the performer remote access to mixing, processing and looping, enabling independent control over sound processes that would otherwise be relegated to a live sound engineer.

The system's aims are to:

1. Explore the continuous control potential of movement to shape evolving timbral characteristics of sound;
2. Achieve nuanced control over sounds that feels natural and intuitive to users;

3. Examine the user experience of performers, especially from the perspective of visualising music, visual monitoring and efficacy of mapping in the predictability and expression of gesture-controlled sound.

Unlike particular cues that are recognised by gesture-recognition systems, this kind of system, which analyses continuous flowing gestures, does not require an instrumentalist to fundamentally or radically alter their approach to their conventional instrument. This sets it apart from gesture-only interfaces or dancer-actuated systems.

Figure 30 shows the architecture of the Gestate system.

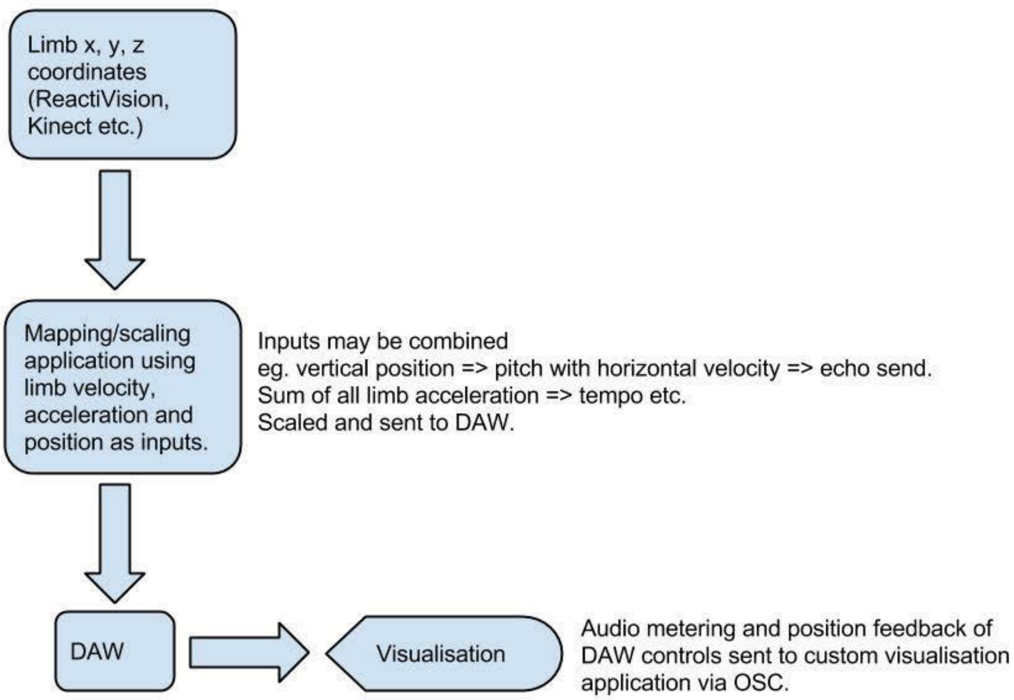

Figure 30: Gestate system architecture

5.3.1 Hardware/Software

Performer movements are tracked with a Kinect depth camera using freely available motion tracking software, Synapse. My motivation to pursue non-invasive control modes that did not constrain movement led me to computer vision, experimenting with webcams and ReacTIVision systems before deciding on the Kinect. Through the remote sensing of physical gesture:

> the human body itself can now be considered as a natural and powerful expressive 'interface' able, once again, to give feeling to performances based on computer generated electro-acoustic music and computer generated visual-art. (Tarabella & Bertini 2000, p. 35)

This freedom enables the performer to apply existing vocal and instrumental performance movements and skills to gestural control with minimal interruption.

5.3.1.1 Software

Max/MSP is an audio-visual programming environment that enables highly customised and flexible data manipulation. It is used to process movement data and route it to dedicated video mapping software (Isadora Core).

Within the patch, acceleration of upper body motion is mapped to two effects bus levels; a looper and a selection of virtual MIDI instruments within Max/MSP and Ableton Live. When the acceleration stops, the bus levels return to 0, much like a sprung wheel control. Minimal movement or static poses return the user to a dry signal. The distance of either limb from the torso is mapped to increasing amplitude and processing amounts, thus linking sonic intensity to effort expenditure.

5.3.2 Gesture Vocabulary

The absence of a universal gestural interaction language places the responsibility on designers to develop their own gestural vocabularies without reference to industry standards. The two types of gestures used to control the current system are first, deliberate or functional gestures, and second, expressive gestures that accompany instrumental and vocal performance. The first type applies to intended gestures controlling discrete functions including activating record and playback in a looper application within Ableton Live. The second type controls continuous parameters such as overall processing levels, with continuous expressive gestures. Incidental gestures with no apparent musical meaning, such as adjusting microphone placement, are also detected by the system and influence the overall sound, as these spontaneous gestures still form part of a performer's overall movement language, even if unintended.

As discussed in Section 2.2, Defining Gestures, expressive gesture encompasses both sound-producing and sound-accompanying gestures, which in combination constitute a performer's unique body language. From my own performances, I identified a different set of expressive gestures during vocal and piano performance. This typology informed the selection of key joints that conveyed expressive content, including the head, hands and elbows. The information from these joints was then used to drive the patch.

When controlling discrete functions, I experimented with a range of gestures inspired by embodied metaphor theory (Antle, Corness & Bevans 2012). Drawing on McNeill's (2005) metaphoric gesture classification, where "an abstract meaning is presented as if it had form and/or occupied space" (McNeill, Brown & Anderson 2006, p. 4), I use the term, 'metaphoric gesture', to describe gestures that visually represent the abstract musical concepts of pitch, dynamics or intensity and the sonic parameters of amplitude and stereo panning.

Metaphoric gestures were employed to explore the following metaphors that linked physical experience to musical and audio mixing parameters:

- Pitch to verticality;
- Panning with the horizontal axis;
- Expansion and contraction with amplitude levels and effects intensity;
- Circular motions with looping;
- Flicking/punching motions with percussive hits.

This idea links with Johnson's (2007) notion that image schemas underpin thought, by providing a way of describing abstract concepts in a form that has an experiential, real-world basis.

Functional and discrete gestures were selected to contrast with continuous expressive gestures, so that the system could easily differentiate between them. These movements also needed to be compatible with vocal and instrumental technique. Sharper, more punctuated gestures were designated to discrete control. These included flicking and punching motions, which were used to trigger chord changes and looping functions. Both of these movements were already incorporated as pre-existing commands in the Synapse application, so did not require additional programming.

5.3.3 Movement Data

After identifying the gestures to be used, decisions were made about what type of motion data would be processed and mapped to sound. Several Max/MSP patches were designed to acquire positional data of the head, arms and hands in relation to the torso, since this information was found to convey significant expressive content, as demonstrated in the relevant literature (see Section 2.2, Defining Gesture).

Acceleration data was used to translate the energetic force behind the movements. Rather than mapping each performer gesture to an individual process or sound, the combined energy of all upper body motion was defined in an algorithm that calculated the overall energy score of the performer. As the movements became more rapid and expansive, effects intensity would increase.

Acceleration was chosen for the varied information it reveals about movement parameters over time, including details about the position, speed and magnitude of gesture. In a system presented at the 1995 International Computer Music Conference that detected conducting movements using a three-dimensional accelerometer, the research team of Hideyuki Sawada, Shin'ya Ohkura and Shuji Hashimoto favoured measuring force of movement over positional data: "The most important emotional information in human gestures [...] seems to be in the forces applied to the body" (Sawada, Ohkura & Hashimoto 1995, p. 257). By developing a system that processes changes in the velocity of *x*, *y* and *z* co-ordinates, valuable emotional information stemming from the forces exercised by and on the body is communicated (Marrin 1996, p. 45). This may explain the popularity of inertial devices as a versatile sensing option, summarising key movement information about inertial measurement and position, inclination, tilt and orientation (Kalatha & Caridakis 2013, p. 99).

In the movement analysis of a dancer, the measured energy, especially the inertial mass of the accelerometer, was found to convert well to sound energy (Schacher & Stoecklin 2011). A comparison of hardware accelerometer and motion-capture sensor data of dancer movement reveals that mass, momentum and inertia appear to be significant carriers of expression (Schacher and Stoecklin, 2011, p. 4). The energy and effort expended by the dancer are more pronounced in the inertial sensor data than the absolute spatial position detected by the motion-capture system Schacher and Stoecklin (2011) use to measure the data.

These discoveries support insights from my own experiments of comparing positional, velocity and acceleration. In my experience, the patches calculating acceleration had an improved feel and produced more interesting musical results, particularly for controlling effects. I could directly sense and physically understand feelings of effort, exertion, inertia and momentum through my movements by hearing their influence on audio processing. It also changed the way I think musically - rather than using position to guide my movements, I found that acceleration data was more effective in representing cyclical and swinging motions associated with my vocal performance.

5.3.4 Embodied Metaphors

The Gestate system borrows from embodied metaphor theory to inform interaction and establish meaningful relationships between gesture and sound. This design approach is inspired by the phenomenological tradition, underpinned by the assumption that body-based experiences shape and structure our understandings of existence and our environment. The theory is informed by the concepts of embodied schemata (Johnson 2007), cross-domain mappings (Lakoff & Johnson 1999) and conceptual blends (Imaz & Benyon 2007). By tailoring movement-based systems to incorporate familiar pre-existing knowledge, grounded in bodily experience, users are armed with a real-world basis for exploring mapping relationships within the system.

The potential benefit of applying image schemas, or repetitive patterns of sensory motor experience, in interaction design is to support intuitive communication and informal reasoning (Wilkie, Holland & Mulholland 2013).

Embodied schemata are implemented to provide users with a better understanding of a system's mapping strategies. Although Gestate continues in the tradition of personalised approaches to mapping, based primarily on my movement style and preferences, I was still interested in finding more generalised and universal gesture-sound connections through embodied mapping to aid intuitive interaction for potential future users of the system and to promote audience understandings of the mappings.

A number of interaction designers incorporate tacit knowledge from physical experience to enable intuitive control and comprehension of abstract musical concepts. Harmony Space (Bouwer, Holland & Dalgleish 2013) is an example of an interaction system that illustrates abstract concepts related to tonal harmony through whole-body interaction. Drawing on Dalcroze philosophy, the authors recognise the benefit of changing the method of learning harmony from notation exercises and performing on a polyphonic instrument, such as the piano, to allowing students to manipulate harmony with their own bodies. The system uses several conceptual metaphors relating tonal harmony to specific concepts (Wilkie, Holland & Mulholland 2010), such as associating musical intervals to steps in various directions around a dedicated floor space.

Another application, the Sound Maker (Antle, Droumeva & Corness 2008), employs an embodied metaphor in a dedicated mapping layer to assist children to learn musical concepts through physical engagement with the interface. In an experiment comparing the implementation of the system with and without the embodied mapping layer (Antle, Droumeva & Corness 2008), a group of children were given a series of musical tasks and asked to vary one musical parameter, such as pitch or amplitude. In learning to control the sound parameters, the children needed to recognise and remember which movements would elicit a desired sound effect. They achieved this task more consistently with the embodied metaphor system version.

The notion of extending knowledge through embodied interaction is at the core of Gestate's design rationale. I applied this concept in simple ways. The main metaphor mappings I used in the system included pitch to verticality, energy to sonic intensity, expansion and contraction for amplitude control in the case of the Mixer application, and stereo panning in relation to horizontal motion.

The verticality schema relates to the body's upright position in space. Zbikowski describes this conceptual metaphor in the following terms: "PITCH RELATIONSHIPS ARE RELATIONSHIPS IN VERTICAL SPACE" (Zbikowski 2002, p. 69). This relationship is reinforced by physical experiences in which lower vocal pitches resonate in the chest, whereas the sound produced by higher vocal frequencies appears to be located closer to the head, establishing a concrete experiential grounding for the verticality schema:

> Mapping *up — down* onto pitch allows us to import the concrete relationships through which we understand physical space into the domain of music and thereby provide a coherent account of relationships between musical pitches. (Zbikowski 2002, p. 71)

Applying this association to two main applications of the Gestate system, Mixer and Arpeggiator, I mapped verticality to pitch so that high pitch is up and lower pitch is down the vertical scale. This mapping is in line with Lakoff and Johnson's (1980) work that associates pitch verticality with the metaphorical mapping "greater is higher", which Cox (1999) associates with the link between the need for increased quantities of air, effort and tension to reach higher notes in vocal performance, suggesting that there is a physical basis for this metaphor.

However the linking of pitch to verticality remains contentious, as previously discussed in Section 2.1.2, Embodied Cognition. Zbikowski (2002) links this metaphor to Western musical notation, citing cultural differences where pitch is conceptualised as “sharp” and “heavy” in ancient Greece and “small” and “large” in Bali and Java. Despite these cultural variations, Eitan and Granot (2006) cite a substantial body of empirical evidence that indicates a pronounced association between pitch height and spatial verticality among Western subjects, tempered by contradictory studies that suggest perceived links between auditory pitch and lateral position. In the latter case, higher pitch corresponds to right-side position and lower pitch to the left, as with the piano keyboard. A study in which participants were asked to visualise an animated figure in relation to brief melodic segments confirmed the complexity of musical and motional relationships, discovering links not only between verticality and pitch contour, but also between lateral motion and pitch, dynamics and verticality (Eitan & Granot 2006, p. 237).

Amidst this complexity, the implementation of the pitch to verticality metaphor in the Gestate system derives validity from certain elements of embodied experience, particularly to patterns of vocal pitch production that appear to reside in different vertical positions of the human body. Similarly, pitches produced by faster vibrations are considered “higher” than those resulting from slower vibrations (Zbikowski 2002, p. 73), reinforcing the physical basis for this metaphor.

The other central metaphor underlying mapping strategies in Gestate is the link between intensity contours and changes in the musical parameters of amplitude and overall processing levels. Increased movement magnitude and scale results in corresponding increases in the intensity of the sound, linking heightened effort and tension to elevated musical energy. I also refer to this as expansion and contraction, an expressive indicator common in gestural design literature within multimodal contexts (Camurri et al. 2004).

Lastly, I experimented with designing mappings based on geometric shapes, characterised by clockwise and anti-clockwise circular motions with the hand, to trigger record and playback functions in a looper application during vocal performance using the Gesture Follower; however I found that the continuous imprecision of my movements caused frequent false-positives, which made it difficult to control the looper reliably and consistently. The result was an interruption to the flow of my movements, making it less effective for discrete control. I wonder, had I been a trained dancer, whether my performance would have been more accurate overall, making this technique more effective.

5.3.5 Few-to-many Mapping

As shown in Table 6, the Gestate mapping scheme is divided into two layers: continuous control for amplitude and effects parameters, and discrete gestural control for chord change triggers and activating the looper functions of record and playback. Combinations of gestures control multiple audio parameters in a few-to-many mapping connection (Hunt & Wanderley 2002).

Table 6: Summary of mappings for sample Gestate applications

Gesture/Movement Types	Movement Data	Sound/Effect
Continual movements associated with vocal and piano performance: Spontaneous or deliberate	Acceleration of sum of following joints: • Left hand • Right hand • Left elbow • Right elbow • Head	Audio effects bus amount or selected effect parameters
Discrete gestures	Right hand swipe	Looping play/record/stop
Metaphoric gestures (visual representation of abstract ideas)	Vertical hand motion	Virtual instrument control: Pitch to verticality
	Horizontal hand motion	Stereo panning
	Scale of movement: Distance between torso and arms	Amplitude/effects intensity

A few-to-many mapping strategy was chosen as it most closely reflects traditional instrument design, making it more familiar to musicians from a range of backgrounds. There is also the potential to encourage expert user interaction and explorability, as performers' interest can be maintained through more complex mapping schemes for extended time periods. Hunt, Wanderley and Kirk (2000) regard few-to-many mapping strategies as more engaging for expert users in the long-term, but require a learning process which makes them less appropriate for novices.

Dobrian and Koppelman (2006) also endorse more complex mapping strategies, arguing that although one-to-one mappings may provide precision, simultaneous shaping of multiple parameters is needed to enable the performer to access richer forms of expression. Simple mapping strategies are thus insufficient for an expert musician to control multiple parameters in an expressive way. This approach draws on the historic evolution of acoustic instruments as well-developed interaction systems where several parameters are often controlled simultaneously - a quality that is sometimes lacking in current real-time processing interfaces.

In some cases, such as for triggering on/off functions, one-to-one mappings are more appropriate, so they were applied to looping and mode change functions in Gestate. One-to-one mappings can also make an interface easier to learn for first-time users of a system, thus making the system more broadly accessible.

5.3.6 Applications

Through a series of *Gestural Études*, presented in Section 4.3, *Gestural Études*, I developed a number of virtual instrument applications to complement the augmented vocal and piano applications. These have been incorporated into Gestate (see Table 7).[28]

Table 7: Main virtual instrument applications of *Gestate*

Application	Control Gestures/Movements	Audio Effect/Sound	Visual Feedback
Mixer	Slow, gradual arm movements — Expansion and contraction in peripersonal space. Divided into bass, mid and high zones in vertical space alongside body.	Control amplitude levels for 6-track MIDI composition	Feedback video effect in Isadora Core on an animated gif.

[28] Video demonstrations of the Mixer, Cube and Arpeggiator applications are available online. Viewed 20 August 2015, <http://www.mainsbridge.com/gestate-demos/>.

Application	Control Gestures/Movements	Audio Effect/Sound	Visual Feedback
Cube	Forward, backward and sideward punching movements with right arm trigger MIDI notes. Acceleration data from arm motion drives effects.	Change chords of physical mallet model	Cube rotates with each punch. 2D particle system of tri-coloured circles for effects.
Arpeggiator	Arm gestures associated with vocal performance; cyclical, swinging. Low, high and mid zones alongside body affect pitch.	Synthesiser and arpeggiator	3D mosaic effect in Isadora Core on an animated gif.
Looper	Swiping gestures — Left, right and up. Tracing a circle in the air.	Trigger record/stop and playback in looper	2D particle system

These applications were primarily designed for augmenting vocal performance by providing a form of accompaniment and visualisation to draw out the movement subtleties of the performance.

In the Mixer application, the vertical position of the hands is mapped to the relative amplitude of notes in a chord. The position of each hand represents a microphone passing over a chord whose notes are arranged vertically from lowest to highest. This simple mapping was designed to explore the viability of amplitude-only control in new instruments.

The Cube application explores basic movement control of virtual objects. The user manipulates a virtual cube on which each face is assigned to a unique chord. Tipping the cube using punch motions plays the chord associated with the face on which the cube settles.

In terms of the system's compositional affordances, each of the applications of the Gestate system, particularly the Arpeggiator, provided an exploratory and almost pre-conscious approach to discovering musical ideas. By experimenting with different motion qualities including the pace, scale and direction of movement, unexpected motifs were discovered and developed. This offered an intuitive approach to generating musical ideas, especially when feeling completely engaged and unselfconscious throughout the process.

However this creative output was constrained by a reliance on pre-composed arpeggiated patterns or MIDI sequences that needed to be preconfigured, requiring a preparation process that prevented completely novel musical outcomes. Although each system application provided an easily navigable environment for the stimulation of compositional material, the set audio-visual environments inhibited more in-depth idea development and organisation, necessitating the use of complementary musical systems, such as digital audio workstations, to facilitate the creation of more complex musical structures.

5.3.7 Visual Feedback

Different forms of visual feedback were designed as a means of providing more nuanced control and immersion during the interaction. The visualisations were designed to fulfil two main purposes; first, as guidance for the performer to promote intuitiveness, and second, to enhance the aesthetic quality of the performance and facilitate an understanding of mapping processes for the audience:

For the performer

- To assist the performer in calibrating their motions, particularly when controlling multiple parameters simultaneously or parameters that require precision such as pitch;
- To aid discoverability and gesture learning in the early stages of adoption;

- To provide insight into how the system is interpreting movement in relation to audio data.

For the audience

- To amplify gestures and illustrate movement-sound mappings to the audience by visualising selected motion and sonic information;
- To add to the aesthetic impact and visual spectacle of the performance.

Figures 31 and 32 illustrate visualisations from the three main applications.

Figure 31: Mixer visualisation

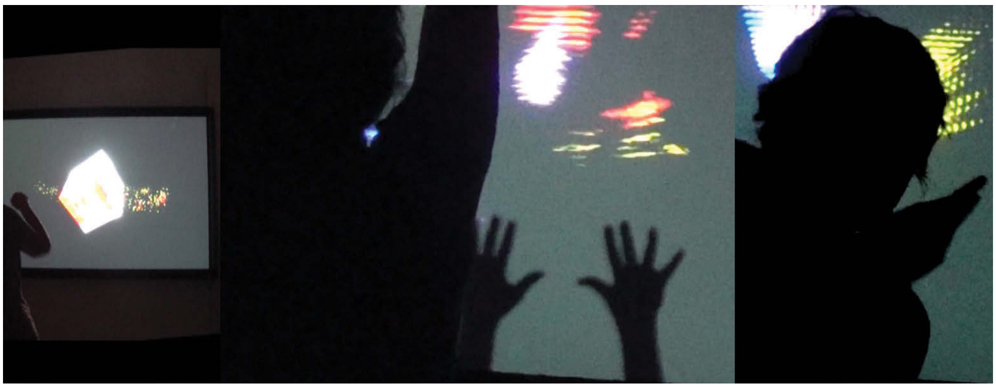

Figure 32*:* Cube and Arpeggiator visualisations

During the 2013 Electrofinge performance, audio signal information and movement position data were mapped to video effects parameters and particle systems in Isadora Core, highlighting evolving relationships between gesture and sound for the audience and promoting more precise control for the performer. Individual patches or scenes were designed within Isadora Core, allowing the performer to switch through different audio-visual environments during a live set.

The visual feedback provided explicit cues to encourage intuitive understanding and mastery of the interface. To display simultaneous feedback to the performer and audience, a transparent scrim was used as the projection surface, revealing a silhouette of the performer behind the projections that highlights the form and essence of the movements. The projected imagery amplified and drew out key characteristics of captured movement data, including trajectories of motion. Figure 33 shows a performance with the Arpeggiator at the Diffuse 2013 Concert Series in Bon Marche Studio at the University of Technology, Sydney.

Figure 33: Performance with Arpeggiator at Diffuse 2013 Concert Series

This approach echoes the design goals of a virtual choir system, *Chorus Digitalis*, by Oliver Perrotin and Christophe d'Alessandro (2014, p. 605), where "introducing visual feedbacks in the mapping process could benefit both the performer and the spectator to better identify the functioning of the DMI". Perrotin and d'Alessandro argue that visual feedback is particularly useful for depicting more complex mappings, which can appear opaque to the audience, affecting their levels of engagement.

For the musician too, visual feedback offers an illustrative capacity, helping them to recognise the effect of their movements in a new context and the way in which the system detects and interprets them. For performers with little or no prior movement training, visual feedback can provide information to aid in the accurate reproduction of predefined gestures, signalling whether a gesture has activated a mode or effect change successfully. This supports the delivery of more precise and nuanced control movements for musicians requiring further skill development in movement-based styles of performance.

Future work is needed to develop the potential of visual feedback to promote transparency and gesture learning for the performer, including incorporation of more detailed visualisations of individual sonic parameters. However this work is beyond the scope of this thesis, which has focused primarily on gestural control of sound, to which visual feedback performs an ancillary and supporting function. More comprehensive investigations dedicated solely to the visual aspects of movement-based interaction presenting further insights into the expressive and guiding functions of visual feedback for users can be found in the research of Hansen (2013) and Anderson (2014).

5.5 Conclusion

In this chapter I have discussed the design criteria and strategies of the gestural performance system, Gestate, which emerged from relevant literature and from previous gestural performance and composition experiments.

The system is controlled mainly by continuous, unrehearsed movements that are compatible with vocal performance and are mapped to continuous sound parameters such as audio effects intensity and amplitude. Predefined gestures control discrete software functions such as mode and parameter changes. Metaphoric gestures were implemented as part of an embodied mapping scheme that explored the metaphoric associations of pitch to verticality and horizontal motion to stereo panning.

The Gestate design was shaped by personal movement inclinations and artistic goals. In order to gain broader insights into musician experiences of gestural control, I conducted an expert user case study involving three representative applications of Gestate, which is described in the next chapter. This case study was designed to determine the efficacy of mapping strategies employing embodied metaphors and visual feedback in meeting the criteria set out in Section 5.2, Design Criteria.

Chapter 6: Expert User Case Study

6.1 Introduction

An expert user case study was conducted between March and June 2014 to gather feedback from musicians from a variety of performance backgrounds who were first-time users of the Gestate system. The goal of the study was to investigate professional musicians' experiences of controlling music through gesture, ascertaining their needs and preferences as target users. This process involved measuring user satisfaction in relation to the design criteria presented in Section 5.2, Design Criteria, by analysing first-hand impressions of the system and assessing its applicability to a range of musicians' purposes.

The evaluation component of the research included qualitative approaches: interviews, video recording and analysis were conducted to access first-person experiential understandings of performers' interactions with an example gestural performance system. The findings formed the basis for refining the design criteria, set out in Chapter 5, and identifying core control features required to create a viable gestural system for performance.

The experience of gestural interaction and its effect on the feeling, sensing body formed a central component of the case study. A phenomenological approach framed the analysis of user perceptions following direct physical engagement with the system. This approach is aligned to research in embodied interaction design approaches that places the experiential body at the forefront (Larssen et al., 2007; Loke 2009; Schiphorst 2009).

6.2 Research Questions

The expert user case study was primarily concerned with gathering information about the experiences of practicing musicians with gestural control in order to determine the applicability of key control features to their professional work.

The principle goals of the case study were to:

- Investigate the experiences of expert users interacting with a gestural performance system;
- Determine a core set of control features required by expert users;
- Discover how effective the system is in meeting the criteria identified during the design process.

The main research questions were addressed according to the following sub-questions:

- What potential barriers exist to the adoption of gestural systems amongst musicians?
- How does gestural interaction influence the creative process and output of musicians?
- What alterations or level of customisation needs to be achieved to ensure the viability and integration of such systems in practicing musicians' skillsets?
- What influence does visual feedback have on gestural interaction in performance?

The study was couched within a broader investigation of the nature of gestural experience in musical performance. It was prompted by a desire to discover why the novelty of gestural control persists, given the increased affordability and accessibility of sensor hardware and software for capturing movement and mapping it to multimedia outputs.

As discussed in Chapter 1, despite the rapid growth of gestural systems and toolkits for building movement-based instruments, only a relatively small number of professional musicians have adopted gestural devices as their main instrument. Within this group, notable practitioners include French composer Laetitia Sonami, who developed the Lady's Glove in collaboration with Bert Bongers at STEIM. The past director at STEIM, Michel Waisvisz, designed and performed with his wearable instrument, The Hands*,* throughout his career. Atau Tanaka performed extensively with the BioMuse biocontroller, powered by muscle tension signals detected using EMG sensors on an armband equipped with electrodes and EEG sensors on a headband.

Gestural controllers in vocal performance continue to be used by Donna Hewitt, Elena Jessop-Nattinger, Sidney Fels and artists from the NIME community.[29] Within wider contemporary musical practice, low usage rates of gestural systems beyond single performance and research projects prompts questions about the types of challenges that prevent further uptake of gestural control in musical performance practice.

Through improvisation sessions with the system and subsequent interviews, case study participants assessed the effectiveness of the primary design strategies underpinning the system, including visual feedback and mappings informed by

---

[29] Recent performance and practice-based research by artists in the area of gestural interaction can be found in archived NIME proceedings available through New Interfaces for Musical Expression, *NIME*, viewed 20 August 2015, <http://www.nime.org/proceedings/ZIPs/>. However, this research is mainly representative of artists and researchers from academic research communities.

embodied metaphors, in achieving nuanced and consistent gestural control of music.

6.3 Set Up

The case study was conducted in a range of settings, including the Digital Research Lab at the Bon Marche building of the University of Technology Sydney Broadway campus. The remaining sessions were conducted in studio environments at the workplaces of participants.

Figure 34: Participant improvises with Gestate Cube application

The Gestate system software ran on a MacBook Pro laptop, using a Microsoft Kinect as the sensor. Visual feedback was displayed on the laptop screen in the studio environments or using a high-definition projector in the lab setting. A Sony HDR–CX220 video camera was positioned beside the participants, to record both visual feedback on the screen and their movements.

The camera-based motion tracking system used in this study functioned as my main instrument for three years, and was customised to suit my own creative purposes and scaled to my physical dimensions. Mapping the movement qualities of energy and extent of motion to a range of audio parameters was determined by what ‘felt’ right to me during performance and composition.

Although Gestate was designed for my own personal use, it offered a starting point for gaining insights into the vision and expectations that other potential users have of gestural systems in relation to their own creative purposes. Pre-configured effects, sounds and functional gestures influence the aesthetics of the system; however, participants were informed that sound banks, gestures and processes were fully customisable should they wish to explore the system further after the session.

6.4 Participants

Nine musicians (four female and five male), with a minimum of fifteen years of professional musical experience, were recruited to take part in the case study. The group included composers, instrumentalists and vocalists. Each participant possessed a high degree of expertise in their professional area, and many participants' skills intersected a number of different areas. Table 8 summarises the background and specific interests of each participant. The limited number of participants enabled in-depth interviews that captured the rich detail and essence of expert users' interaction experiences.

Table 8: Case study participant backgrounds and system preferences

No.	Gender	Profession	Date	Musical Background	Movement Training/ Prior use of gestural systems	Desired Features
1.	Male	Drummer	23.2.14	Music technology, programming, education.	No movement background.	Augmented drumming application.
2.	Male	Bassist	28.2.14	Upright and electric bass, music technology.	No movement background.	Augmented upright bass.

No.	Gender	Profession	Date	Musical Background	Movement Training/ Prior use of gestural systems	Desired Features
3.	Male	Composer/ producer	9.3.14	Conducting, arranging, film and television scoring.	Conducting	Real-time composition and mixing.
4.	Male	Cellist, guitarist, composer, instrument builder	13.3.14	Performance art, improvisation.	Presented workshops in Contact improvisation.	Composition, detailed control of note generation and timbre.
5.	Female	Vocalist/ meditation practitioner	21.3.14	Ensemble performance, sound therapy.	Practices yoga regularly.	A multimodal system with direct links between movement, sound and image. Layering harmonies.
6.	Female	Electro-acoustic composer and IT worker	23.3.14	Archivist, over 20 years of electro-acoustic composition experience.	Participated in designing and using a range of gestural systems.	Customisable sounds.
7.	Female	Vocalist	28.3.14	Theatre, therapy, movement training.	Attended Body-Mind Centring workshops, movement-based therapy.	Detailed control over note generation.
8.	Female	Composer, flautist, bassist	20.5.14	Graphic scores, noise music, electronic music.	Composed gesture themed work.	Detailed control of timbre and visual details.

No.	Gender	Profession	Date	Musical Background	Movement Training/ Prior use of gestural systems	Desired Features
9.	Male	Electronic music performer and producer, electrical engineer	21.5.14	Modular synthesisers, audio-visual instrument building.	No movement background.	Live performance.

6.5 Procedure

Participants were presented with three representative system applications offering virtual instrument, effects and mixing controls, each with a different form of visual feedback. These distinct audio-visual environments included Arpeggiator, a virtual instrument physical mallet model with effects; Cube, an audio-visual instrument that pairs a visualisation of rotating cube movements with chord triggers; and Mixer, that enables level and panning control of pre-composed MIDI parts.

A set of instructions explaining the basic functions of each application was provided on a printed sheet with additional information provided verbally if participants sought clarification. The participants were invited to improvise with the system for as long as they wished. Each session lasted an average of 1.5 hours.

6.6 Methods for Data Collection

Notes were taken during the improvisation session and compared with interview responses and video recordings of the sessions. Triangulation between these three sources of qualitative data was used to evaluate how participants interacted with the system. The feedback gathered represented a mixture of feelings, impressions, initial reactions and perceptions on the experiences of participants exposed to the system for the first time.

Thematic analysis of interview data, observation notes and video recordings was conducted using qualitative analysis data software, NVivo.[30] I read the interviews transcripts numerous times to immerse myself in the data. Coding was conducted to ascertain the emerging themes from the interviews.

The interview addressed user impressions in the following key areas:

- Intuitive interaction / discoverability;
- Nuance;
- Explorability;
- Consistency;
- Flexibility;
- Physical experiences;
- The effectiveness of visual feedback.

During a semi-structured interview, the following questions were asked of participants:

1. Overall, how did you find the experience of using this system?
2. Do you have any comments about how easy or hard it was to understand how to use the system?
3. Did you feel in control of the audio output?

[30] QSR International, *NVivo*, Version 10, viewed 20 August 2015 <www.qsrinternational.com/products_nvivo.aspx>.

4. Were the visual effects altered by your movement? How?
5. Did you find that the visual feedback was assisting in the control of the system?
6. Do you have any comments about the relationships between your movements and the sounds the system made?
7. How did you find the latency?
8. Did the system offer room for exploration and development of new ideas?
9. What areas of improvement would you suggest?
10. Would you consider adopting a similar system in your own work? If so, what would need to be changed or improved?
11. Are there any other applications you could envisage for this system?

6.7 Findings

From the video recordings of the improvisation sessions and accompanying notes, the following general observations emerged:

- The first application, the Arpeggiator, was perceived to be the most engaging and the majority of participants spent the greatest amount of time improvising with it. Some users found it delivered a type of real-time composition, allowing improvisation with multiple instrumental parts simultaneously in a way that stimulated ideas and encouraged physical exploration by freeing them their usual stationary modes of working.

- Most participants faced the screen, treating the visual feedback as the main feedback modality. Some instrumentalists, however, preferred to concentrate on audio feedback, as they found it easier to become immersed in improvisation.

- Participants who experimented most actively and enthusiastically with the system, without feelings of self-consciousness, achieved the most varied sonic outcomes from each of the featured applications.

In terms of meeting the predefined design criteria, the system received the following feedback from participants.

6.7.1 Intuitive Interaction/Discoverability

Generally, the majority of participants were able to easily understand the system, performing competently with it within several minutes. Participant 8 found that "it was quite easy and not fiddly and intuitive so it didn't take long to find out how what you did affected the energy". Participant 2, a bass player, reiterated this sentiment, commenting, "it wouldn't take too long to get some sort of a creative thing happening. It's not like a new instrument where you have to learn…. It's a very intuitive interface — for me anyway". For a participant who had previously been involved in using a range of gestural systems but had not made this type of music in recent years, it felt that "you're making it very natural for someone to come and experiment with it".

The contribution of the embodied metaphors to intuitiveness in the mapping schemes was also considered. The pitch to verticality metaphor employed in the Arpeggiator and Mixer applications was considered intuitive by the majority of users, with Participant 5 commenting that "I like that going up and down to the side like this [performs vertical arm movements to the side of her body] changes pitch. Intuitively it makes sense".

Most participants were able to intuitively comprehend the expansion and contraction metaphor for amplitude in the Mixer application and processing intensity in the Arpeggiator. Some participants enjoyed playing with the outer extremes of their movement range, extending their arms and discovering new sounds when exploring these applications.

Participants generally related well to left hand control of effects and right hand note generation in the Cube and Mixer applications, some suggesting that the left hand could also control the textural elements of the sound. Participant 7 made sense of the association by comparing the interaction design to the piano interface, where the right hand conventionally performs melodic material while the left hand controls accompaniment. However, she did find the left hand's role to be too limited as a controller for effects, wishing that it could also be used for note generation in order to produce layered parts.

6.7.2 Nuanced Control

Most participants felt able to control the audio adequately, though some felt limited by the degree of control over continual parameters associated with transforming timbre and effects over time. Participant 4 believed that this type of control needed to be available for musicians in order to "be able to take a note and manipulate it like clay". As a string player, he wanted the ability to transition more easily between continuous and discrete control; similar to alternating between bowing and plucking strings.

The Arpeggiator application was most likened to a compositional tool, evoking the most pronounced feelings of nuanced control. As one participant observed during the improvisation session, "you know you can actually find a place in the note generation where you actually feel like you're creating something". It was the easiest example for most participants to learn, but one user found this feature limiting, saying that once she worked it out she wanted to move on.

However, most other participants spent the longest time on this instrument, one commenting that it was the “easiest [on which] to see the effect of what you were doing”.

General mappings between gesture and sound were discerned by most participants; however, the level of detail and overlap in cross-coupled mappings caused some to question the clarity of the relationships. The overlap between pitch and effects controls led to confusion for some participants, who sometimes found it difficult to distinguish between these parameters and control-specific parameters in isolation. Cross coupling a combination of movements with several simultaneous audio parameters at times restricted detailed control of individual parameters.

These few-to-many mappings sometimes made it challenging for users to isolate particular parameters. Participant 3 commented, “I really liked the control on the right hand, that was good, for the pitch of the arpeggiator. I was getting good feedback, but then I was kind of altering other things that I didn't really want.” He emphasised the need to separate individual parameters using one-to-one mappings in order to achieve the level of expression he required in performance.

Participant 5 found that even the slightest, most detailed movements made a huge difference to the sound, and felt that the achievement of consistent pitch changes to be especially challenging. The difficulty in reaching the desired pitch consistently was mentioned by several other participants, highlighting an area requiring significant improvement.

Interested to explore the system's potential as an alternative mixing interface, Participant 3 observed:

> when I locked onto a sound here in the middle, I wanted to bring it up in level but I didn't know if I should go out and up, but then I was getting into the next one.

The confusion caused by overlapping parts suggests the need for a revision of the Mixer mapping, providing a clearer separation between sounds and explicit feedback to guide the user's movements.

It was interesting to observe whether the acceleration aspect contributed to an enhanced sense of control for participants. Most participants were not aware of the acceleration component; they only noticed it once they were informed of it afterwards. Users mainly detected the influence of hand position on pitch and volume, and the force of the punch required to hit the chord trigger in the Cube application. However, participant 1 did sense that the system detected more movement information than simply positional data. He found that Gestate evoked a whole new way of moving compared to playing an instrument, relating more to speed of movement and how constantly a user moves. This participant felt a need to change their usual style of performance, which differed from their established drumming technique. For another user, this mode did not feel natural, as maintaining a constant effects level with acceleration was perceived as more difficult than the possibility of using velocity.

6.7.2.1 Effects

Controlling the audio effects proved slightly frustrating for some participants, as the dry signal could only be achieved through minimal or no movement, and could easily become over-saturated and distorted if the user moved intensely and constantly over a short period of time. Processing was best activated over individual phrases and then allowed to subside before being triggered again. However, this technique was not readily apparent during a short amount of time with the system.

Although instrument augmentation with effects was not included in this evaluation, three participants expressed interest in exploring this aspect of the system with their own instruments. They voiced interest in customising the system effects to their specific sound palette to augment their existing instruments, rather than using it as an open air interface, which they did not find compatible with their existing performance practice.

6.7.3 Explorability

Some participants felt that their capacity for exploration was limited by the inbuilt aesthetic choices featured in each of the system examples. The Arpeggiator, which had no pre-composed material, inspired the most exploration, as users felt they were starting with a blank state, evoking comments like "I could spend a whole day on that and really get into it" (Participant 3).

Though preset effects of the systems were a deterrent for some participants, others felt this gave them structure and initial ideas with which to improvise. Participant 3, for example, considered "that resonant delay that was going on in the left hand was really good. It's good accompaniment".

The main concern for many participants was the inability to change generating parameters or transition between effects without also altering the whole system state. Users wanted a more seamless way of moving between effects settings. The ability to change timbre and visualisation smoothly over time was also a need commonly reiterated throughout the case study.

Participant 8, a composer, felt that the system conformed to a particular style that typifies common sound processes found in many interactive systems, for example, granular delay. The user preferred to begin with a raw and unadulterated sound environment that enabled her to realise personal compositional aims without being confined to a particular style. However, the integration of pre-composed material was also recognised as beneficial by another participant, who found that they could adopt the system immediately in their performance practice, without extensive need for customisation.

This difference in perception highlights the varying needs for customisation among performers. Some participants consider the availability of default preset sounds as a form of creative stimulus that saves them time from programming sounds and mapping parameters, while other musicians find that the presence of preset options distracts them from their usual creative process. Artists who were interested in improvising and generating ideas quickly found the presets to be a suitable starting point, whereas composers with certain ideas of what they wanted to create did not want to be influenced by the preset settings, and preferred to start with a blank canvas.

Another limitation to prolonged exploration was the inclusion of pre-composed material in the Mixer application, where the volume of six MIDI parts could be controlled simultaneously by moving between high, low and mid-range parts arranged according to corresponding vertical zones alongside the body. This caused a degree of confusion, which hampered further exploration, as discussed in Section 6.7.2, Nuanced Control.

However Participants 1 and 5 enjoyed the expansion and contraction aspect of the interaction. They found that they started the improvisation while moving in a small, restricted space, then, as they increasingly expanded their arms and body out further, they started sensing increased sonic variations and intensity, realising there was added detail to be found in the outer reaches of their peri personal space. This encouraged them to explore their movement potential beyond their usual range, as they pursued further sonic variations.

Different movement styles and approaches were also found to influence levels of exploration and the perception of explorability. The vocalists represented in the study exhibited the most enthusiasm when exploring the interface out of any professional group, demonstrating a willingness to experiment extensively. They considered that the system offered ample possibilities for enhancing their vocal performance, by providing a form of accompaniment and facilitating ideas-generation for song writing.

The overall range of sounds achieved during the improvisations differed from and enhanced my own personal discoveries with Gestate. Participant 2 discovered how to maintain feedback on a part by raising their left arm above their head while generating additional notes with their left arm as a form of accompaniment. This suggests that the system enables different movement patterns and combinations to produce a range of sonic effects for users who experiment with the system.

Musicians who tended to repeat the same types of gesture in a constant fashion received less varied sonic results, and became easily bored. Some participants could not warm to the task, communicating feelings of awkwardness and self-consciousness. However, those who experimented with different movements found the experience more rewarding overall. They appeared to produce more varied sound textures, which encouraged them to continue experimenting and exploring new types of movements.

This demonstrates the significance of the individual's contribution to defining an interesting and satisfying gestural interaction. It is therefore not adequate merely to test the system in isolation, but also to examine the physical contributions of the performer.

One participant suggested that trained dancers would be able to extract more subtlety and nuance from the system than musicians with no prior movement training, and therefore felt unable to provide accurate feedback on the feel of the controls. The distinction between musicians and dancers in terms of control again highlights the influential role of the performer in determining the level of nuance available through gestural manipulation of virtual instruments and digital audio effects.

6.7.3.1 Discoverability vs. Explorability

The fine balance between ease-of-use and explorability did not attain the right balance for some participants, who found the overall interaction too straightforward to maintain interest for a prolonged period of time. Interestingly, the two participants who voiced this concern most strongly were both electro-acoustic composers; they were unable to relate to the aesthetics of the example sounds and did not feel completely comfortable with exploring the system through physical improvisation. It was easy to compose with the Arpeggiator, one of these participants reported, because much of the composition has already been prepared in terms of offering pre-composed elements. The other participant felt self-conscious during the experience, inhibiting her ability to move past a perception of the novelty of gestural control, which lessened her overall enjoyment and engagement during the experience.

6.7.4 Consistency

All of the participants reported that the system performed well in terms of latency. Due to the character of the sounds, which were not percussive, apart from the Cube, some degree of looseness was found to be acceptable and easily compensated for.

The Cube application caused the most frustration in terms of predictability, as several participants encountered difficulties in consistently triggering system responses with punching movements. Participant 6 in particular found the experience irritating, attributing it to the lack of muscular strength in their right arm. Participant 2 also perceived their lack of physical ability and co-ordination in relation to the task was the reason for the application not performing predictably.

In terms of precise and reliable control, Participant 7 found it difficult to maintain a constant pitch. When they attempted to reach a certain tone, it repeatedly seemed a semitone out. The pitch control did not achieve the level of consistency they hoped for. This frustration related to the cross coupling of effects with pitch, where different parameters simultaneously influence each other.

Limited repeatability did not deter Participant 2, who found the capacity for constant variation to be a potential strength of the performance system:

> It’s spontaneous, and depending on the sounds, it’s not something you can reproduce. So it’s going to have a present moment, unless you record it obviously, but it’s got to be related to the performance, which is cool. (Participant 2)

6.7.5 Flexibility

Without exception, all participants called for more detailed and customised control to affect not only sound and audio-visual effect selection and amount, but also the detailed evolution of timbres and increased subtlety within certain visual shapes and colour configurations. A number of participants requested the introduction of small-scale gestures including finger movements to balance out the large-scale gestures that the Kinect affords, especially for tasks requiring accuracy and precision such as system mode changes. Participant 4's comment is indicative of this call for a higher degree of customisation and personalisation among participants:

> it's as if you can't move from one generating parameter to another. I can imagine that if you had the right hand doing that, generate an ostinato pattern I suppose, and with the left hand, maybe do something more textural, so you'd have a composition going between the two different kinds of voices — that could be good. (Participant 4)

For this participant, we spent time customising the parameters of several applications, including the Arpeggiator, where the speed and key of the tempo was adjusted to achieve the appropriate feel and aesthetic for the performer.

Two participants wanted the system to emulate almost tactile expression, or the ability to mould sound as if it were a malleable substance. Participant 4, a composer and cellist, voiced a need for the ability to easily move out of arpeggiation into continuity — likening the process to moving from legato to staccato on a bowed instrument.

6.7.5.1 Naturalness of Movements

The level to which participants could express their unique movement language was another indicator of the system's level of flexibility. Whether the system was adaptable to the participants' varied movement styles and preferences became another prime consideration in evaluating the flexibility of the design. Some participants found that the system set up a particular context, thereby guiding and also influencing the performer's movements by setting up specific behavioural expectations. The style of the audio-visual content was also perceived as influencing gestural reactions. For example, the Mixer application, which featured sustained synthesiser pad sounds, encouraged gradually evolving gestures from a range of users such as Participant 2, whose motions resembled gradual Tai Chi movements that mirrored the quality and slow attack of the sounds.

Levels of satisfaction with the different applications appeared directly related to the types of gestures used to control them. The Cube in particular, caused a sense of disconnection among participants, Participant 6 reporting, “it’s not a movement that’s natural to me”. With a history of using motion-based systems for music, this participant was used to performing with slower movements. The closest they had come to similar motions in the past was to use flicking gestures in an interaction.

Other participants found that the punching motion driving chord changes in the Cube application was also the most foreign to their existing movement style. Performing the gesture often evoked a sense of frustration due to the inconsistency of musical results produced:

> I found the punching one the hardest, cause I couldn’t get it to activate properly, and maybe that’s something I didn’t do properly. There was a point where I got it spot on and I got the feedback holding, and that was great, then I couldn’t get back to where it was. (Participant 3)

Participant 6 suggested that a flicking gesture might have been more appropriate, as it does not require the same amount of force, which could prove exhausting if continuously repeated during performance. She compared the Cube interaction to martial arts practices like kickboxing. Participant 5 warmed to this gesture for this reason, finding it similar to the combination of dance and combat movements found in capoeira, and wanted to also introduce leg kicks in the interaction to involve the whole body in the interaction.

Participants generally preferred to control the system with more varied movements, as exemplified by the Arpeggiator application, which is controlled by continuous spontaneous movements, rather than discrete gestures. However, Participant 5 commented that there was still a need for certain predetermined gestures in the system. She suggested that sounds should be should be activated with matching movement types; for example, a flinging gesture could trigger a delay and a swell in the sound could be traced as a corresponding wave shape in space.

6.7.6 Physical experiences

Participants reported a range of physical experiences and exhibited varied physical approaches. Polarised physical reactions ranged from feelings of over-exertion and self-consciousness caused by an aversion to "moving for movement's sake" (Participant 8) to enthusiasm and excitement around embodied ways of making music. Some participants felt tired, particularly when improvising with the Arpeggiator and raising their arms above their heads for prolonged periods. Others welcomed increased levels of movement compared to stationary ways of producing or creating electronic music with the computer, where using the device for hours on end becomes a burden. A producer found the experience refreshing, likening it to their conducting experiences, but less physically draining:

> I know when you conduct non-stop for three hours, your arm starts aching, but this is all muscle memory. If you want to use it, you've got to get used to it. I think it's good for use, cause it turns a non-active thing into something that's active. (Participant 3)

Musicians from different backgrounds reacted to the system in ways that reflected their professional experience. Electronic musicians, who were accustomed to being more stationary than vocalists and instrumentalists, felt reluctant to develop a completely new physical playing style to gain the most out of the system. However, they did feel relieved to perform mixing tasks without the need to sit at a desk.

One suggestion from participants who experienced over-exertion was to combine the continuous large-scale arm movements with more detailed and contained movements, so that the performer could alternate between the two:

> I wonder if you can change it so smaller movements can change the effects rather than the big movements cause it's so tempting to want to shift and move and play that you're making these really big movements. (Participant 7)

This observation highlights the importance of implementing gestures that reflect the energy levels of the performer. For musicians not accustomed to moving overtly in performance, there was a need to find a balance between their existing physical abilities and the potential for physical expression through the system.

Another suggestion to improve physical engagement was to incorporate a foot switch, using full body interaction to balance energy output and spread it more evenly throughout the body. This could benefit a performer, particularly during extended performances, when the arms, and particularly the right arm, are continuously controlling sound.

Another participant felt a sense of self-consciousness, appearing out of their comfort zone when performing gestures without a tangible instrument or device. In a couple of instances, participants felt that their own perceived limited movement ability affected their capacity to fully explore the system's creative potential. In contrast, two other participants found that the longer they used the system, the more their movements range and scope expanded, leading to more diverse sonic outcomes.

Participant 7, a vocalist with a background in a movement awareness discipline called Body-Mind Centring (BMC),[31] was immediately engaged in the experience, reporting that “something to do with connecting your body and sound is incredibly invigorating for me”. The experience assisted her in joining the two modalities of movement based therapy and musical performance together.

6.7.7 Effectiveness of Visual Feedback

Most participants found that the visual effects were influenced by movement and contributed to an understanding of the overall interaction and sound-movement mapping. However, many users found that the connection was not always obvious. Although the link between movement and visual feedback was generally well understood, clearly defined links between visuals and sound were missing for some participants, who questioned the rationale behind the choices of certain colours and shapes. According to Participant 8:

> I was often wondering about the relationship between the images and the sound, and I guess that’s why I was asking why you chose the colours or the graphics that you did because I didn’t see a direct relationship between the sounds and the images. (Participant 8)

This observation reveals that the primarily aesthetic considerations influencing the visual choices did not always communicate clear links to users of the system. Ties

---

[31] Body-Mind Centring is an experiential study that takes an embodied approach to movement, body and consciousness. Founded by Bonnie Bainbridge Cohen, it uses movement, touch and voice to explore body-mind relationships. Viewed 20 August 2015, <www.bodymindcentering.com/>.

between sound, audio and visual feedback were deliberately obvious in the Cube application; however, the influence of different sound processes on the formation or manipulation of shapes and colours appeared less clear and direct in the Arpeggiator and Mixer applications for many participants. However, participants who had access to a full projection screen and were able to see the images in full scale had a greater tendency to rate the visual feedback more positively.

The Cube was generally perceived as offering the least convincing form of visual feedback. As it was three-dimensional, Participant 8 was frustrated that they could not physically hold and manipulate it: "It seemed kind of foreign to moving. It's almost like you want to move the cube by holding it. Everything else is so fluid that the cube is kind of the antithesis of that". On the whole, participants reacted more positively to the detail and subtlety of the particle system that represented the presence of effects in the Cube application, as it seemed to fit with the granular delays that formed part of the effects processing.

For audio-focused individuals, the visual feedback was not seen as important. They tended to respond predominantly to the audio feedback. The Arpeggiator was perceived as the most self-explanatory, so was less reliant on visual feedback for illumination. Some participants found the visuals pleasing to observe, but did not rely on them to guide their understanding of the interaction.

Several participants felt the need for more explicit visuals that showed clear correlations between sound and movement, almost like tracing visual shapes that correspond sympathetically to certain sound effects; for example, drawing a wave pattern to indicate increasing and decreasing effects levels. One participant in particular identified herself as a visual person who found the video component essential in complementing listening during applications such as vocal augmentation with digital audio effects, where audio feedback on its own can be hard to follow. Other participants stated the need for a type of control panel surface with explicit visual cues that only the performer could see.

Certain aesthetics governed the visuals. One user found the Mixer application visuals to be like fireworks or the stage lighting of a rock concert, likening the experience to a Guitar Hero game. Another participant thought that the visualisation, imitated the slow movement of the planetary spheres, which inspired her to explore the interaction further. Another participant commented that the visual feedback could aid a performer in understanding their movement abilities:

> For someone interested in movement rather than expressive dance, they might be quite interested, seeing an image of themselves. Something outside of themselves rather than an external kind of expression or an interpretive expression. (Participant 4)

Suggestions for improving the visuals were mainly focused on a call for more explicit feedback; for example Participant 1 commented that acceleration could be depicted by a flywheel, where it gathers momentum and then gradually slows down as it stops to portray a sense of inertia.

I was also interested in exploring the connection between visual and proprioceptive feedback, particularly for first-time users of the system. For users who said they thought in a ‘visual’ way, visual feedback provided a useful guide for navigating through the system and helping calibrate their gestures in relation to sound. Yet for more experienced musicians with a strong audio focus, the presence of visual feedback was sometimes distracting and they preferred to let the audio feedback be their primary form of guidance, as one participant reported:

> If the instrument is really good it's better not to have it cause it's another level of distraction and sometimes you're thinking about the wrong thing. So I think with that first instrument it was unnecessary cause there was so much to explore and each hand was doing something different and it kind of became irrelevant, which was great, I think. (Participant 3)

Another comment in relation to the display of audio-visual relationships by Participant 8 suggested that the moving performer be obscured from audience view by the screen, to eliminate all self-consciousness and encourage further freedom of expression. This participant found that the act of gesturing in performance could produce feelings of discomfort that might hamper a musician's expressive capacity, and saw the visuals as a way of overcoming this any embarrassment a musician might experience when first adopting gestural control in their performances.

The majority of participants believed that the visual feedback did assist in their comprehension of the system. Several participants recommended the addition of explicit visual feedback that clearly demonstrated links between audio and movement parameter changes. Another suggestion to make the visuals more convincing was to utilise a three-dimensional projection surface to increase the 'believability' of the three-dimensional visual feedback. To make the visuals appear embodied, three-dimensional projections could possibly enhance user experience, creating an illusion of entering and directly engaging with the projection, particularly in the case of the rotating three-dimensional cube. For one participant, the three-dimensional images of the particle system in the Cube could potentially visualise sound spatialisation.

For Participant 6, the visual feedback:

> allowed me to understand the virtual space I was working in better and without it I guess it would have taken longer to sonically understand what I was doing. So yes, as much as I say I was ignoring the visuals, it helped me

> understand what I was doing in the sound space much faster than I would have.

Similarly, Participant 9 found that:

> not being familiar with the patch beforehand I didn't know really what to expect. But the visual feedback is definitely helpful. I can see that my actions have an effect and there's definitely that relation between sound and movement.

These comments are indicative of an overall feeling among participants that the visual feedback did perform an illustrative role in explaining mappings to the novice user.

6.7.8 Movement Awareness

For some participants, self-consciousness associated with performing without their instrument created feelings of discomfort, which in some cases led to self-censorship. Perhaps more limits need to be imposed in gestural systems for musicians, as absolute freedom of movement can sometimes have the unintended effect of freezing a performer's self-expression when they have no fixed reference point to organise their behaviour around.

Certain behavioural expectations or constraints may be necessary to some degree. Even if players choose to ignore design restrictions, they have some way to frame their actions — a prerequisite that is particularly important for instrumentalists who are already accustomed to specific stylised ways of moving. As Participant 8, a bass player observed: "when you have too much freedom, you feel like you actually have no freedom and you don't know what you're doing it for". One participant compared the style of interaction with the theremin, considering the limitations that it imposes on the performer to be beneficial.

Because the theremin possessed only two main controls, the player can act within a clear set of parameters, developing their own movement style in relation to the interaction.

For musicians engaging in gestural interaction for the first time, there is also a need to transcend habituated ways of moving (Noland, 2009) to adapt to this new context. For a participant with conducting experience, gestural control fitted easily with established styles of moving. It also resonated with musicians from a movement background, like those who had participated in theatre-based movement workshops as well as somatic education such as Body–Mind Cantering. These participants experienced fewer challenges triggering sounds with pre-defined gestures and managed quite varied effects by experimenting with a range of different movement patterns and styles. Participant 2 described the learning phase as a process of "tuning my ears into my movements" — a process of calibrating the body to sonic processes and exploring potential connections.

Self-censorship may also affect the willingness of participants to experiment more actively with the system. Making sounds in mid-air can initially be an unnatural experience. It is not always possible to automatically adapt to gesturing overtly outside of the usual contexts of speech and instrumental or vocal performance. However, for participants with some movement training, this transition appeared easier.

6.8 Study Conclusions

Overall, the study found that musicians' prior instrumental and movement backgrounds influenced early experiences with gestural control and requirements from a gestural instrument. For musicians with past movement experience, there was a greater inclination to physically experiment and improvise with the gestural system for extended time periods, making it an influential aspect in achieving varied creative outcomes and subsequent improved user satisfaction.

Each participant’s performance background and orientation also had a direct relationship to their physical impressions and requirements from the system. Vocalists seemed more open to explore a less restricted gestural vocabulary, though Participant 5 did think that the gestural vocabulary should include more commonly used vocalist gestures.

On the whole, vocalists valued system applications that related to accompaniment, idea generation, part layering, looping and arranging. Similarly, a participant with conducting experience found it easy to adapt to the system and to perform open air gestures without a physical reference point due to past experience in the area, becoming excited about the creative potential of mixing and layering sounds without being bound to a standard computer interface or a mixing console.

Some instrumentalists were less comfortable with free air gestures that strayed too far from their habituated ways of moving. Electronic musicians accustomed to performing in a mostly stationary position were divided — some embraced gestural control while others felt inhibited by the formlessness of it. Acoustic instrumentalists also fluctuated between enthusiasm and frustration. Those who were challenged by the experience kept framing the interaction in relation to their own instrument, so strong was the relationship. One participant, a bassist, commented that they did not want to gesture for gesture’s sake, finding that gesturing in an entirely unfamiliar context did not feel at all natural. Certain instrumentalists appeared to be more comfortable with gestures that were based on their existing technique, contributing to feelings of self-consciousness during the improvisation, which in turn affected their willingness to experiment with their movements.

The presence of pitch–verticality and expansion–contraction metaphors were easily understood; however, the ability to achieve consistent and precise control also hinged on prior performance motor skills. In some cases, visual feedback was helpful in structuring and guiding the experience, but in many cases musicians preferred to focus directly on auditory feedback when navigating the system, finding it distracting to focus on both modalities at once. The varying needs of performers reaffirms the need for diversity in the gestural interface design field, while also highlighting the challenge of creating a gestural system that suits a range of performer aspirations. One questions to what degree the standardisation of mappings and gestural vocabularies is possible.

On the whole, many potential practical applications for the system were recognised, including constructing soundtracks for film; mixing; a real-time song writing or compositional tool for composers, instrumentalists and vocalists who wish to work more spontaneously; and as a form of accompaniment for live performers. Table 9 documents the potential applications for the system in their case study participants identified in their creative practice.

Table 9: Projected uses of the system for three main professional groups

Main professional groups	**Projected uses for gestural system**
Vocalists	• Looping • Layering multiple voices • Compositional tool • Multi-sensory performance group – video projections with musical ensemble.
Instrumentalists	• Augmented bass • Augmented drums • Music classes for people with disabilities
Composers	• Mixing soundtrack piece • Left and right hand note generation • Exploring ideas of proximity in a performance art video work, where performers have heightened awareness of their relationship to the space and the geometry of it • Interactive learning environment

6.8.1 Composition

Instrumentalists who were also composers or songwriters wished to use the system to generate initial compositional ideas, or to compose in a real-time live context; for example, holding an ostinato pattern with the right hand and then applying textural variations to the generated material with the left hand, rather than simply applying effects. At the same time one participant had reservations about applying a traditional compositional framework to an alternative controller:

> Maybe it's a mistake to try and think of it in traditional terms, you know, composition, where you've got several voices and just creating this kind of interplay between the voices.... You could also go more for something that's about texture and effects I suppose. (Participant 4)

For a vocalist working accustomed to performing as a soloist, the potential to loop selected phrases and layer harmonies was viewed as a quick and effective way of building instrumental beds and exploring embryonic compositional ideas. Otherwise, she was dependent on an ensemble or full studio setup to achieve such aims. For someone with little equipment and used to collaborating with other musicians, this potential represented a form of liberation, bridging live and studio contexts.

The idea of generating ideas through performance rather than recording them one track at a time, gave the process a flexible and adjustable nature, encouraging interplay of different variations till an overall satisfactory layering could be achieved:

> to drop things in and see how I can weave bits together with that freedom, that spontaneity is what I guess it is. To be able to be spontaneous and create something like that, which you're not when you have to deal with the first bit and go back and do it again, and then listen to that and try to do a third bit. Whereas if you do this you can layer it and say, well that really worked, that didn't, that did. (Participant 5)

This comment suggests the relevance of the system to studio applications, a view reinforced by Participant 3, who suggested,

> if you have multiple vocals to create and you want to organise 20 odd tracks, the Mixer could be very useful. I think we need to find new ways of working anyway, so anything is better than being tied to some surface that is foreign to us. Just the possibility of not being strapped to a chair, looking at a screen.

6.8.2 Key Control Features

The widely varying control features requested by participants reflected varying creative aims and priorities. The main suggestions can be summarised in the following points:

- Increased inclusion of note level control and more detailed control of pitch (step-based transitions) in combination with "conducting" style of control over pre-composed material;
- Timbral envelope shaping — a greater ability to gradually shape timbre over time;
- Whole body interaction — balancing the energy distribution throughout the body;
- Clearer relationship between visuals and sound — currently the visuals mainly amplify movement, not sound. Some participants want clear correspondence between all three layers.
- Finer movements — the ability to detect not only expansive movements but also fine-grained finger movements.

This chapter has provided insights into how expert musicians from a range of professional backgrounds engaged with three representative applications from Gestate, a gestural system designed for musical performance. The main findings emphasised the high degree of customisation required by musicians from varying professional backgrounds, from preferred types of control gestures to sonic processes and broad- or fine-grained levels of control.

For some instrumentalists, the absence of a tangible instrument or device to interact with and structure their physical experience was sometimes a barrier to further exploration. In these cases, engagement with the system evoked feelings of self-consciousness, which contributed to lowering the overall levels of creative explorability. In contrast, participants with a movement and/or vocal background appeared most open to experimenting with movement-based interaction, exhibiting a greater tendency to explore new ways of moving to attain more diverse sonic outcomes. This finding demonstrates how influential professional background can be in shaping gestural interaction experiences, affecting the types of gestures, sound production processes and visual feedback users prefer. It also underlines the reasons behind the high degree of customisation in the field of gestural interface design, particularly in the musical production and performance areas where aesthetic and skill considerations substantially shape musicians' experiences.

The most common preference that emerged from the study was the tendency to favour continuous and spontaneous control gestures, as opposed to discrete and deliberate predefined gestures, which were sometimes at odds with participants' usual ways of moving and physical aptitude. However, continuous gestures also raised issues about achieving precise and nuanced control with more exacting musical tasks, such as altering pitch and amplitude in smooth and regular increments. For participants from a non-movement background, it was particularly challenging to achieve subtle and predictable control with large-scale movements, prompting a call for more fine-grained, finger-based control, in which many instrumentalists are highly skilled, for discrete functions such as mode or parameter changes.

The following chapter presents the next iteration of Gestate, which incorporates participant feedback from the case study to develop a design that incorporates whole-body interaction, working towards promoting the development of movement awareness among musicians through clearer and more direct correlations between movement, sound and visual feedback. The new system builds on the metaphoric approach established in the initial version of Gestate to support sympathetic mental, kinaesthetic and musical imagery to aid in structuring the experience.

Of the three system applications, the Arpeggiator was perceived as most effective in promoting all of the design criteria, particularly explorability and naturalness of movements, both for myself and for the participants of the study. As a result it has become a template for the next stage of creative work and system development. Aspects of the two other applications also informed the next design phase. The Cube, even though less well received than the Arpeggiator, still demonstrated the effectiveness of controlling percussive physical models with sudden, directional effort, while the Mixer offered insights into how visual, sound and gesture can combine to form a stimulating improvisational environment. These findings were integrated into a multi-faceted version of the system directly responsive to the performer needs of explorability, a high degree of customisation, engagement and satisfaction with the physical aspects of performance.

Chapter 7: Bodyscapes

Reduced to our own body, our first instrument, we learn to play it, drawing from it maximum resonance and harmony.

Yehudi Menuhin (Iyengar 2005, p. xi)

7.1 Introduction

This chapter discusses the revised version of Gestate, which incorporated expert user feedback from the case study and personal insights emerging from past performances. The new design iteration resulted in a movement-controlled virtual instrument called the Telechord, and an evaluation of its application within performance.

Bodyscapes is an audio-visual performance that integrates whole-body interaction. Through this piece I continued to explore the role of visual feedback, the evolution of a personal movement language, and mapping ideas that evoke familiar sonic associations grounded in real world experiences. The transformative effects of performing with a gestural system, leading to the continued development of specialised musicianship for gestural performance, emerged as an overarching theme of the work.

7.2 Telechord: Body as Instrument

The revised system included the Telechord, an adaptable gestural instrument aimed at facilitating movement exploration and enabling a performer to arrive at new movement-sound associations through combined musical and movement improvisation.

7.2.1 Outline

The Telechord integrates real-time physical modelling synthesis with video generation derived from improvised body postures and movement patterns. The instrument enables pitch control and harmonic layering of physical models with whole body movement. Using a string instrument metaphor, four virtual strings are stretched across the apex joints of the skeleton. As the body moves, the length of the virtual resonating wires surrounding the body changes the pitch of four separate tones. The shifting relationships between selected joint positions produce harmonies that reflect the unique geometry of the human form.

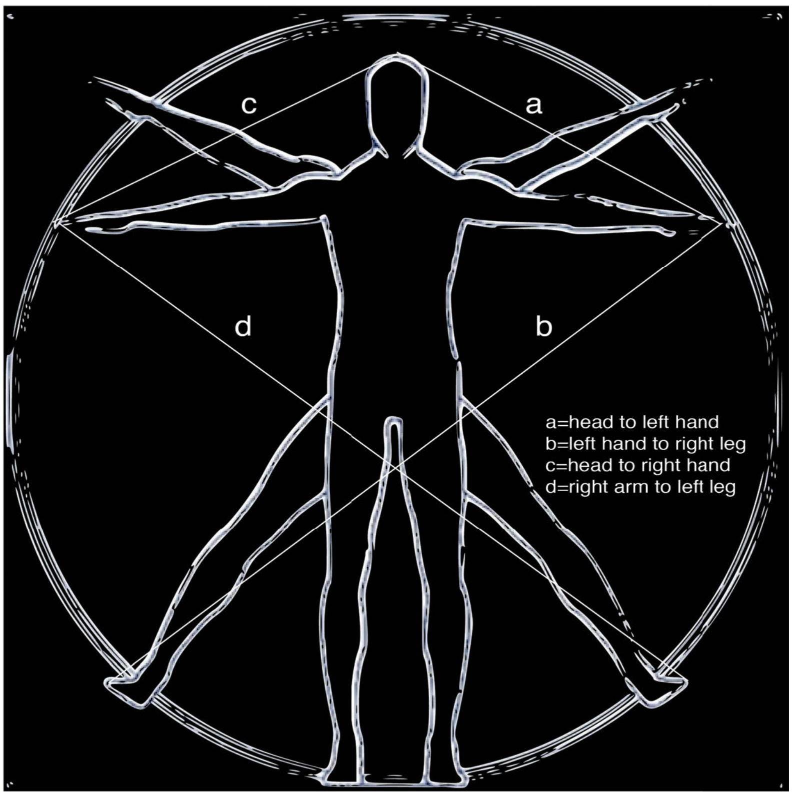

Figure 34: Virtual string positions for the Telechord

The string metaphor facilitates the production of chordal harmonies directly with the body. Virtual resonating strings linking the limbs and head change in pitch when the body moves, affecting frequency in relation to the distances between selected joints, as shown in Figure 34.

Inspired by somatic practices like yoga that seek to unite body and mind, the frequencies produce harmonies that signify relationships between joints that have been identified as significant in conveying expression during musical performance through motion-tracking studies (see Section 2.2.2, Expressive Gestures). The aim of the instrument is to induce a state of alignment by depicting relationships and associations derived from the body rather than imposing arbitrary one-to-one correspondences.

The Telechord provided an environment in which to explore relationships between different body parts within particular postures and movement patterns. When improvising and performing with the virtual instrument, envisioning the imaginary strings gave me a powerful mental image I could structure my actions around, offering the freedom to experiment further, with less self-consciousness than I had felt during previous performances with Gestate.

In response to participant feedback calling for less preset system sounds during the expert user case study in Chapter 6, I chose to implement rudimentary physical models that afforded a high degree of user customisation for sound generation. I also integrated note-level control — one of the features most requested by case study participants. The initial inspiration for the design was to produce an instrument that functioned as a polyphonic version of the theremin. The name, Telechord, was developed to convey the communicative capacity of the instrument over a distance, signifying the transferral of communicative intent between the performer and audience. It was also a reference to one of the first string instruments; the monochord, invented by Pythagoras.

The Telechord was modelled on geometric representations of the body's architecture and spatial dimensions dating back to Leonardo da Vinci's *Vitruvian Man* (c. 1490) illustration and Pythagorean harmony. It links the body's proportions and ratios between the limbs, torso and surrounding space to activate virtual physical models and harmonic intervals. Its aim is to integrate a mapping scheme founded on familiar natural associations — in this case the geometric proportions of the moving human form.

The Telechord uses four physically modelled objects virtually connected to selected body joints to produce sound by exciting each object proportionately to the joint motion at the point of connection. Motion thus has the effect of exciting the object while adjusting its virtual size (and therefore pitch). By altering the properties of the materials used to create each object, various tunings were formulated for each piece discussed in this chapter. Table 10 summarises the core sounds crafted for the *Bodyscapes* performances. These can also be viewed as software patches[32] and video demonstrations.[33]

[32] Telechord sounds – software patches, viewed 21 August 2015, <http://www.mainsbridge.com/telechord-software/>.
[33] Telechord sounds – demonstration videos, viewed 21 August 2015 <http://www.mainsbridge.com/telechord-demonstrations/>.

Table 10: Main sounds of the Telechord

Sound	Object	Exciter	Size Range
1. Whirr 1	Rectangular membrane	A (Head velocity + Left hand velocity) B Left hand velocity + right foot velocity C Head velocity + right hand velocity D Right hand velocity + Left foot velocity	A 0.1 x 0.1m – 0.8 x 0.8m B 0.1 x 0.1m – 0.8 x 0.8m C 0.1 x 0.1m – 0.4 x 0.4m D 0.1 x 0.1m – 0.4 x 0.4m
2. Hybrid distort	One-dimensional string	A (Head velocity + Left hand velocity) B Left hand velocity + right foot velocity C Head velocity + right hand velocity D Right hand velocity + Left foot velocity	A 1m – 4m B 1m – 4m C 0.5m – 2m D 0.5m – 2m
3. Tri oscillator (vocal exciter)	Circular membrane / String hybrid resonator whose input is driven by voice and joint velocity. Joint position also melds between membrane and string	A (Head velocity + Left hand velocity) B Left hand velocity + right foot velocity C Head velocity + right hand velocity D Right hand velocity + Left foot velocity	Several differently tuned plates and strings (see software patch)[34]
4. Whirr 2	Rectangular membrane	A (Head velocity + Left hand velocity) B Left hand velocity + right foot velocity C Head velocity + right hand velocity D Right hand velocity + Left foot velocity	A 0.1 – 0.5m B 0.1m (fixed) C 0.1 - 2m D 0.1m (fixed)

[34] Tri oscillator, Telechord sound software patch, viewed 20 August 2015 <http://www.mainsbridge.com/tri-oscillator/>.

Sound	Object	Exciter	Size Range
5. Hybrid oscillator	Rectangular membrane	A (Head velocity + Left hand velocity) B Left hand velocity + right foot velocity C Head velocity + right hand velocity D Right hand velocity + Left foot velocity	A 1 x 1m – 4 x 4m B 1 x 1m – 4 x 4m C 1 x 1m – 4 x 4m D 1 x 1m – 4 x 4m

Three basic types of physical actions produce sound on traditional acoustic instruments: blowing (also incorporating vocalisations), rubbing (including bowing and scraping) and striking (including plucking) (Cook, 2002). The Telechord supplements these actions with continuous and discrete improvised gestures applied to simulated physical materials.

The decision to progress to whole body interaction was motivated by a desire to extend bodily engagement and improve the overall visual impact of my performances. Whole body interaction is particularly prevalent in dance, installations and specific music applications such as Harmony Space (Wilkie, Holland & Mulholland 2010). England, Sheridan and Crane (2010, p. 4466) employ the term, whole body interaction, to signify a user-centred approach as opposed to terms like 'mobile' and 'ubiquitous interaction' that focus on technology rather than the way the body moves in space. This focus aligns with their intention to find techniques that encourage well-developed, rich whole body interaction.

The Telechord's design was initially intended to encourage exploratory movement, improvisation and experimentation. My aim was to develop new forms of musicianship that nurtured kinaesthetic awareness, shifting the focus from technical design aspects to the acquisition of skills and approaches intended to extract the most from gestural performance systems in live contexts.

7.2.2 Interaction Design

The Telechord's design draws on classical Greek philosophy, where mathematical understandings are sought from the natural world. The virtual physical models are designed to reflect "geometry that gives us a tangible image of space" (Newlove & Dalby 2004, p. 23), coupled with a geometric simplification of the human form. Also inspired by Pythagorean understandings of the mathematical correspondence between string lengths and harmonic intervals, the pairing of human proportions to harmonic ratios guides the control of pitch, harmony and timbre in the Telechord.

Roman architect Vitruvius' architectural understanding of the human form was resurrected in the Renaissance through Leonardo da Vinci's *Proportional study of a man in the manner of Vitruvius* (c. 1487). Vitruvius regarded the body as the basis for geometry, in line with Pythagorean notions of nature as the root of knowledge. The illustration, on which the Telechord's design is based (see Figure 22), depicts the human form both standing and in motion, nestled within a circle and set square. The navel forms the central point, from which a compass can be placed to trace the outline of the circle, representing the ideal human proportions proposed by Vitruvius.

Related to this work, which seeks to represent the natural world in mathematical terms, is the relationship between the length of a vibrating string and its fundamental pitch, a discovery often attributed to Pythagoras. Through his invention of the monochord, a single stringed instrument with a movable bridge, Pythagoras was able to study the harmonic relationships between vibrating strings of varying lengths (Caleon & Ramathan 2007, p. 450). As shown in Table 11, when two strings of the same length are sounded together, they have the same pitch and the relationship between them is referred to as unison, represented as a 1:1 relationship. When an oscillating string is stopped halfway along its length it becomes an octave in relation to the string's fundamental tone, while a ratio of 2:3 results in a perfect fifth and a ratio of 3:4 creates a perfect fourth.

Table 11: Pythagorean intervals

Harmonic Interval	**Ratio**
Unison	1:1
Octave	1:2
Perfect fourth	3:4
Perfect fifth	2:3

When linked with Pythagorean thought, the body's proportions suggest parallels with harmonic ratios. The link between these two philosophies grounded in natural laws offered a starting point for designing the Telechord interaction, one that leveraged the body's proportions and the way in which individual joints relate to each other during movement. The associations between the joints were seen as equally important as isolated joint data — perhaps even more significant.

This importance is highlighted by England, Sheridan and Crane (2010), who recognise the inadequacy of only including individual joint information in interaction design:

> recent research suggests that while looking at one's internal state (due to emotion, for example), can produce mechanical changes at the individual joint level, looking at one joint does not provide sufficient information for successfully predicting the cause of the change. The current hypothesis is that the success of such predictions depends on how multiple joints (i.e. signals) interact. (England, Sheridan & Crane 2010, p. 4467)

Similar principles guide the somatic practice of Bartinieff Fundamentals, offering the underlying principle, "The whole body is connected. All parts are in relationship. Change in one part changes the whole" (Hackney 1998, p. 217). This concept of interrelationship influenced the interaction design of the Telechord, and the linking of string lengths to the relative positions of the right arm and left leg, the left arm and right leg, head and right hand, and head and left hand. These relationships are depicted in Figure 34.

The Telechord's design also echoes works from the Russian and German avant-garde art movements of the twenties, which explored the geometry of the human form, particularly during the Bauhaus movement. Bauhaus artist Oskar Schlemmer, who explored the moving human form, created systems that investigated geometric elements and space, demonstrated in works such as the *Mathematical Gesture Dance* and *Dance in Space*. In Schlemmer's *Stäbetanz* (Stick dance) project, which emphasises the geometry of the human figure's traces through space with white stick extensions, the black-clad body of the performer recedes into the background and instead reveals the essence of the human form. The torso is depicted as the central pivot and core for all movement, accentuating the lines of the human form and the shapes the moving body makes in space.

This work bears a strong resemblance to the visual component of the Telechord, in which the essence of the body's movement is reduced to simple lines and geometric patterns, as shown in Figures 35 and 36. Figure 35 demonstrates the two visualisation modes. On the left are the virtual strings linking selected joints and on the right is the Smokescreen visualisation. It is possible to layer the two modes or feature them separately.

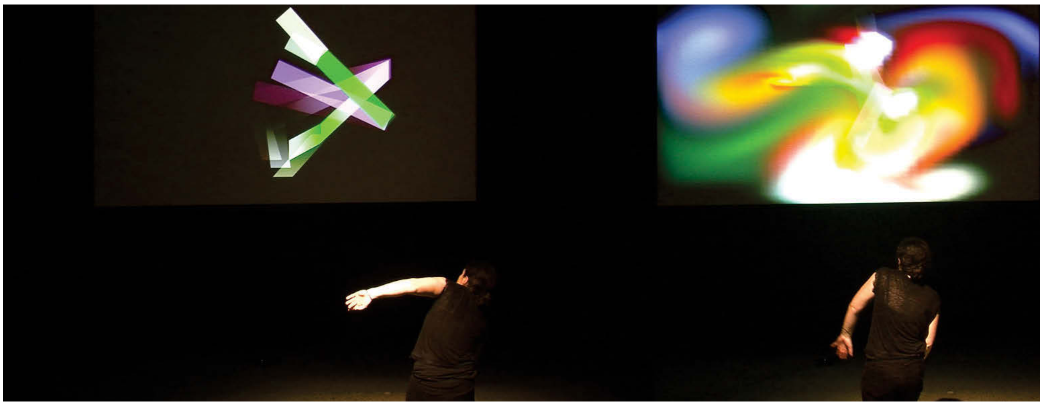

Figure 35: Telechord visualisations

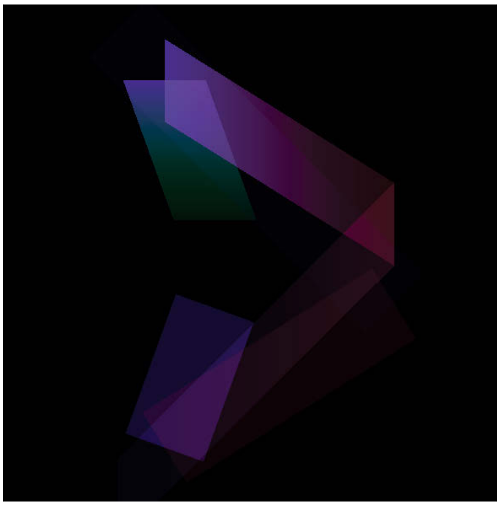

Figure 36: Telechord visualisation: screenshot

Explorations of the geometry of the moving body continue to inspire recent interactive works. As discussed on Section 2.5.1, Design Considerations, Mandancini and Sapir configured the interaction design for their work, *Disembodied Voices: A Kinect Virtual Choir Conductor* (2012) using the *Vitruvian Man* (c. 1487) representation to define control zones in the three-dimensional spherical space surrounding the body. Their approach demonstrates the usefulness of applying this metaphor for designing interactive works that employ the Kinect, with its skeleton tracking feature that enables the lines and relations between the joints to be easily extracted.

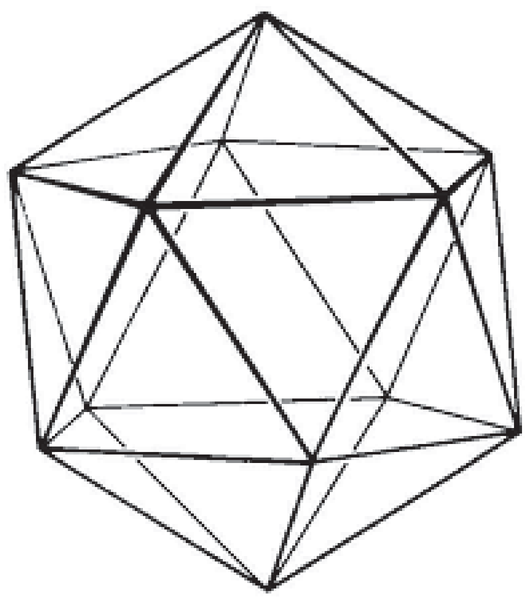

Figure 37: Icosahedron

Also drawing on geometric and natural principles, Laban's study of crystalline forms offers a further explanation of how the body moves in space. Of the five regular convex polyhedral forms, which include the tetrahedron and cube, the icosahedron (Figure 37) is the most voluminous with twenty faces. Laban developed a range of movement scales within the icosahedron for exploring the three spatial dimensions he identified: upwards and downwards, backwards and forwards and sideward motion (Newlove & Dalby 2004). These scales offer a foundation for exercises targeted at trained dancers, aiding in the development of spatial awareness and balance. This area is sometimes referred to as Space Harmony, designed to enable dancers to learn more about how they move within their kinesphere. Laban also refers to the spatial pulls and tensions that reside in crystalline forms to describe where movements are going in space, aiding in the discovery of the aesthetic and meaningful movement combinations that can be achieved in harmony with natural principles (Bradley 2009, p. 25).

Laban's a regular and symmetrical view of the space surrounding the human body and concept of space harmony or choreutic scales that are analogous to musical scales provide an additional perspective to the Telechord's implementation of an interaction metaphor based on a string under tension to stimulate sound-movement associations and chordal harmonies.

7.2.3 System Architecture

SimpleKinect[35] was chosen as the middleware to direct Open Sound Control (OSC)[36] messages from the Kinect sensor to Max/MSP. This made it adaptable to single user and multi-user contexts, allowing it to be used in both performances and installations. The instrument design process comprised the following steps:

---

[35] Bellona, J. 2014, *SimpleKinect*, viewed 20 August 2015 <https://github.com/jpbellona/simpleKinect>.

[36] Open Sound Control (OSC) is a protocol enabling communication between computers and other multimedia hardware, viewed 20 August 2015 <http://opensoundcontrol.org/>.

- Position was obtained from the following joints — hands, feet and head. The distances between hands to head and hands to feet were applied to modifying harmonic intervals.
- Calculation of the distances between selected joints to form virtual strings.
- Use of IRCAM's Modalys[37] software to simulate a range of vibrating bodies, termed 'objects' — a palette of sounds was designed to suit each of the sections in the following works.
- Modulation of the continuous parameters of frequency and timbre in a similar fashion to controlling a synthesiser, but with the entire body rather than two hands.
- Acceleration from previous patches was introduced to control the excitation of each note, allowing additional expression in relation to the force of movements.

7.2.3.1 Physical Models

The sounds listed in Table 10 were designed in Modalys physical modelling software, which facilitates virtual instrument design by offering a variety of materials, including plates, strings and membranes, that can be matched with different exciters, including bows and hammers. Using several examples provided with the program as a starting point, alterations were made to each sound in Modalisp[38] before being exported to Max/MSP for real-time performance use.

---

[37] Modalys. 2014, *Modalys*, Ircam, Paris, France, viewed 20 August 2015 <http://support.ircam.fr/docs/Modalys/current/co/publication-web.html>.
[38] ModaLisp is a standalone program powered by LISP. Modalisp, viewed 20 August 2015 <http://support.ircam.fr/docs/Modalys/current/co/publication-web.html.

Further refinements were then undertaken during testing and rehearsals to achieve appropriate levels of responsiveness and fine-tune the timbre and attack of specific sounds to suit each piece. Varied movements produce different effects on the sounds. For example, slow and gradual movements can function like a violin bow by producing legato with the virtual strings. In contrast, sharp movements result in more percussive, sonic attack, producing plucked string sounds and accented, or marcato, chords.

The rationale behind using physical modelling was to find a sound-generation technique more closely aligned with playing acoustic instruments than other synthesis methods. Traditional sound synthesis techniques have incorporated oscillators, wavetables, filters, time envelope shapers and digital sampling of natural sounds. David M. Howard and Stuart Rimmel (2004) argue that physical models of musical instruments offer less abstract parameters that are more connected with musicians' experiences of playing traditional instruments. They recognise the need for electro-acoustic musicians to have control over all elements of a sound, and propose that physical modelling delivers more intuitive control, as the method is based on the physical vibrating properties of objects found in everyday life, such as strings and membranes. The user is thus more likely to predict the result of a particular action compared to other synthesis techniques.

Howard and Rimmel (2004) argue that when physical modelling is used as a basis for sound synthesis, the output closely resembles acoustic instruments on which the technique is based, a hypothesis echoed by Chafe in relation to DMI design:

> It is the essences that are produced by physical modelling techniques. Looking closely at the figuration in a rock or boulder, one tries to imagine

> the shaping processes behind the appearance[….]From first principles of instrument physics and player gestures, musical characters are to be discovered in the same way. The future approach is to bind instrument and control more closely, and build a terrain of boulders, cliffs and mountain ranges from an integrated set of rules. (Chafe 1999, p. 96)

In *Real sound synthesis for interactive applications* Cook (2002, p. xiii) writes, “Our evolution and experience in the world has trained us to expect certain sonic responses from certain input gestures and parameters”. By incorporating these expectations into interaction design, it may be possible to establish a familiar grounding from which to develop coherent and believable mappings that are supported by understandings based on physical experience.

The potential of physical models to provide a sonic environment in which to explore gesture has attracted much attention from researchers: “Much of the recent interest in gesture modelling has been stimulated by advances in physical modelling” (Leman, Styns & Bernadini, 2008, p. 30). However, when applying gesture to the control of physical models, the way in which the sound is controlled can produce artificial effects that make its source difficult to detect:

> When using a physical model to simulate an acoustic instrument, the way it is controlled is as important as the quality of the model itself. A physical model that is potentially capable of simulating any sound of an acoustic instrument will still sound very unnatural if it is not controlled correctly. (D’Haes 2004, p. 7)

The challenge of creating a balance between the original sound’s integrity and the gestural input thus became a primary consideration in the design of the Telechord.

7.2.4 Role of the Visualisation

The Telechord was also represented in visual form, depicting the distances between the legs, arms and head as lines or virtual strings. This abstraction emphasised the links between key joints. Additionally, the amplitude of the instrument and the movement of the captured joints were depicted as a particle system, showing the amount of energy being injected into the system. Programmed in OpenGL (Open Graphics Library),[39] the particle system was created from a two-dimensional smoke simulation generated by a customised application called Smokescreen.

Table 12: Mapping movement/audio data and visualisation in Telechord

Movement/Audio Data	**Visual Feedback**
Distances between: • Left hand to head • Right hand to head • Left hand to right foot • Right hand to left foot	Line representing the virtual object size and position mapped to 2D projection.
Amplitude of instrument	Velocity of emitted smoke particles at current joint position.

Smoke particles are injected into a two-dimensional fluid simulation, where the fluid is disturbed by their motion. Over time, the fluid disturbance decays to zero and the smoke particles diminish in brightness. Movement thus traces a path that is constantly altered by previous movements and amplitudes. The image is intended to echo the nature of musical memory while indicating to the performer the positions they have recently visited.

[39] OpenGL, viewed 20 August 2015 <https://www.opengl.org>.

In the *Bodyscapes* performances at the 2014 Sydney Fringe Festival, the visualisation was projected onto a scrim with the performer behind it. The performer was illuminated by two strong spotlights to highlight their movements behind the screen, creating a multi-layered visual effect. The scrim was intended to create the impression of a control surface for the player that could be shared with the audience.

Figure 38: Smokescreen visualisation with lines: screenshot

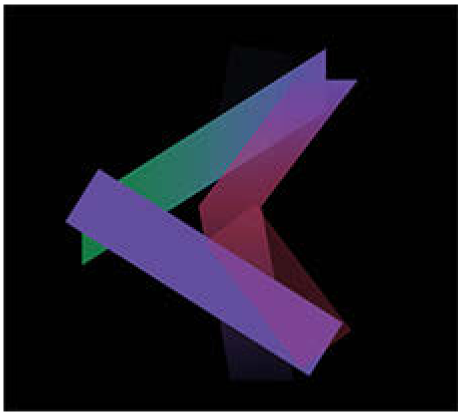

Figure 39: Lines visualisation: screenshot

The aesthetic choice to employ abstract visuals rather than explicit visuals was motivated by artistic priorities, leaving interpretations of the connections between movement, audio and visuals open for the performer and audience. This sentiment is echoed in Fdili Alaoui, Henry and Jacquemin (2014, p. 161), who discovered the effectiveness of abstract forms of feedback through a series of dance and movement studies:

> More abstract visuals allow for a wider range of conceptual responses than visuals obtained from motion capture or image processing. Interviews with performers and online experiments showed the keen interest of the artists in working with such abstract forms of visual feedback.

These observations relate particularly to the *Chiselling Bodies* performance with ballet dancer Marion Cavaillé, which is based on an improvisation incorporating the dancer's movement qualities and an abstract visualisation derived from mass spring physical models. Cavaillé found that she could build a relationship with the projected model, almost as if it were a separate performer, through ongoing improvisations with it (Fdili Alaoui, Henry & Jacquemin 2014, p. 177).

From her qualitative research with dancers, Fdili Alaoui also concluded that interaction with these abstracted forms of feedback assisted in refining performance and developing new movement content (Fdili Alaoui et al. 2013). These findings support my earlier hypothesis that visual feedback might aid movement exploration and the generation of new mappings and sonic content.

Hansen (2012, p. 258) also stresses the importance of visualising movement: "Visualisation of physical movement in interaction design enables a conceptual exploration of novel communications." Examining the communicative potential of movement, Hansen looks to choreographic approaches such as Fdili Alaoui's and regards visualisation as a tool that aids the design process, making movement more accessible in a manner akin to sketching ideas on paper early in a system's conception (Hansen 2012, p. 252).

Buxton (2007, p. 136) emphasises the importance of sketching ideas in a range of formats to draw out key aspects of interactive design that "capture the essence of design concepts around transition, dynamics, feel, phrasing, and all the other unique attributes of interactive systems". This illustrative capacity of visualising movement helped to accentuate the geometric forms underpinning the interaction design of the Telechord, providing insight into how the moving body was being interpreted by the system.

7.3 *Bodyscapes*

Bodyscapes was performed on the 20th of September at the 2014 Beams Arts Festival and on the 26th and 27th of September 2014 at the PACT Centre for Emerging Artists, Erskineville, as part of the Sydney Fringe Festival. The forty-minute work was written specifically for the Telechord, accompanied by electronic drums, audio samples and video art. Excerpts and the full video recording of the Sydney Festival performance, filmed on the 27th of September 2014, is viewable online.[40]

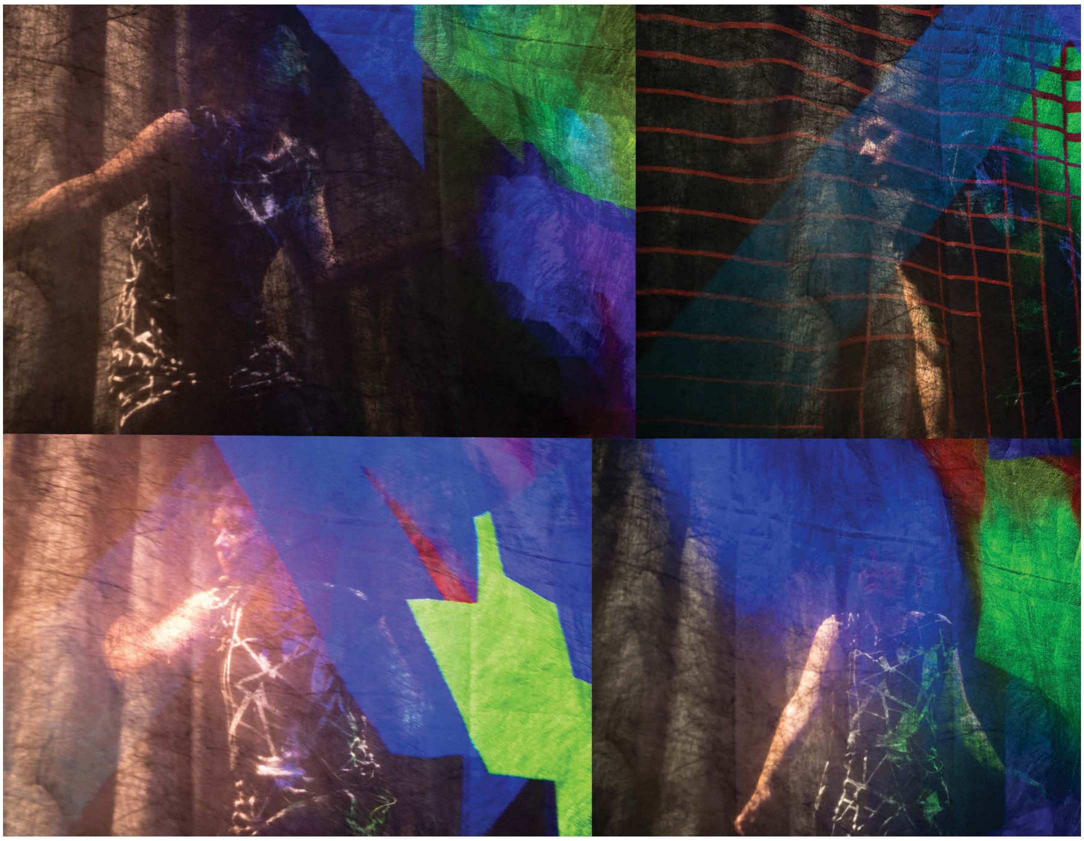

Figure 41: *Bodyscapes* performance images

[40] *Bodyscapes* video recordings, 2014 Sydney Fringe Festival, viewed 20 August 2015, <http://www.mainsbridge.com/bodyscapes/>.

7.3.1 Motivation

In response to the limitations associated with pre-composed elements in the previous iteration of the system, I sought to progress beyond the use of movement to trigger sound. To achieve greater nuance through gestural performance, I needed to embrace approaches more novel than simply copying a mouse-style point and click interaction.

This piece marked a transition from using a gestural controller to performing with a gestural instrument that could become more integrated into my performance movement style. The work addressed the original focus of this research, which was to explore the notion of body as instrument. Sonifying the proportions and movement patterns of the human form guided the conception of this work.

Feedback from the expert user case study was integrated into the revised design of the instrument — the request for bowing and staccato note control was adopted in the instrument design to enable more versatility and variability of expression. The idea of beginning with a completely blank canvas that would accept raw movement information informed the instrument's early development. The motivation to let instinct come to the fore — to control and guide every creative decision through the body — was paramount.

As mentioned in Section 6.7, Findings, simplicity in terms of well-defined constraints was found to be essential in allowing freedom of exploration for first-time users of Gestate. Boundaries needed to be defined before they could be tested and pushed further. With the Telechord, these constraints were related to the geometry of the body and the relative distances of key joints, placing the onus on the performer to achieve variations through the exploration of these naturally-occurring ratios, reinforced by the visual imagery of imagined strings. By linking harmony to the body's proportions, I experienced a sense of structure that almost provided the feel of a tangible instrument. Unlike a conventional instrument, however, it did not impose constraints on my behaviour that were at odds with my body, but rather worked with its dimensions.

7.3.2 Work Outline

As with previously discussed works, the piece explored notions of expansion and contraction, this time influencing the size of harmonic intervals. Fully extended limbs produced large intervals of octaves, while more contained postures produced major and minor thirds, and perfect fourths and fifths. The mapping was designed to be clear and direct, providing coherent audio-visual cues for the audience while attempting to remain intuitive for the performer. Unlike the *Gestural Études*, the mapping was constant and consistent throughout, to facilitate clear communication with the audience.

The exploration of harmony in relation to the body was a key aspect of this piece. Movement of each limb controlled the continuous parameters of frequency and timbre. Early development of the work required refinements to avoid an unwanted glissando effect when changing pitch, and to achieve clean steps between each pitch transition. Harmony was also sought on a physical level, by exploring different configurations of the whole body. Unlike previous works that focused on upper body motions only, whole body interaction was seen as a means to achieve a more balanced use of the body.

The instrument provided a range of options — either to inject noise or an oscillator into the system, or to use my voice as an audio input and alter its tone with selected materials and exciters. When using the latter input mode, the voice was often transformed to such an extent as to be unrecognisable. It sometimes assumed a percussive texture, stuttering or becoming drawn out with a reverberant ringing tone. In this mode I could combine the two variables of voice and movement to alter the original physical model, transforming my playing style as the voice became a new type of entity, at times unfamiliar and alien.

The performance comprised five individual works, each employing a different physical model. For each work there was a different gesturally controlled physical model originally sourced from the Modalys library, including Whirr, a breathy sound with controlled by an oscillator; Hybrid Distort, a sustained distorted sound made from white noise, and Tri Oscillator, a virtual instrument regulated by vocals. Whirr did not have a defined attack, making it sound more atmospheric and air-like sound than the other physical models.

The performance began with a solo improvisation using the Hybrid Distort sound, where distances between selected joints controlled the pitch of four virtual strings (see Table 10), creating harmonies when combined. With sweeping sideward head movements, I was able to apply distortion, similar to the activation of a guitar distortion foot pedal. I used this effect when necessary to exaggerate and prolong sonic textures.

The performance began with this direct one-to-one relationship between body actions and sound to introduce an understandable mapping to the audience, employing a similar technique to Schloss and Jaffe's work, which combines the Dislavier and Radio Drum to perform a piano concerto with percussive movements (Schloss 2003, p. 3). They intentionally start the performance with minimal movements before progressing to more complex chords and interaction. This technique is aimed at accentuating causal relationships between action and sound and providing transparency to the audience.

The first piece, *Steamfields*, used the Whirr 1 sound to produce sustained, breathy chords designed to create an atmospheric effect, particularly during sparse sections with no strict pulse.

The second piece, *Cracea*, reintroduced the Hybrid distort sound against a strong rhythmic foundation created from distorted percussion sounds, building the intensity of the performance. The third piece, *Beam*, featured vocals processed through the Tri oscillator, allowing me to shape the sound of a circular membrane and hybrid string sound with spoken word, singing and body movements. The fourth piece, *Alignment*, shared the same ephemeral and breathy character of *Steamfields* with the Whirr 2 sound. The set ended with a vocal piece, *This is That*. I used the Hybrid oscillator as a form of instrumental accompaniment rather than feeding the voice through it to ensure clarity and adequate pitch control.

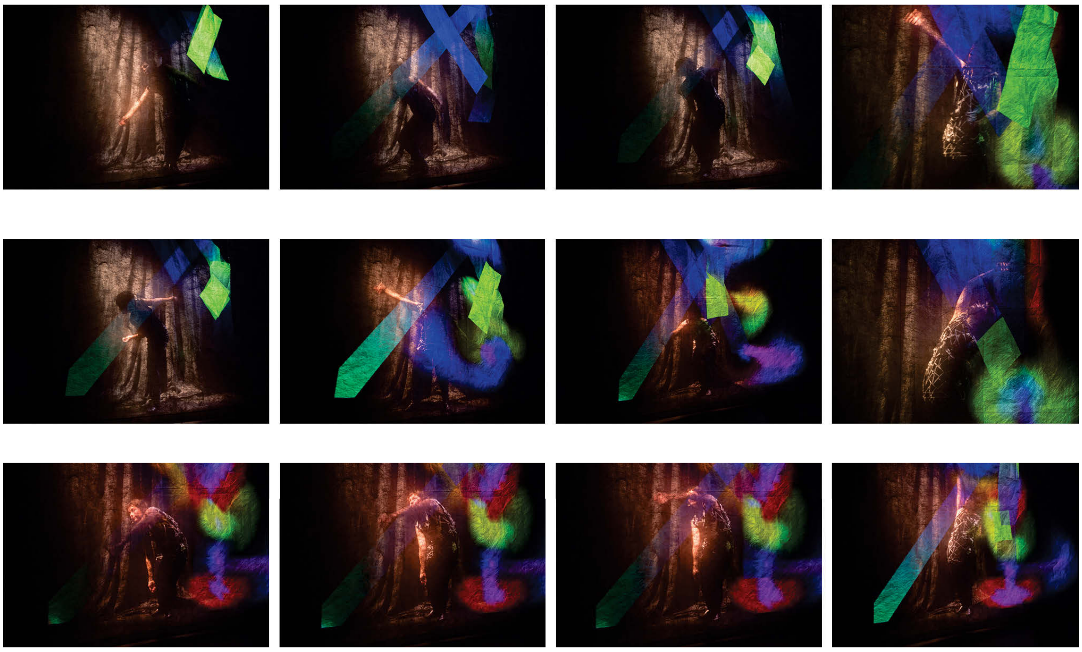

Figure 40: Bodyscapes representative gesture vocabulary[41]

Figure 40 demonstrates representative movements in the opening section of *Steamfields* during the Bodyscapes performance on September 26, 2014, highlighting the geometric nature of the various poses. Fluctuating between crouched and fully extended poses, I activated higher notes in the upper reaches of my kinesphere and mid-range and lower notes as I leant towards the floor. The characteristic movements of the performance included sweeping, cyclical, twisting and torso rotating actions suited to the breathy and ethereal quality of the Whirr 1 sound. I alternated between slower, flowing movements and punctuated flicking gestures, using the latter to emphasise the attack and definition of selected accented notes.

As demonstrated in the instrument demonstration of Whirr 1, my movement style is dominated by flowing and fluid gestures that sweep across the available pitch spectrum, periodically extending to the outer reaches of my kinesphere. The

[41] ‘Steamfields’ (Section 1), *Bodyscapes*, 2014 Sydney Fringe Festival, viewed 5 February 2016, < https://vimeo.com/154261272>.

motion qualities can be described as sweeping and expansive. Gradual movements produced scraping and sliding notes in the high and mid-range parts. When I bent towards the ground, reverberant bass tones added to the harmony of the higher notes. At times I traced ball-like shapes with my arms to create rounded phrases that ended abruptly with a stationary, crouched posture.

In the middle of the *Bodyscapes* performance I used the Tri oscillator sound to enact the string metaphor in the improvised interlude of *Beam*[42]. The opening gestures represented in Figure 41 are marked by low arm swings and pacing across the stage, introducing gently sliding, descending passages featuring a slow attack sinusoidal sound. As the improvisation developed, my movements become more emphatic, as I swung my arms above the head and over the shoulders, causing the pitch range to widen. After a brief pause, the arm circling extended to the full extent of my kinesphere, causing creating passages that swept across the full frequency spectrum. As I then alternate between upward, sideward and downward arm gestures against the curtain behind me, I imagined that I was plucking the strings of a harp, which helped to guide my actions in this section.

After several bars of fully extended, swinging arm gestures, I began swaying and bending my torso towards the ground, producing smooth, long notes. I continued with slow, wafty movements that had little weight to them. It appeared that I was scattering fragments of the sliding sounds through the air. The passage ended with subtle and subdued movements and shorter phrases of glissando notes as my hands lifted and fell gradually, while the scale and frequency of my movements became increasingly minimal.

---

[42] 'Beam' (Interlude), *Bodyscapes*, 2014 Sydney Fringe Festival, viewed 5 February 2016, < https://vimeo.com/139416555>.

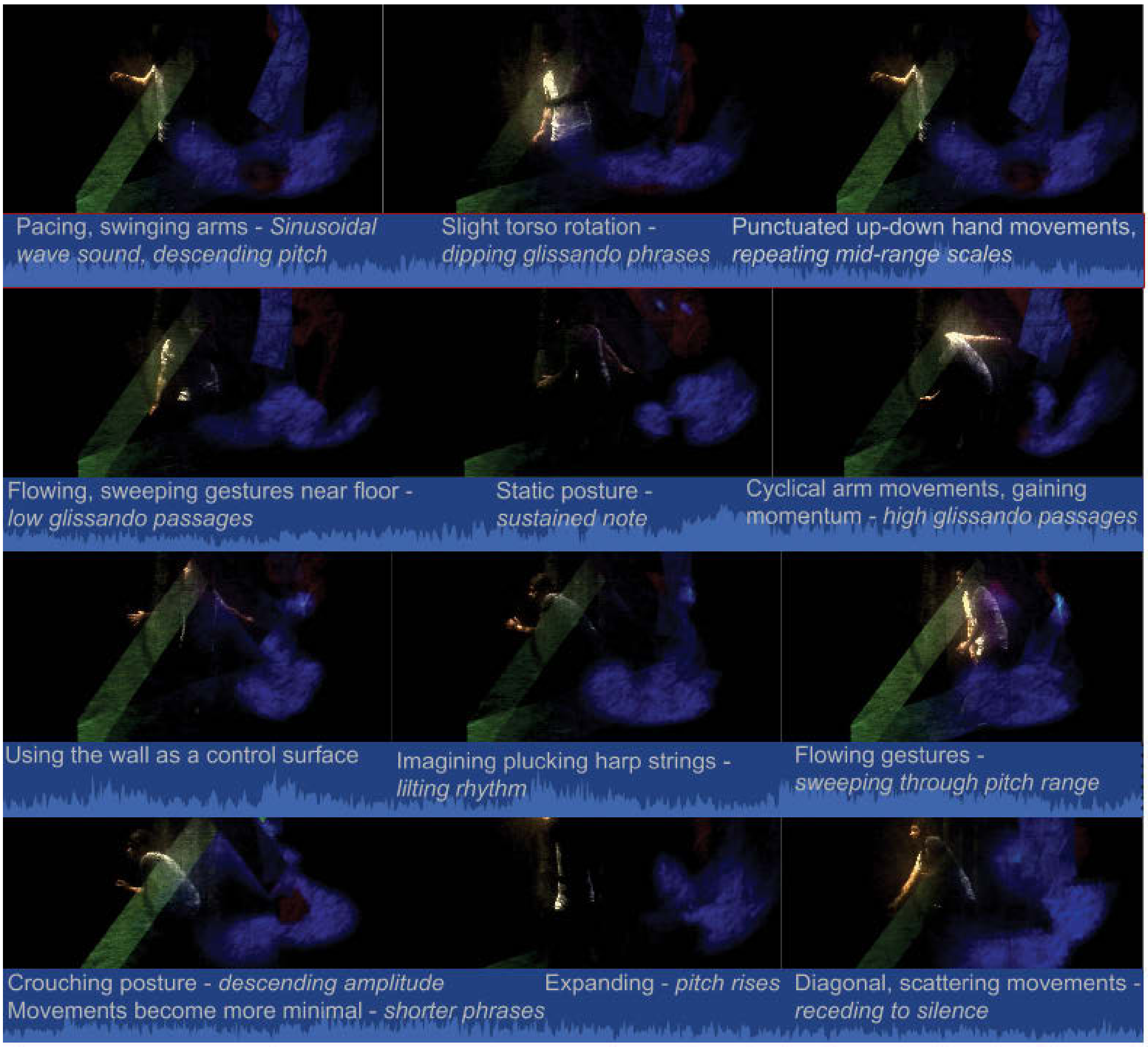

Figure 41: *Beam* (interlude) - Movement and sound relationships

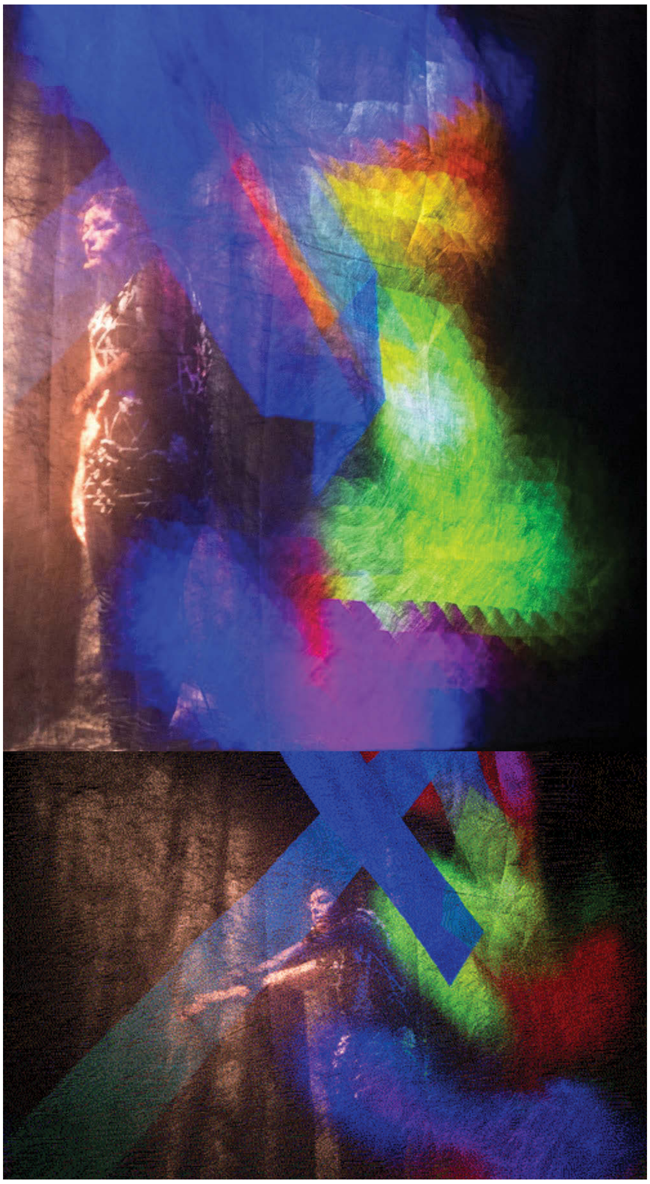

Figure 42: *Bodyscapes*, Sydney Fringe Festival, 2014

7.3.3 Discussion

During rehearsals and performances of *Bodyscapes,* I found myself progressively moving beyond my usual movement range and habits, occasionally crossing into the dance realm. Throughout this work I sought a sense of fluidity — the capacity to transform and shift my movements rather than becoming fixed in a habitual state of being. This approach fits in with Moshe Feldenkrais' (1972, p. 21) view that full awareness of all the joints and surfaces of the body results in a complete self-image, an ideal condition that is rarely achieved. Feldenkrais regards the systematic transformation of our self-image, comprising the four components of movement, sensation, feeling and thought, as more effective than a piecemeal approach that focuses on changing the body through one action at a time:

> Improving the general dynamics of the image becomes the equivalent of tuning the piano itself, as it is much easier to play correctly on an instrument that is in tune than on one that is not. (Feldenkrais 1972, p. 24)

This metaphor is directly relevant to my own work, summarising the experience of refining my bodily awareness and abilities to extract the maximum expressiveness from the Telechord.

My regular physical activities have influenced my posture, movement pace and patterns. Yet through this type of movement-based performance, which transcends the physical constraints of a particular instrumental technique, I could explore new terrain, experimenting with different movement approaches through sonic interaction. The body became its own reference point, moving beyond ingrained habits and cultural connotations.

Ongoing physical engagement with the instrument throughout the design process helped me develop a grounded, embodied understanding of how movement worked within the interaction environment that was created. Drawing on physically motivated design approaches, such as the work of Hummels, Overbeeke and Klooster (2006), I sought insights into movement-based interaction through direct engagement with movement.

The simple act of building four-part chordal harmonies with my body promoted a sense of intense physical concentration and awareness that is often missing in my instrumental performances. This pause for awareness is a consistent feature of other major somatic practices such as Alexander technique, which offer specific exercises that encourage awareness of neglected areas of the body in order to reframe usual movement styles.

7.3.3.1 Sound-Movement Improvisation

Unexpectedly, the Telechord inspired me to relax, evoking movement awareness while fulfilling a therapeutic function. It encouraged stillness but also physical exploration and experimentation. Upon first hearing a sound, I instinctively stopped to pay attention. Then I gently and gradually began moving to discover ways to physically manipulate it. During the performance I sometimes entered into a trance-like state, shielded from direct audience attention by the scrim. The sensor became a focal point, helping orient my actions, as an interplay developed between the sensor and the sensed.

As I advanced beyond pre-established movement patterns, I started moving past inner criticisms and restrictions that usually regulated my body movements. As Feldenkrais (1972) posits, our self-image shapes our thoughts and movements. The experience of presenting and developing this work profoundly altered my self-image as a performer. My performance intention was no longer to convey competency, expressiveness and innovation as an instrumentalist or vocalist, but to explore the sonic potential of my movements by becoming or embodying the instrument.

I realised that I needed to refine my movements to achieve more consistent and repeatable sonic results, particularly in the area of pitch control and the construction of harmonic layering. To help control and calibrate the pitch transitions, I visualised the instrument as a physical entity. At one point I was plucking invisible strings on the curtain behind me. At other times I made circular motions with my torso, mimicking the expressive motions a guitarist makes with the head of their instrument.

For other performers of ‘air’ instruments like Clara Rockmore, the importance of performing with visual imagery drawn from prior instrumental technique is essential to envisioning the movements between regular steps and transitions. Rockmore drew on a string metaphor to create a mental image to guide performance with the theremin. This imagery stems from her background as a concert violinist, but string manipulation also holds similarities to the continuous and gradual changes afforded by gestural instruments.

The primary metaphor informing the Telechord’s design linked string lengths to the body’s ratios. This assisted me to develop internal visual imagery that could inform my movements in relation to sound. The idea helped to structure the performance as I mentally referenced real-world objects to produce more precise and subtle control. The metaphor became effective in guiding my actions in the absence of a tangible instrument, as I informed my movements through imagined bowing, plucking and striking gestures to vibrate the virtual strings.

Even though the visual feedback displayed this metaphor through lines connecting the active joints, I found myself relying more on an internal mental image of the strings in association with audio feedback to structure my experience. It was sometimes hard to distinguish between each of the four individual tones when playing the instrument if solely relying on the audio feedback, making it challenging to construct harmonies. During such times, the string metaphor assisted in isolating the sounds through a mental image that enabled me to envisage the parts of each chord as individual strings or wires.

7.4 Design Implications

How the system design has evolved since the earliest inception of Gestate relates to two main areas, incorporating whole body interaction and refining movement skills and sensitivities to satisfy the design criteria outlined in Section 5.2, Design Criteria. In *Bodyscapes*, nuance was explored through the body, not the system. The body became the source and the instigator of the interaction. Rather than focusing on improving system responsiveness through technical approaches only, I aimed to expand the body's potential through movement improvisation in order to achieve the initial design goals of nuance, explorability and consistency.

Linking the instrument seamlessly with my practice is an ongoing process, impossible to master in several performances. This is still a relatively new form of presentation, abandoning acoustic instruments and digital instruments inspired by conventional instrument interfaces in favour of free-form movement combined with the voice.

The transition to movement-based styles of performance has highlighted the importance of aesthetic and experiential considerations over technical concerns associated with system functionality (Wilde 2011, p. 39). Focusing on technical feature improvements only partially answers the need to address the individual physical and artistic preferences that characterise each performer. Like Wilde's work with body-worn technologies, such as *hipDisk*, the Telechord provides an open framework that facilitates experimentation and exploration of movement in a context outside everyday movement patterns.

This evolving design approach of Gestate pursued the principles of intuitiveness, idiosyncratic and nuanced movement through an embodied mapping strategy. The underlying conceptual metaphor for the system of a string under tension also functioned as internal visual imagery of the performer. Below is a summary of the complete list of strategies and principles that characterise the Gestate design environment.

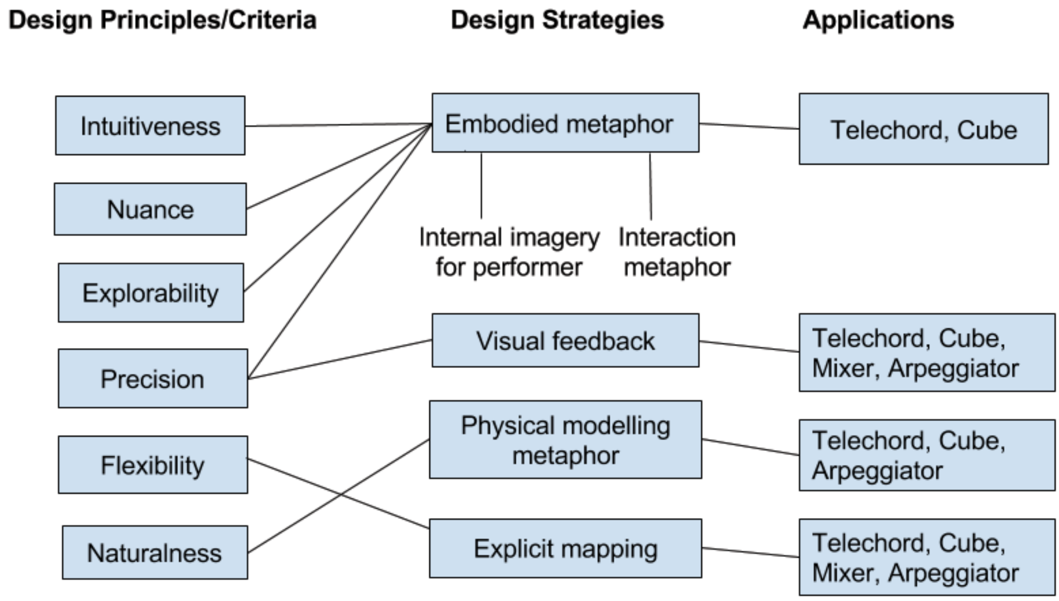

Figure 43: Gestate design environment

Performances with the Telechord have revealed effectiveness of relationships between design principles and matching strategies. The string metaphor aided in structuring and guiding the interaction, offering a space to explore sound-movement associations without exhausting the available creative possibilities, satisfying the criteria of intuitiveness and explorability. The physical modelling metaphor of the string reinforced familiar expectations of acoustic instrument properties, evoking plucking and bowing movements that contributed to a feeling of naturalness grounded in established embodied experience.

Visual feedback was less effective in promoting precision, as I relied more on the internal imagery to guide my actions during the Telechord performances. Pitch control was challenging to achieve consistently, leading me to focus inwardly, relying on my kinaesthetic and aural senses rather than on external vision.

The explicit mapping strategy depicted in Figure 44 facilitates flexibility and is applicable to all the virtual instruments, allowing it to be adapted to changing performance conditions, body types and compositional needs.

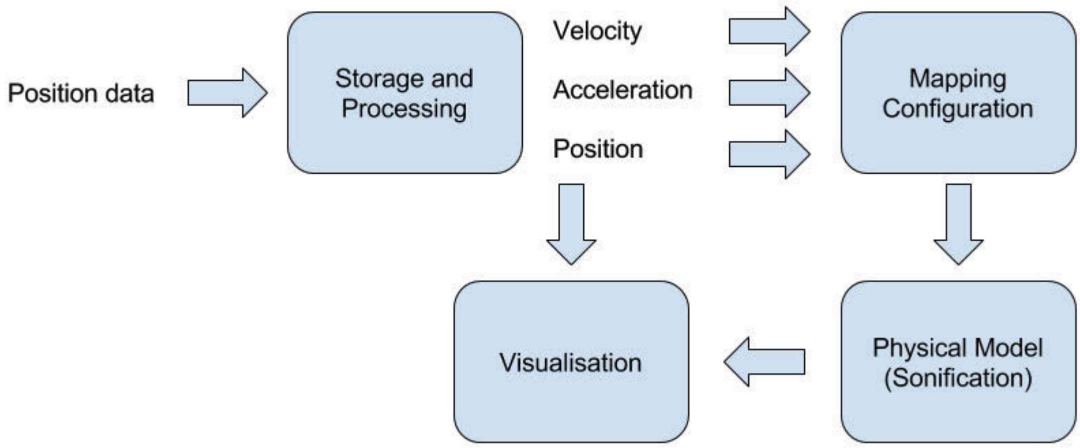

Figure 44: Gestate mapping framework

Three dimensional joint position data is used to calculate velocity and acceleration in a processing module. A mapping module assigns these values to a sonification module, which forwards values in its state (audio amplitude, panning position or other configured value) to a visualisation module. It may optionally incorporate values from the processing module.

In the Cube application, the mapping module took the form of a machine learning algorithm, which sent interpreted actions (punch and direction) derived from position to the sonification module.

7.5 Transforming Musicianship

Throughout this research, I oscillated between designs that encouraged spontaneous movements and those that embodied more critical movement reflection. In the end, I opted for Shusterman's (2009, p. 135) two-pronged approach, which integrates unreflective spontaneous performance with reflective bodily awareness. The problem of using spontaneous movements alone in gestural performance is that they are a product of acquired habits, and without conscious reflection some of these habits can prove to be far more damaging than we realise (Shusterman 2009).

For musicians, a lack of conscious bodily awareness can manifest in muscular tension during more challenging sections of a performance or when technical systems are not performing as expected. Over a long performance career, these physical responses can have a tremendous impact on a performer's health and the longevity of their performing life, affecting overall levels of enjoyment and effectiveness. Attending to these patterns using body awareness techniques drawn from somatic disciplines like Alexander Technique and Feldenkrais may contribute to addressing unwanted movement habits. Periodically engaging in conscious reflection can make the performer more aware of potentially damaging movement habits.

In the learning phases of attaining the new sensorimotor skills associated with playing an instrument, critical attention to all of the body parts engaged in the activity is required. Shusterman advises that this attention should include attending to breathing and the proprioceptive feel of the act (Shusterman 2009, p. 138). He argues that movement awareness should continue long after the initial learning phase has been completed:

> Learning is never over because not only is there room for further refinements and extensions of the acquired skill, but also because we so often lapse into bad habits of performance or face new conditions of the self (through injury, fatigue, growth, raging, and so on) and new environments in which we need to correct, relearn, and address our habits of spontaneous performance. (Shusterman 2009, p. 138)

The pragmatic benefits of body awareness and critical reflectiveness in reshaping acquired habits to improve perception and performance, according to Shusterman, include overcoming restrictive habits and developing mental flexibility and neural plasticity by forming new thought patterns derived from greater movement variation (Shusterman 2009, p. 139).

To nurture and maintain this type of critical self-awareness, I deliberately utilised a basic system with simple mappings designed to refine my skills in movement-based performance. Examining the way in which musicians physically engage with their instruments, I drew on the research of Nijs, Lesaffre and Leman (2009) (see Section 5.2, Design Criteria) to acquire an understanding of how the Telechord design could form a natural extension of the body and be integrated into the body schema.

The notion of an interactive system that is absorbed into the body schema is at the heart of Paine's (2015) techno-somatic design approach. He defines the techno-somatic dimension as:

> the 'feel' of an instrument, formed through both somatosensory feedback and listening, representing the cognitive map a performer develops about how to play an instrument, the technique, and how the instrument responds under different circumstances. (Paine 2015, p. 84)

Paine compares the widespread user base of the Nintendo Wii Remote (WiiMote) gaming controller to the limited user base of the more idiomatic and specialised Eigenharp[43] instrument, attributing this difference to the lack of design attention paid to attaining a fit between the instrument and body in the latter design (Paine

[43] Eigenlabs, *Eigenharp*, viewed 21 August 2015 <www.eigenlabs.com/>.

2015, p. 86). The WiiMote, on the other hand, "provides a well-executed somatic fit to the hand and makes available a large number of control parameters of varying characteristics" (Paine, 2015, 85). This contrast again highlights the importance of addressing the feel of an instrument in order to create a design that attracts a broader spectrum of users.

Perhaps a greater focus on the somatic dimension, as it relates to performance technique and learning, can increase the general applicability of new gestural musical interfaces beyond the NIME community, Paine (2015) argues. Uniting technical design priorities with attention to somatic aspects that address "how the instrument fits the body, how nuanced the relationships are between exertion of the body (breath, gesture) and the resultant sound" (Paine 2015, p. 88) could thus make gestural systems more viable options for musicians from a range of genres.

The *Bodyscapes* performances revealed the potential of combining sound and movement improvisation to not only uncover new gestural vocabularies but also develop a feel for the body as instrument — working with inner resistances, stiffness, balance and strengths. Designs that encourage mapping development through movement offer one possible approach to refining embodied instruments using experiential methods.

Finally, the Telechord did serve as a transparent extension of the body, or, in this case, *provided* a transparent relationship with the body. There were times during the *Bodyscapes* performances when I was completely immersed and in a flow state. More time is needed, however, to refine my skills in certain areas, particularly in relation to the aesthetics of movement and kinaesthetic awareness, to produce more polished performances and precise control over pitch and sonic nuances.

7.6 Conclusion

Using a string metaphor, the Telechord allows the body to construct four-part harmonies by altering the tension of virtual strings stretched over the apex joints of the limbs through different postures and patterns of movement. Contributing to existing research on whole body interaction, the Telechord's design explores ways to create a direct and transparent mapping that draws on the architectural proportions of the body. By connecting virtual string lengths with mathematical ratios and geometric shapes characterising the space surrounding the body, mappings inspired by the universal laws of nature helped structure performances and compositions for the instrument. The choice of physical modelling synthesis for sound generation was motivated by a similar intention to establish movement–sound relationships based on familiar associations between actions and sounds found in acoustic instruments.

The string metaphor underlying the Telechord's design incorporated the physical principles and expectations of acoustic instrument design, to inform movement-based control of hybrid physical models activated by the voice and movement. The aim of this metaphor was to support kinaesthetic learning and the construction of internal imagery and cognitive maps during performance, aiding in control of the instrument. In this way, the designs of Gestate and the Telechord leveraged the mental imagery techniques (Rosenberg & Trusheim 1989) that musicians use to practice and perform music to create more personally satisfying gestural performance experiences.

By using projected visual imagery in association with embodied mapping, the virtual instrument was designed to gain form in the player's experience, assuming part of their acquired body schema. The internal imagery of the musician was reinforced by layered visual feedback that simultaneously depicted the strings connecting active joints and a two-dimensional particle system that traced paths of performer movement.

Unlike traditional acoustic and electronic instruments, where repetitive strain injury is possible and tensions form in specific parts of the body, the Telechord offers an opportunity to balance the use of different body parts and achieve a renewed sense of physical harmony. Going against the intellectual tradition of Western art music that ignores or glosses over the body (McClary 1995), the Telechord draws on embodied interaction design approaches "that highlight the senses, body, and movement through critical physical inquiry" (Schiphorst 2009, p. 2437), establishing connections between technical design considerations and increased movement awareness among musicians.

Throughout the research I have grappled with the elusive concept of 'feel' to describe the relationship between the performer and their instrument. Paine (2015) stresses the importance of prioritising this relationship in DMI design. His conceptualisation of the "techno-somatic dimension", encapsulates the space that resides between the body and the instrument (Paine 2015).

Interestingly, in his assessment of the WiiMote in performance, Paine (2015) observes that game developers are dedicating more focus to the somatic dimension than designers of new digital instruments, who tend to emphasise functionality instead. This focus on what an instrument can do limits the expressiveness of emerging gestural instruments, Paine (2015) argues, relegating them to controller rather than instrumental status. Paine's observation goes to the heart of this research, which highlights the need to reflect and nurture the performer's relationship with their body through movement-based interaction design.

Additionally, an understanding of a performer's relationship with their body is also necessary for developing more nuanced control in gestural interface design. It is important to address the fraught relationship that many musicians with formal instrumental training have with their bodies. This stems from the emphasis on correct technique over balanced physical engagement. In musical training, the instrument is often considered superior to the needs of the performer's body. The musician is taught to minimise their movements and become almost transparent to make the instrument 'sing':

> Professional music training drills students to minimise the body in their performing activities: All "extraneous" motions, such as foot-tapping or dramatic gestures, are discouraged — often through physical punishment. Such suppression of bodily activity and its attendant tensions often results in severe, permanent injuries. (McClary 1995, p. 102)

To avoid this type of disembodiment, I focused on strengthening musicians' awareness of how they relate to their bodies through the Telechord design.

Inspired by designers who embrace embodied interaction design approaches, such as Wilde (2011), I was interested in developing an environment where movement could be explored. Wilde notes that:

> By providing novel opportunities to experience in and through the body, and gain insight into the body's capacities and affordances when contexts for engagement are shifted, I hope that people will be able to develop their sensorimotor knowledge and skills. (Wilde 2011, p. 116)

Similarly, Kozel and Schiphorst's work, *Whisper* (2002), nurtures kinaesthetic awareness and proprioceptive skills, as does Levisohn's mixed reality system, which enables users to experience hand movement in a different way by augmenting visual and aural perception (Levisohn 2007, p. 486).

Wilde (2011) also recognises the potential of interactive systems to reframe the way we see our bodies:

> The *Light Arrays* devices provide free-form expressive spaces that encouraged different qualities of attention: on the task at hand, the actions and gestures of the body, as well as on the results of those actions, rather than on the actions themselves, participants may be able to enhance their ability to learn physical skills. (Wilde 2011, p. 114)

This emphasis on attention to movement through exploration was integral to the Telechord's design and development, offering a holistic approach to playing the instrument by stimulating a greater awareness of the movement possibilities available in performance.

The *Bodyscapes* performances provided opportunities to explore new forms of musicianship that emphasised enhanced kinaesthetic skill to attain more detailed, consistent and precise control while delivering diverse musical outcomes. The Telechord, a new instrument within the Gestate system, was designed to address the need for enhanced movement skills identified through the expert user case study (Chapter 6) and my own performances (Chapter 4) to extend the potential use of gestural systems for musical performance. Through the application of a string metaphor to facilitate movement-based control of hybrid physical models, the Telechord offered an audio-visual environment that facilitated the development of movement skills and mapping associations based on the geometric proportions of the body in relation to harmonic intervals.

In the next chapter I summarise the contributions and future directions based on the findings drawn from this performative research.

Chapter 8: Conclusion

8.1 Overview

Throughout this research I was interested in why many musicians continue to prefer traditional acoustic instruments and instrument-inspired digital controllers to gestural systems for performance. Musicians navigating this highly personalised field require both well-developed technical and physical skills to design or adapt existing gestural systems for their own use, limiting accessibility to those without prior training in these areas.

To address these obstacles, I adopted a design approach that prioritised movement awareness and intuitive access to developing associations between movement and sound processes. In an underrepresented area of gesture and music, this work explored design strategies that built on developing movement awareness during performance and recognising the primacy of the moving body as it assumes the role of instrument in a gestural system.

This approach was tested and developed through three practical implementations — an audio-visual non-tactile gestural instrument, a hyperinstrument augmentation of the piano, and an augmented vocal application. The designs were intended to leverage musicians' existing skills and expressive gestures to complement existing practice. These applications provided a path to demonstrate and develop the research objectives through an iterative design process informed by a series of performances.

This chapter outlines the results and implications arising from an exploration into musicians' experiences of gestural interaction relative to the research aims. The initial research questions that framed this study guided the performance and design projects presented in this thesis:

1. What are the main control features for successful that characterise gestural instruments?
2. How can musicians integrate gestural interaction into their existing performance practice?
3. What design strategies can be applied to improve precision, explorability and nuance in gestural instruments?

The practical tone of these questions reflects an emphasis on evaluating design effectiveness in real-world contexts to gain a greater understanding of musician experiences with gestural interfaces throughout the early adoption, learning, design, customisation and performance phases of engagement.

In Chapter 1 I examined the role of the body in electronic music, presenting my motivations for pursuing this research, which included the need to transcend the movement restrictions of laptop performance, acoustic instruments and instrument-inspired controllers to create more engaging, individualised performances that reflected the nuances contained in physical movement.

In Chapter 2 I extracted recurring themes from existing DMI and gestural interface design literature to form a list of the design features that would make gestural instruments a more attractive and enduring option for practicing musicians from different backgrounds. I explored the design and performance issues relating to gestural controllers developed for musical, dance and installation applications, examining techniques employed by artists using these types of systems as their primary instrument. I also reviewed widely varying definitions of gesture (Section 2.2, Defining Gesture), highlighting how gesture classifications from gesture studies, HCI and gesture and music research can inform gestural interface design. I then examined potential applications for a range of gesture typologies for music (Section 2.2.1, Instrumental Gestures; 2.2.2, Expressive Gestures), and their application in the design of interactive systems that incorporate gestural manipulation of audio-visual material, voice and acoustic instruments.

Chapter 3 outlined the methods underpinning the investigation, framed by phenomenological and embodied interaction design approaches. Drawing on performative inquiry and the autoethnographic tradition, I presented a research design founded on a first-person account of experiences with gestural prototyping and experimentation in my own performance practice, before conducting a case study involving expert users from the musical performance and sound production fields, to gain broader knowledge of the feelings and perceptions associated with gesture-based interaction in musical contexts.

Chapter 4 charted my early development in gestural performance and composition through the works *Concentric Motion* and the *Gestural Études*. The motivations and challenges behind this process were presented in an analysis of the works and subsequent performances. Through performative research, I examined the claim that gestural interfaces promise opportunities to pursue a more natural form of user interaction in live electronic music, expression and dynamism in musical performances.

Chapter 5 presented the design strategy that governed the development of Gestate, a gestural performance system for augmenting vocal and instrumental performance. The system's aim was to achieve seamless integration of gestural control in my existing performance work. Gestate's design was guided by five key design goals drawn from commonly identified DMI design criteria and usability guidelines specified for gestural interface design in HCI — intuitiveness, nuanced control, explorability, consistency and explorability.

The two main techniques implemented to meet these criteria were the integration of conceptual metaphors in the movement-sound mapping and the introduction of visual feedback. The mapping strategy was inspired by recent embodied trends in interaction design (Macaranas, Antle & Riecke 2015) that use conceptual metaphors to support the development of internal mind maps and visual imagery in order to guide system learning. This embodied mapping approach was linked with a primary design imperative to nurture the kinaesthetic awareness of the performer in order to maximise the gestural system's potential.

The system was further evaluated through an expert user case study, detailed in Chapter 6, to ascertain whether the selected design criteria were effective and in line with the needs of practicing musicians. The study elicited a broad range of responses, from feelings of discomfort and self-censorship to a sense of physical and creative liberation. The diversity of participant feedback revealed the influence of different musical backgrounds on quality of engagement with gestural systems. Users with prior movement training or experience, for example, were more likely to enjoy the interaction. For some instrumentalists, improvising with a gestural system felt far from natural, revealing the challenge of performing in an unfamiliar context without physical reference points and tactile feedback.

Chapter 7 presented a new iteration of the Gestate system, incorporating interdisciplinary insights from dance, somatic practices and somaesthetics. The revised system included the Telechord, an adaptable gestural instrument designed to facilitate movement exploration and enable a performer to arrive at new movement-sound associations through combined musical and movement improvisation. The string metaphor represented in the design of the instrument aimed to give structure to the interaction, reflecting internal visual imagery used by Clara Rockmore to master the theremin.

The ultimate aim of the Telechord was to ease musicians' self-consciousness around using gestural instruments, promoting a new type of stagecraft that has received little attention in literature on gesture and music, although it has attracted some interest in the wider field of gesture-based interaction:

> The types of changes in performance that users would create in order to make an interface work practically and socially in different contexts of use is relatively unknown, which makes it difficult for designers and implementers to add the right kind of flexibility and customisation to an interface. Because it is important for users to feel comfortable and in control while using an interface, flexibility in personal performance while maintaining accuracy could greatly improve the usability of gesture-based interfaces overall. (Rico, Crossan & Brewster 2011, p. 184)

To improve widespread adoption of gestural systems in musical performance, it is therefore necessary to understand the feelings and responses they evoke among users. The performative research and expert user case study presented in this thesis have contributed to insights in this area.

The main challenge Wechsler identifies in interactive performance is not only about improving technology but also about "developing an understanding of its implications — the changes in the mindset and sensibility of artists as they put it to use" (Wechsler 2006, p. 75). As a performer, Wechsler is well aware of the adjustments interactive artists must undergo to achieve a coherent transition to a new style a performance — one that demands dancers think like musicians, musicians like dancers and composers like choreographers.

In relation to gestural performance, where a single gesture can control a series of musical processes and distribution of independent events over time, Waisvisz (1999) observes:

> Thinking about the aesthetics of electronic music produced by distributed instrumental systems means following the performer's **decision-making process** and his/her **physical acts and gestures**. It means valuing the virtues of the chess-player and the violinist/dancer rolled into one person. There will be much appreciation of the performer's ability to know how and when to change roles and when to combine them simultaneously. (Waisvisz, 1999, 123)

Looking to practitioners who have achieved this aim (Sections 2.3.1, 2.3.2 and 2.3.3), the balance of somatosensory skills and an appropriately customised system have allowed them to extend their bodies as expressive instruments.

The specific forms of musicianship that were fostered by the Gestate system included movement awareness, and enhancing the development of mental imagery and internal cognitive maps. A musician's willingness to assume new roles and perspectives — as a dancer, composer, as well as a choreographer — was also found to be a pivotal aspect in the successful adoption of gestural interaction in performance practice.

8.2 Limitations

The limitations of this research include the need for a more comprehensive user study to establish the long-term viability of gestural systems. The results of the existing expert user case study were based on a relatively short period of engagement with the Gestate system, averaging 1.5 hours in duration to limit the possibility of fatigue and physical over-exertion. However a longer period over an extended timeframe and in different rehearsal and performance conditions could generate further insights into how participants transition from novice to advanced user status. This would offer a greater understanding of the way in which the system could be used on an informed basis and its level of effectiveness in professional musical practice. Additionally, the inclusion of participants in a single occupational group relating to my own creative practice, for example vocalists or pianists, may have provided more in-depth data.

A deliberate choice was made to focus on the first-hand accounts of performers – balancing my perception with and those of other musicians in order to conduct a detailed investigation into the gestural performance. However future research could benefit from the inclusion of an audience evaluation component, in which the clarity and coherence of selected sound-movement mapping strategies could be assessed and applied to the development of future performances and design iterations.

8.3 Contributions

The main contribution of this thesis is a design perspective that shifts the focus in non-tactile gestural instrument design, from a predominantly technical and engineering focus to design approaches that prioritise movement awareness, in order to improve the accessibility and effectiveness of gestural interfaces for musicians. Knowledge is advanced in a new way by embracing creative practitioner perspectives that emerge from live performance scenarios, revealing experiential insights that can inform future gestural interface design.

The findings of this research have broader implications for this growing field. First-hand experiential insights throughout early adoption to longer-term use of gestural interfaces revealed insights into the types of conditions that promote precision, consistency, intuitiveness and flexibility — criteria that span both musical and more general gestural interaction contexts.

This research emphasises the significance of musicians' existing skills, learning methods and movement awareness, to promote a sense of familiarity compatible with their current practice. This focus aligns this work with emerging approaches in performance studies that value first-hand accounts over viewing 'the performer' as an abstract entity, emphasising that:

> Integrating embodied artistic practice into musical thought requires thinking about it in terms of the musical instrument and the performer's bodily engagement with it. (Doğantan-Dack 2015, p. 172)

This statement goes to the core of this research — the relationship of the performer to their instrument and body provided a framework for the design and development of the Gestate system. Exploring the concept of body as instrument adds to further understandings of movement in performance by placing the embodied individual performer at the heart of the design process. It also contributes to gestural interface design research by evaluating strategies based on the 'feel' of the instrument and its fit with the performer.

In summary, this research presents:

- Contributions to an understanding of potential barriers to the accessibility and long-term viability of gestural control systems for a broad range of musicians spanning a range of genres and practices;
- A flexible gestural performance system that offers a starting point for musicians to physically experiment with sound-movement mappings while developing physical and technical confidence in the area of gestural performance;
- A performance-based evaluation of design strategies aimed at promoting kinaesthetic or movement awareness as a means to achieving exploratory and nuanced control of musical processes with non-tactile gestural systems.

The Gestate system presented in this thesis incorporates a set of design criteria and usability guidelines that it is hoped will assist future designers and musicians without prior programming experience or movement training to navigate the gestural performance field and acquire the skills necessary to achieve nuanced control through engagement with gestural systems.

8.4 Implications and Future Work

The repetitive nature of everyday life constrains our movement patterns, restricting our overall flexibility. Our bodies bear the imprint of our life decisions and primary activities. For office workers and other sedentary occupations, prolonged sitting can affect future health, as can detrimental habits like bad posture. These effects can be counterbalanced by conscious and consistent efforts to improve movement patterns through dance, exercise, and stretching or somatic disciplines. Another option is to utilise interactive systems that encourage movement.

Within musical performance, the effect of playing gestural instruments on musicians and novice users can be equally transformational in terms of encouraging the performer to widen their physical expressiveness as well as transcend established movement patterns and a lifetime of physical habits. Flexible gestural systems offer access to alternative forms of musicianship, which can be used therapeutically for musicians suffering from muscular problems relating to physically demanding and repetitive instrumental practice.

Future applications envisaged for the Gestate system include using it as a tool for realigning posture and easing muscular tension before and after extensive practice to help musicians regain movement awareness, in a similar way to somatic disciplines like Alexander Technique, Bartenieff Fundamentals and Feldenkrais.

The development of embodied metaphors in future designs are planned to determine their long-term effectiveness in performance applications. Future collaborations are also planned with dancers to develop the aesthetic potential of the movements used to control Gestate. As part of this process I intend to undertake training in somatic disciplines to improve my movement awareness and motor skills. Further involvement in somatic practices and collaborations with dance practitioners and theorists could provide access to more structured improvisation methods, varied poses and movement patterns, helping to expand my usual prescribed movement vocabulary.

A more thorough integration of the ideas presented in Laban's body of work on dance movement in particular could contribute to refining movement awareness and articulation in space in my own movement-based performance practice while also offering improvisation techniques that are sympathetic with whole body interaction systems such as the Telechord.

The visual feedback of Gestate can also be developed further from a performer perspective, by experimenting with explicit control panel style visuals that guide precise and nuanced musical control. The distinct advantages of abstract versus explicit visuals would also be an interesting area for future investigation.

8.5 Final Words

When controlling The Sphinx, a new instrument that offered immediate control of analogue control voltages through direct finger contact, Waisvisz (1999) and the audience observed the transformation of the electronic sound by the tension patterns inherent in his physical effort: “when human curves were applied to electronics, it made those people believe that what they were listening to wasn’t electronics at all” (Waisvisz 1999, p. 120). Suddenly the electronics sounded like voices and mechanical noises. The mere act of controlling the synthesiser in a more physical way had altered its original sonic characteristics. This approach to electronic music that is shaped by the individual human traces of the performer motivated this investigation.

My research continues in the tradition established by Waisvisz, producing music that reflects a musician’s unique movement qualities in sonic form. An emphasis on intuition and exploration as guiding principles in design resists the tendency of many electronic instruments and gestural systems to “force us to think first” (Waisvisz 1999, p. 124). By placing the body and movement awareness at the centre of the design process, it may be possible to achieve a sense of immediacy through gestural performance, allowing the body to become a conduit for sounds otherwise inaccessible.

Appendix A: Supplementary Material

Documentation of the works and performances described in Chapters 4 – 7 consist of recorded concert performances, instrument demonstrations and software. This material is available at the following link: www.mainsbridge.com

Chapter 4

Video recordings of *Concentric Motion* and the *Gestural Études* performances detailed in Chapter 4:

Concentric Motion: Concerto for Voice, Piano and Gestural Controller performance at Newcastle Conservatorium, New South Wales on September 1, 2012 — video excerpt of Third Movement and full performance video.

Gestural Études performance at the Electrofringe Festival, Newcastle, New South Wales on October 6, 2013 — video excerpt of Arpeggiator improvisation and full performance video.

Gestural Études, Electrofringe Festival 2013 — full performance.

Piano improvisations with and without gestural processing — these videos form part of a series of improvisations recorded for the purposes of studying common gesture types I use in piano performance and experiments with controlling digital audio effects, tempo and looper playback.

Chapter 5

Demonstration videos provide an illustration of the following Gestate system applications presented in Chapter 5, accompanied by system software patches —

- Mixer
- Cube
- Arpeggiator

Gestate — The system software, developed with Max/MSP, is available at the following link: http://www.mainsbridge.com/gestate-software/

Chapter 7

Bodyscapes performance recorded at PACT Theatre as part of the Sydney Fringe Festival on September 27, 2014 — video excerpts and full performance video.

Telechord — video demonstrations illustrating the main sounds presented in Chapter 7 and designed for the *Bodyscapes* performances.

Telechord — The software patches for each of the sounds developed for the instrument is available at the following link:

http://www.mainsbridge.com/telechord-software/

Appendix B: Performances and Installations

2015

- Bodyscapes, Art.CHI2015, Seoul, Korea – Catalogue accompanying workshop and exhibition of interactive media works at CHI 2015, bringing together researchers and practitioners in the field of human-computer interaction (HCI): http://art-chi.org, 18–19 April 2015.

2014

- *Bodyscapes,* Sydney Fringe Festival, PACT Theatre, Sydney, NSW, 26–27 September 2014.
- *Vendome*, performance & installation, BEAMS arts festival, Chippendale's laneways, Sydney, NSW, 20 September 2014.
- *Gestate* installation, Electrolapse BYOB (Bring Your Own Beamer), Vivid Festival, Sydney, NSW, 31 May–1 June 2014.
- *Velocimixer* installation, Museum of Contemporary Art (MCA), Artbar, Sydney, NSW, 28 February 2014.

2013

- Diffuse Concert Series, Bon Marche Studio, University of Technology, Sydney, NSW, 24 October 2013.
- Faculty of Arts and Social Sciences 2013 Postgraduate Conference Mindfulness, University of Technology, Sydney, 15 November 2013.
- *Gestural Études*, Electrofringe 2013 Showcase, THIS IS NOT ART (TINA) Festival, Newcastle, NSW, 6 October 2013.
- *Alignment*, 9th ACM Creativity and Cognition Conference, Eugene Goosens Hall, ABC Ultimo Centre, Sydney, 19 September 2013.

2012

- *Concentric Motion: Concerto for Voice, Piano and Gestural Controller*, Finalist in Innovative Category of the International Space Time Concerto Competition, Newcastle Conservatorium, NSW, 2 December 2012.
- Diffuse Concert Series: Interaction, Bon Marche Studio, University of Technology, Sydney, 14 June 2012.

Appendix C: List of Publications

Publications

Mainsbridge, M. 2014, ‘Non-tactile Gestural Control in Musical Performance’, in *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO’14)*, Ircam, Paris, France.

Mainsbridge, M. & Beilharz, K. 2014, ‘Body as Instrument –Performing with Gestural Interfaces’, *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, ACM, Goldsmiths, University of London, UK.

Mainsbridge, M. & Mudrazija, R. 2013, ‘Alignment: improvised gestural performance’, *Proceedings of the 9th ACM Conference on Creativity & Cognition*, ACM, Sydney, NSW.

Presentations

Mainsbridge, M. 2014, 'Musician experiences with gestural interaction', *Practice-based workshop at the International Conference on New Interfaces for Musical Expression (NIME’14),* London, UK.

Mainsbridge, M. 2012, 'Body as instrument – an exploration of gestural interface design', artist talk presented to the *Australasian Computer Music Association Conference – Interactive*, ACMA, Brisbane, Australia.

Appendix D: Expert User Case Study: Ethics Documents

UTS Creativity and Cognition Studios
2-page Ethics Approval Application

From: MARY MAINSBRIDGE

Project Number 2013-9* HREC 2013000135

1. Title

Participatory design studies with *Gestate* - a gesturally controlled audio-visual mixing system.

2. Aims

To examine user experiences with a prototype audio-visual system controlled by movement. The non-tactile system tracks user motions, mapping them to a range of musical software functions including volume, effect parameters, and control of MIDI sequences and software instruments.

3. Methodology

Participants will use the system to perform two tasks (a mixing and filter control task), followed by an unstructured improvisation.
Semi-structured retrospective interviews will be conducted to gather participant impressions of the system.
Each session will be video recorded and stored securely for further analysis.

4. Significance

User feedback is sought to gain insights into the effectiveness of design principles underpinning the system. This process is aimed at developing a deeper understanding of the factors that contribute to intuitive interaction and user satisfaction in gestural interface design for musical applications.

5. Number of participants and justification of numbers

The study will involve up to 20 participants.

As the research is directed at obtaining insights into user experience based on detailed first-hand accounts, the number of participants will allow a focus on the richness of individual impressions.

6. Selection/exclusion criteria

Participants will be professional producers or sound engineers recruited on the basis of their technical and artistic expertise.

7. Children under 18 years of age will participate in the evaluation.

No.

8. Procedures

Participants will be contacted by phone or email and informed about the aims and procedures of the study. If they agree to take part, they will be asked to sign a consent form (see attached).

During the participatory design studies, participants are invited to:

1. perform a mixing and filter control task using the gestural controller;
2. improvise with the system;
3. reflect on their experience during semi-structured interviews with the recorded video to facilitate recall.

Participants will be video recorded as they use the system. The interviews will be audio and/or video recorded and notes taken as required.

9. Time commitment for participants

The total duration of each session is approximately 1 hour.

10. Location of research

The participant's workspace or Bon Marche Studio at UTS.

11. Consent procedures

Signed consent sheet (see attached)

12. Additional Risks (additional to those noted in the CCS Generic Approval)

Fluctuating sound levels may contribute to participant fatigue.

13. Strategies to cope with risks mentioned in 12.

Noise exposure will be limited to a safe hearing range according to international audiometric standards.

14. Other issues

No other issues have been identified.

*Number obtained from CCS Ethics Administrator.

UTS: IT: Creativity & Cognition Studios

PARTICIPATORY DESIGN Studies   Project number 2013-9
UTS HREC REF 2013000135

Participatory Design Studies with Gestate – A gesturally controlled audio-visual mixing system

GENERAL INFORMATION

WHO IS DOING THE RESEARCH?

The research is being performed by Mary Mainsbridge as part of a PhD at UTS.

WHAT IS THIS RESEARCH ABOUT?

The research aims to gain insights into user experiences of gestural interaction while operating a prototype audio-visual mixing system controlled by movement called *Gestate*.

IF I SAY YES, WHAT WILL IT INVOLVE?

The study will involve an improvisation session with the system, which will be video recorded. I will ask about your impressions of using the system during the session and afterwards in an interview. The interview will be audio and/or video recorded.

ARE THERE ANY RISKS?

The study has been designed to minimise risks and protect individual data and identity.

WHY HAVE I BEEN ASKED?

You have been asked due to your level of professional and technical expertise in the field of audio technology and production.

DO I HAVE TO SAY YES?

You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think my supervisor or I can help you with, please feel free to contact me at ________________________________.

This study has been approved by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research that you cannot resolve with the researcher, you may contact the UTS Ethics Committee through the Research Ethics Officer at UTS Broadway, Building 1, Level 14; or 9514 9771; or Research.Ethics@uts.edu.au. Please quote the UTS HREC reference number.
Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UTS: IT:
Creativity& Cognition Studios

PARTICIPATORY DESIGN STUDIES: ***Gestate*** **–**
A Gesturally controlled audio-visual mixing system

Project Number 2013-9 HREC 201300015

I ___________________________________ *(participant's name)* agree to participate in the research project *Title* (*HREC 2013000135 project number 2013-9)* being conducted by *Mary Mainsbridge* of the Creativity and Cognition Studios at the University of Technology, Sydney.

I understand that the purpose of this study is to gather insights into user experiences of gestural interaction in the field of contemporary music. This is part of a programme of postgraduate research leading toward a PhD. Data gathered in the *Gestate* study will form part of the ongoing research of Mary Mainsbridge and may also be made available to other researchers in the Creativity & Cognition Studios.

I agree that the researcher may record video and audio during our session and interview. The video and audio recordings will be used for analysis only, and will not be made publicly available. I understand that what I say in interviews may be quoted and used in academic publications. Any quotes used will be published in a form that does not identify me.

I understand that my participation in this research will involve no perceivable risk.

I am aware that I can contact Mary Mainsbridge ([redacted]) or the University of Technology Sydney Human Research Ethics Committee if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Mary Mainsbridge has answered all of my questions fully and clearly.

____ ____/____/____
Signed by

____ ____/____/____
Witnessed by

NOTE:
This study has been approved by the University of Technology, Sydney, Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research that you cannot resolve with the researcher, you may contact the UTS Ethics Committee through the Research Ethics Officer at UTS Broadway, Building 1, Level 14; or 9514 9772; or Research.Ethics@uts.edu.au. Please quote the UTS HREC reference number.
Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

References

Acitores, A.P. 2011, 'Towards a theory of proprioception as a bodily basis for consciousness in music', in D. Clarke & E. Clarke (eds), *Music and consciousness: philosophical, psychological, and cultural perspectives*, Oxford University Press, Oxford, UK, pp. 215-30.

Acocella, J.R. 1993, *Mark Morris*, Noonday Press/Farrar Straus Giroux, New York.

Anderson, F.S. 2014, 'Gesture learning in human computer interaction', PhD Thesis, University of Alberta, Edmonton, Canada.

Anderson, L. 2006, 'Analytic autoethnography', *Journal of Contemporary Ethnography*, vol. 35, no. 4, pp. 373-95.

Antle, A.N., Corness, G. & Bevans, A. 2013, 'Balancing justice: comparing whole body and controller–based interaction for an abstract domain', *International Journal of Arts and Technology*, vol. 6, no. 4, pp. 388-409.

Antle, A.N., Corness, G. & Droumeva, M. 2009, 'Human-computer-intuition? Exploring the cognitive basis for intuition in embodied interaction', *International Journal of Arts and Technology*, vol. 2, no. 3, pp. 235-54.

Antle, A.N., Droumeva, M. & Corness, G. 2008, 'Playing with the sound maker: do embodied metaphors help children learn?', *Proceedings of the 7th International Conference on Interaction Design and Children (IDC'08)*, ACM, Chicago, IL, pp. 178-85.

Arfib, D., Couturier, J.M., Kessous, L. & Verfaille, V. 2002, 'Strategies of mapping between gesture data and synthesis model parameters using perceptual spaces', *Organised Sound*, vol. 7, no. 2, pp. 127-44.

Badler, N.I. & Smoliar, S.W. 1979, 'Digital representations of human movement', *ACM Computing Surveys (CSUR)*, vol. 11, no. 1, pp. 19-38.

Bahn, C., Hahn, T. & Trueman, D. 2001, 'Physicality and feedback: a focus on the body in the performance of electronic music', *Proceedings of the International Computer Music Conference (ICMC)*, ICMA, Havana, Cuba, pp. 44-51.

Bartleet, B. 2009, 'Behind the baton: exploring autoethnographic writing in a musical context', *Journal of Contemporary Ethnography*, vol. 38, no. 6, pp. 713-33.

Bartleet, B. & Ellis, C. (eds) 2009, *Music autoethnographies: making autoethnography sing / making music personal*, Australian Academic Press, Brisbane, QLD.

Bau, O., Tanaka, A. & Mackay, W.E. 2008, 'The A20: musical metaphors for interface design', *Proceedings of the 8th International Conference on New Interfaces for Musical Expression (NIME'08)*, University of Genova, Genova, Italy, pp. 91-6.

Behringer, R. 2007, 'Gesture interaction for electronic music performance', in J. Jacko (ed.), *Human-Computer interaction. HCI intelligent multimodal interaction environments*, Springer-Verlag, Berlin Heidelberg, pp. 564-72.

Bell, B., Kleban, J., Overholt, D., Putnam, L., Thompson, J. & Kuchera-Morin, J. 2007, 'The multimodal music stand', *Proceedings of the 7th International Conference on New Interfaces for Musical Expression (NIME'07)*, ACM, New York, pp. 62-5.

Beller, G. 2014, 'The Synekine project', *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO'14)*, Ircam, Paris, France, pp. 66-9.

Bencina, R. 2005, 'Metasurface: applying natural neighbor interpolation to two-to-many mapping', *Proceedings of the 5th International Conference on New Interfaces for Musical Expression (NIME'05)*, University of British Columbia, Vancouver, Canada, pp. 10-4.

Bencina, R., Wilde, D. & Langley, S. 2008, 'Gesture ≈ sound experiments: process and mappings', *Proceedings of the 8th International Conference on New Interfaces for Musical Expression (NIME'08)*, Genova, Italy, pp. 197-202.

Berdahl, E., Niemeyer, G. & Smith III, J.O. 2009, 'Using haptics to assist performers in making gestures to a musical instrument', *Proceedings of the 9th International Conference on New Interfaces for Musical Expression (NIME'09)*, Carnegie Mellon University, Pittsburgh, US, pp. 177-82.

Bevilacqua, F., Schnell, N. & Fdili Alaoui, S. 2011, 'Gesture capture: paradigms in interactive music/dance systems', in G. Klein & S. Noeth (eds), *Emerging bodies: the performance of worldmaking in dance and choreography*, vol. 21, Verlag, Beilefeld, Germany, pp. 183-93.

Billinghurst, M. & Buxton, B. 2011, 'Gesture-based interaction', in W. Buxton (ed), *Haptic input*, vol. 24, viewed 10 August 2015, <http://www.billbuxton.com/input14.Gesture.pdf>.

Birnbaum, D., Fiebrink, R., Malloch, J. & Wanderley, M.M. 2005, 'Towards a dimension space for musical devices', *Proceedings of the 5th International Conference on New Interfaces for Musical Expression (NIME'05)*, University of British Columbia, Vancouver, Canada, pp. 192-5.

Blom, L.A. & Chaplin, L.T. 1988, *The moment of movement: dance improvisation*, University of Pittsburgh Press, Pittsburgh.

Boal Palheiros, G. & Wuytack, J. 2006, 'Effects of the 'musicogram' on children's musical perception and learning', in M. Baroni, A.R. Addressi & R. Caterina (eds), *Proceedings of the International Conference on Music Perception & Cognition (ICMPC9)*, Bologna, Italy, pp. 1264-71.

Bokowiec, M.A. 2011, 'VOCT (Ritual): an interactive vocal work for Bodycoder system and 8 channel spatialization', *Proceedings of the 11th International Conference on New Interfaces for Musical Expression (NIME'11)*, University of Oslo, Norway, pp. 40-3.

Bolt, R.A. 1980, 'Put-that-there: voice and gesture at the graphics interface', *Proceedings of SIGGRAPH 1980 7th Annual Conference on Computer Graphics and Interactive Techniques*, *SIGGRAPH '80,* ACM, New York, pp. 262-70.

Bongers, A.J. 1998, ‘Tactual display of sound properties in electronic musical instruments’, *Displays*, vol. 18, no. 3, pp. 129-33.

Bongers, B. 2000, ‘Physical interfaces in the electronic arts’ in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 41-70.

Bouwer, A., Holland, S. & Dalgleish, M. 2013, ‘Song Walker harmony space: embodied interaction design for complex musical skills’ in S. Holland, K. Wilkie, P. Mulholland & A. Seago (eds), *Music and human-computer interaction*, Springer-Verlag, London, pp. 207-21.

Bowers, J. 2002, ‘Improvising machines: ethnographically informed design for improvised electro-acoustic music’, MA Thesis, University of East Anglia, Norwich, UK.

Bradley, K. 2009, *Rudolf Laban*, Routledge, London.

Brent, W. 2011, ‘Aspects of gesture in digital musical instrument design’, *Proceedings of the International Computer Music Conference (ICMC)*, ICMA, Huddersfield, UK, pp. 429-36.

Brent, W. 2012, ‘The gesturally extended piano’, *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME’12)*, University of Michigan, Ann Arbor, viewed 10 August 2015, pp. 332-5.

Broughton, M. & Stevens, C. 2009, ‘Music, movement and marimba: an investigation of the role of movement and gesture in communicating musical expression to an audience’, *Psychology of Music*, vol. 37, no. 2, pp. 137-53.

Brown, N. 2006, ‘The flux between sounding and sound: towards a relational understanding of music as embodied action’, *Contemporary Music Review*, vol. 25, no. 1-2, pp. 37-46.

Buck, B., MacRitchie, J. & Bailey, N.J. 2013, ‘The interpretive shaping of embodied musical structure in piano performance’, *Empirical Musicology Review*, vol. 8, no. 2, pp. 92-119.

Bullough, R.V. & Pinnegar, S. 2001, 'Guidelines for quality in autobiographical forms of self-study research', *Educational Researcher*, vol. 30, no. 3, pp. 13-21.

Burt, W. 1990, ‘Fair exchanges: an account of the 3DIS computer / dance / music project’, *Writings on dance: local practice*, no. 5, pp. 38-44.

Buxton, W., Buchla, D., Chafe, C., Machover, T., Mathews, M., Moog, B., Risset, J., Sonami, L. & Waisvisz, M. 2000, 'Round table: electronic controllers in music performance and composition' in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 415-38.

Buxton, B. 2007, *Sketching user experiences: getting the design right and the right design*, Morgan Kauffman, Burlington, MA.

Buxton, W. 1986, ‘There is more to interaction than meets the eye: some issues in manual input’, in D.A. Norman & S.W. Draper (eds), *User centered system design: new perspectives on human-computer interaction*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 319-37.

Cadoz, C. 1988, ‘Instrumental gesture and musical composition’, *Proceedings of the International Computer Music Conference (ICMC)*, ICMA, Cologne, pp. 1-12.

Cadoz, C. 2009, ‘Supra-instrumental interactions and gestures’, *Journal of New Music Research*, vol. 38, no. 3, pp. 215-30.

Cadoz, C. & Wanderley, M.M. 2000, ‘Gesture-music’, in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 71-94.

Caleon, I. & Ramanathan, S. 2008, 'From music to physics: the undervalued legacy of Pythagoras', *Science & Education*, vol. 17, no. 4, pp. 449-56.

Camurri, A. 2004, ‘Multimodal interfaces for expressive sound control’, *Proceedings of the 4th International Conference on Digital Audio Effects (DAFx’04)*, Naples, Italy, pp. 1-4.

Camurri, A., Hashimoto, S., Ricchetti, M., Ricci, A., Suzuki, K., Trocca, R. & Volpe, G. 2000, ‘Eyesweb: toward gesture and affect recognition in interactive dance and music systems’, *Computer Music Journal*, vol. 24, no. 1, pp. 57-69.

Camurri, A., De Poli, G., Leman, M. & Volpe, G. 2001, 'A multi-layered conceptual framework for expressive gesture applications', *Proceedings of the International MOSART workshop,* Barcelona, Spain, pp. 1-6.

Camurri, A., Lagerlöf, I. & Volpe, G. 2003, ‘Recognizing emotion from dance movement: comparison of spectator recognition and automated techniques’, *International Journal of Human-Computer Studies*, vol. 59, no. 1, pp. 213-25.

Camurri, A., Mazzarino, B., Ricchetti, M., Timmers, R. & Volpe, G. 2004, ‘Multimodal analysis of expressive gesture in music and dance performances’, in A. Camurri & G. Volpe (eds), *Gesture-based communication in human-computer interaction: 5th International Gesture Workshop*, GW 2003, vol. 2915, Springer, Berlin Heidelberg, pp. 20-39.

Camurri, A., Mazzarino, B. & Volpe, G. 2004a, 'Analysis of expressive gesture: The EyesWeb expressive gesture processing library', in A. Camurri & G. Volpe (eds), *Gesture-based communication in human-computer interaction: 5th International Gesture Workshop*, GW 2003, vol. 2915, Springer, Berlin Heidelberg, pp. 460-7.

Camurri, A., Mazzarino, B. & Volpe, G. 2004b, ‘Expressive interfaces’, *Cognition, Technology & Work*, vol. 6, no. 1, pp. 15-22.

Camurri, A. & Moeslund, T.B. 2010, ‘Visual gesture recognition: from motion tracking to expressive gesture’, in R.I. Godøy & M. Leman (eds), *Musical gestures: sound, movement and meaning*, Routledge, New York, pp. 238-63.

Camurri, A. & Volpe, G. 2010, 'Multimodal analysis of expressive gesture in music performance', in J. Solis and k. Ng (eds), *Musical robots and interactive multimodal systems*, Springer, Berlin Heidelberg, pp. 47-66.

Camurri, A., Volpe, G., Poli, G.D. & Leman, M. 2005, 'Communicating expressiveness and affect in multimodal interactive systems', *IEEE Multimedia*, vol. 12, no. 1, pp. 43-53.

Caramiaux, B. 2012, 'Studies on the relationship between gesture and sound in musical performance', PhD Thesis, University of Paris, France.

Caramiaux, B. 2014, 'Motion modeling for expressive interaction: a design proposal using Bayesian adaptive systems', *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO'14)*, Ircam, Paris, France, pp. 76-81.

Cascone, K. 2002, 'Laptop music-counterfeiting aura in the age of infinite reproduction', *Parachute*, pp. 52-9.

Castagne, N. & Cadoz, C. 2002, 'Creating music by means of 'physical thinking': the musician oriented Genesis environment', *Proceedings of the 5th International Conference on Digital Audio Effects (DAFx-02)*, Hamburg, Germany, pp. 169-74.

Castellano, G., Bresin, R., Camurri, A. & Volpe, G. 2007a, 'User-centered control of audio and visual expressive feedback by full-body movements', in A. C. R. Paiva, R. Prada & R. W. Picard (eds), *Affective computing and intelligent interaction*, Springer, Berlin Heidelberg, pp. 501-10.

Castellano, G., Bresin, R., Camurri, A. & Volpe, G. 2007b, 'Expressive control of music and visual media by full-body movement', *Proceedings of the 7th International Conference on New Interfaces for Musical Expression (NIME' 07)*, ACM, New York, pp. 390-1.

Castellano, G., Mortillaro, M., Camurri, A., Volpe, G. & Scherer, K. 2008, 'Automated analysis of body movement in emotionally expressive piano performances', *Music Perception: An Interdisciplinary Journal*, vol. 26, no. 2, pp. 103-19.

Chadabe, J. 1997, *Electric sound: the past and promise of electronic music*, Prentice-Hall, Upper Saddle River, NJ.

Chadabe, J. 2002, 'The limitations of mapping as a structural descriptive in electronic instruments', *Proceedings of the 2nd International Conference on New Interfaces for Musical Expression (NIME'02)*, Media Lab Europe, Dublin, Ireland, pp. 38-42.

Chafe, C. 1999, 'Interplay(er) machines' *Contemporary Music Review*, vol. 18, no. 3, pp. 89-97.

Chang, H. 2008, *Autoethnography as method*, vol. 1, Left Coast Press, Walnut Creek, CA.

Clarke, D. & Clarke, E. 2011, *Music and consciousness: philosophical, psychological, and cultural perspectives*, Oxford University Press, Oxford, UK.

Coniglio, M. 2000, *MidiDancer*, viewed 15 August 2015 <http://www.troikaranch.org/technology.html>.

Conigilo, M. 2002, 'ISADORA "almost out of beta": tracing the development of a new software tool for artists', viewed 17 February 2015 <http://www.sdela.dds.nl/sfd/isadora.html>.

Conigilo, M. 2015, *Isadora Core*, version 2.0, viewed 15 August 2015 <http://troikatronix.com/new-in-isadora-2-0/>.

Cont, A., Coduys, T. & Henry, C. 2004, 'Real-time gesture mapping in PD environment using neural networks', *Proceedings of the 4th International Conference on New interfaces for Musical Expression NIME'04*, Shizuoka University of Art and Culture, Shizouka, Japan, pp. 39-42.

Cook, P. 2001, 'Principles for designing computer music controllers', *Proceedings of the 1st International Conference on New Interfaces for Musical Expression (NIME'01),* ACM, Seattle, Washington, pp. 3-6.

Cook, P. 2002, *Real sound synthesis for interactive applications*, A K Peters Limited, Natick, MA.

Cook, P. 2009, 'Re-designing principles for computer music controllers: a case study of SqueezeVox Maggie', *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME'09)*, Carnegie Mellon School of Music, Pittsburgh, Pennsylvania, pp. 218-21.

Cox, A. 1999, 'The metaphoric logic of musical motion and space', PhD Thesis, University of Oregon.

Csikszentmihalyi, M. 1996, *Creativity: flow and the psychology of discovery and invention*, Harper Collins, New York.

Cuykendall, S., Schiphorst, T. & Bizzocchi, J. 2014, 'Designing interaction categories for kinesthetic empathy: a case study of synchronous objects', *Proceedings of the 2014 International Workshop on Movement and Computing*, Ircam, Paris, France, pp. 13-8.

Dahl, L. 2014, 'Triggering sounds from discrete air gestures: what movement feature has the best timing?', *Proceedings of the 14th International Conference on New Interfaces for Musical Expression (NIME'14),* Goldsmiths, University of London, UK, pp. 201-6.

Dahl, S. & Friberg, A. 2007, 'Visual perception of expressiveness in musicians' body movement', *Music Perception*, vol. 24, no. 5, pp. 433-54.

Damasio, A.R. 2000, *The feeling of what happens: body, emotion and the making of consciousness*, Random House, London.

Davidson, J.W. 1993, 'Visual perception of performance manner in the movements of solo musicians', *Psychology of Music*, vol. 21, no. 2, pp. 103-13.

Davidson, J.W. 1994, 'What type of information is conveyed in the body movements of solo musician performers', *Journal of Human Movement Studies*, vol. 6, pp. 279-301.

Davidson, J.W. 2001, ‘The role of the body in the production and perception of solo vocal performance: a case study of Annie Lennox’, *Musicae Scientiae*, vol. 5, no. 2, pp. 235-56.

Davidson, J.W. 2007, ‘Qualitative insights into the use of expressive body movement in solo piano performance: a case study approach’, *Psychology of Music*, vol. 35, no. 3, pp. 381-401.

Davidson, J.W. 2012, ‘Bodily movement and facial actions in expressive musical performance by solo and duo instrumentalists: two distinctive case studies’, *Psychology of Music*, vol. 40, no. 5, pp. 595-633.

Davidson, J.W. & Correia, J.S. 2002, ‘Body movement’ in R. Parncutt & G. E. McPherson (eds), *The science and psychology of music performance: creative strategies for teaching and learning*, Oxford University Press, Oxford, pp. 237-50.

Da Vinci, L. c. 1487, *Proportional study of a man in the manner of Vitruvius*, Leonardo’s Vitruvian Man, viewed 20 August 2015, <http://leonardodavinci.stanford.edu/submissions/clabaugh/history/leonardo.html>

DeLahunta, S. & Bevilacqua, F. 2007, 'Sharing descriptions of movement', *International Journal of Performance Arts and Digital Media*, vol. 3, no. 1, pp. 3-16.

Delalande, F. 1998, ‘La gestique de Glenn Gould [The gestures of Glenn Gould]’ in G. Guertin (ed.), *Glenn Gould Pluriel [Glenn Gould: Plural],* Louise Courteau, Verdun, Canada, pp. 85-111.

Denzin, N.K. 2003, *Performance ethnography: critical pedagogy and the politics of culture*, Sage, Thousand Oaks, CA.

Denzin, N.K. 2006a, ‘Analytic autoethnography, or déjà vu all over again’, *Journal of Contemporary Ethnography*, vol. 35, no. 4, pp. 419-528.

Denzin, N.K. 2006b, ‘Pedagogy, performance, and autoethnography’, *Text and Performance Quarterly*, vol. 26, no. 4, pp. 333-8.

Dixon, S. 2007, *Digital performance: a history of new media in theater, dance, performance art, and installation*, MIT Press, Cambridge, MA.

Dobrian, C. & Koppelman, D. 2006, ‘The’E’in NIME: musical expression with new computer interfaces’, *Proceedings of the 6th International Conference on New Interfaces for Musical Expression*, Ircam, Paris, pp. 277-82.

Doğantan-Dack, M. 2006, ‘The body behind music: precedents and prospects’, *Psychology of Music*, vol. 34, no. 4, pp. 449-64.

Doğantan-Dack, M. 2008, ‘Recording the performer’s voice’, in M. Doğantan-Dack (ed.), *Recorded music: philosophical and critical reflections*, Middlesex University Press, London, pp. 293-313.

Doğantan-Dack, M. 2011, 'In the beginning was gesture: piano touch and an introduction to a phenomenology of the performing body' in A. Gritten & E. King (eds), *New perspectives on music and gesture*, Ashgate, Farnham, UK, pp. 243-65.

Doğantan-Dack, M. 2012, 'The art of research in live music performance', *Music Performance Research*, vol. 5, pp. 34-48.

Doğantan-Dack, M. 2015, 'The role of the musical instrument in performance as research: the piano as a research tool' in M. Doğantan-Dack (ed.), *Artistic practice as research in music: theory, criticism, practice*, Ashgate, Farnham, Surrey, UK, pp. 169-202.

D'haes, W. 2004, 'Automatic estimation of control parameters for musical synthesis algorithms', PhD thesis, University of Antwerp.

Donnarumma, M. 2012, 'Incarnated sound in Music for Flesh II. Defining gesture in biologically informed musical performance', *Leonardo*, vol. 18, no. 3, pp. 164-75.

Dourish, P. 2004, *Where the action is: the foundations of embodied interaction*, MIT Press, Cambridge, MA.

Drummond, J. 2009, 'Understanding interactive systems', *Organised Sound*, vol. 14, no. 02, pp. 124-33.

Eitan, Z. & Granot, R.Y. 2006, 'How music moves: musical parameters and listeners' images of motion', *Music Perception*, vol. 23, no. 3, pp. 221-47.

Elblaus, L., Hansen, K.F. & Unander-Scharin, C. 2012, 'Artistically directed prototyping in development and in practice', *Journal of New Music Research*, vol. 41, no. 4, pp. 377-87.

Electrofringe Festival 2013, *Electrofringe festival*, viewed 20 August 2015 <http://electrofringe.net>.

Ellis, C. 1999, 'Heartful autoethnography', *Qualitative Health Research*, vol. 9, no. 5, pp. 669-83.

Ellis, C. 2004, *The ethnographic I: a methodological novel about autoethnography*, AltaMira Press, Oxford.

Ellis, C.S. & Bochner, A. 2000, 'Autoethnography, personal narrative, reflexivity: researcher as subject', in N.K. Denzin & Y.S. Lincoln (eds), *The handbook of qualitative research*, Sage, Thousand Oaks, CA, pp. 733-68.

Ellis, C. & Bochner, A. 2006, 'Analyzing analytic autoethnography: an autopsy', *Journal of Contemporary Ethnography*, no. 35, pp. 429-49.

Emmerson, S. 2007, *Living electronic music*, Ashgate Publishing, Aldershot, UK.

England, D., Sheridan, J. G., Crane, B., 'Whole body interaction 2010', *Proceedings of CHI EA '10 Extended Abstracts on Human Factors in Computing Systems*, ACM, New York, pp. 4465-4468.

Erkal, E. 2012, 'Thereminspace: the next challenge for digital design tools?' *Dosya: Computational Design,* no. 29, viewed 10 August 2015, <http://www.mimarlarodasiankara.org/dosya/dosya29eng.pdf>

Fdili Alaoui, S., Caramiaux, B., Serrano, M. & Bevilacqua, F. 2012, 'Movement qualities as interaction modality', *Proceedings of the Designing Interactive Systems Conference*, ACM, Newcastle Upon Tyne, UK, pp. 761-9.

Fdili Alaoui, S., Bevilacqua, F., Bermudez Pascual, B. & Jacquemin, C. 2013, ‘Dance interaction with physical model visuals based on movement qualities’, *International Journal of Arts and Technology*, vol. 6, no. 4, pp. 357-87.

Fdili Alaoui, S., Henry, C. & Jacquemin, C. 2014, ‘Physical modelling for interactive installations and the performing arts’, *International Journal of Performance Arts and Digital Media*, vol. 10, no. 2, pp. 159-78.

Feldenkrais, M. 1972, *Awareness through movement: health excercises for personal growth*, Harper & Row, New York.

Fels, L. 1999, 'In the wind clothes dance on a line', PhD Thesis, University of British Columbia, Vancouver.

Fels, S., Gadd, A. & Mulder, A. 2002, ‘Mapping transparency through metaphor: towards more expressive musical instruments’, *Organised Sound*, vol. 7, no. 2, pp. 109-26.

Fels, S., Pritchard, R. & Vatikiotis-Bateson, E. 2009, ‘Building a Portable Gesture-to-Audio/Visual Speech System’, *Proceedings of the International Conference on Auditory-Visual Speech Processing (AVSP2008)*, CiteseerPiscataway, USA, pp. 13-8.

Ferguson, S. & Wanderley, M.M. 2010, ‘The McGill Digital Orchestra: an interdisciplinary project on digital musical instruments’, *Journal of Interdisciplinary Music Studies*, vol. 4, no. 2, pp. 17-35.

Forbes, A. 2014, ‘Doctoral research through music performance: the role of the exegesis’, in L. Ravelli, B. Paltridge & S. Starfield (eds), *Doctoral writing in the creative and performing arts*, Libri Publishing, Oxfordshire, pp. 263-79.

Foster, S.L. 1986, *Reading dancing: bodies and subjects in contemporary American dance*, University of California Press, CA.

Franinović, K. & Serafin, S. 2013, *Sonic interaction design*, MIT Press, Cambridge.

Funk, M. & Coeckelbergh, M. 2013, ‘Is gesture knowledge? A philosophical approach to the epistemology of musical gestures’, in H. De Preester (ed.), *Moving imagination: explorations of gesture and inner movement*, John Benjamins Publishing Company, Amsterdam, pp. 113-31.

Gallagher, S. 2005, *How the body shapes the mind*, Oxford University Press, New York.

Gallese, V. 2009, ‘Mirror neurons, embodied simulation, and the neural basis of social identification’, *Psychoanalytic Dialogues*, vol. 19, no. 5, pp. 519-36.

Gambetta, C. L. 2010, ‘Creating a fresh approach to conducting gesture’, *Journal of the Conductors Guild,* vol. 13, no. 2, pp. 12-30.

Geertz, C. 1988, *Works and lives: the anthropologist as author*, Stanford University Press, Stanford, California.

Gelineck, S. 2012, ‘Exploratory and creative properties of physical-modeling-based musical instruments’, PhD Thesis, Aalborg University, Copenhagen.

Gelineck, S. & Böttcher, N. 2012, '6to6Mappr: an educational tool for fast and easy mapping of input devices to musical parameters', *Proceedings of the 7th Audio Mostly Conference: A Conference on Interaction with Sound*, ACM, New York, pp. 117-23.

Gergen, M.M. & Gergen, K.J. 2011, 'Performative social science and psychology', *Historical social research/Historische sozialforschung*, vol. 12, no. 1, pp. 291-9.

Gibson, J.J. 1986, *The ecological approach to visual perception*, Taylor & Francis, New York.

Gillian, N. 2007, 'Gesture recognition for musician computer interaction', PhD Thesis, Queen's University Belfast.

Gillian, N. & Nicolls, S. 2012, 'A gesturally controlled improvisation system for piano', Gillian, N. & Nicolls, S. 2012, 'A gesturally controlled improvisation system for piano', *Proceedings of the 1st International Conference on Live Interfaces: Performance, Art, Music (LiPAM),* Leeds, UK, Leeds, UK, viewed 11 August 2015, <http://www.nickgillian.com/archive/publications/GillianLIPAM2012.pdf>.

Ginsborg, J. 2010, 'Beating time: the role of kinaesthetic learning in the development of mental representations for music', in A. Mornell (ed.), *Art in motion*, Peter Lang, Vienna, pp. 121-42.

Godøy, R.I. 2001. 'Imagined action, excitation, and resonance' in R. I. Godøy & H. Jørgensen (eds), *Musical imagery*, Swets & Zeitlinger, Lisse, Holland, pp. 237-250.

Godøy, R.I. (2004). 'Gestural imagery in the service of musical imagery' in A. Camurri & G. Volpe (eds): *Gesture-based communication in human-computer interaction: 5th International Gesture Workshop*, GW 2003, vol. 2915, Springer Verlag, Berlin, pp. 55-62.

Godøy, R., Haga, E. & Jensenius, A. 2006, 'Playing "air instruments": mimicry of sound-producing gestures by novices and experts' in S. Gibet, N. Courty, and J. –F. Kamp (eds), *Gesture in human-computer interaction and simulation*, Springer, Berlin Heidelberg, pp. 256-67.

Godøy, R.I. 2010, 'Gestural affordances of musical sound', in R. I. Godøy & M. Leman (eds), *Musical gestures: sound, movement, and meaning*, Routledge, New York, pp. 103-25.

Godøy, R. 2011, 'Sound-action chunks in music', in J. Solis and K. Ng (eds), *Musical robots and interactive multimodal systems*, Springer, Berlin Heidelberg, pp. 13-26.

Goldberg, R. 2000, *Laurie Anderson*, Thames & Hudson, London.

Goldin-Meadow, S. 2003, *Hearing gesture: how our hands help us think*, Harvard University Press, Cambridge, MA.

Goudeseune, C. 2003, 'Interpolated mappings for musical instruments', *Organised Sound*, vol. 7, no. 02, pp. 85-96.

Griffiths, M. 2011, ‘Research and the self’, in M. Biggs & H. Karlsson (eds), *The Routledge companion to research in the arts*, Routledge, London, pp. 167-85.

Gritten, A. & King, E. 2006 (eds), *Music and gesture*, Ashgate, Aldershot, UK.

Gritten, A. & King, E. 2011, ‘Introduction’ in A. Gritten & E. King (eds) *New perspectives on music and gesture*, Farnham, Ashgate, pp. 1-9.

Guedes, C. 2005, ‘Mapping movement to musical rhythm: a study in interactive dance’, PhD Thesis, New York University.

Hackney, P. 2002, *Making connections: Total body integration through Bartenieff Fundamentals*, Routledge, New York.

Halmrast, Guettler, K., Bader, R. & Godøy, R.I. 2010, ‘Gesture and timbre’, in R. I. Godøy & M. Leman (eds), *Musical gestures: sound, movement, and meaning*, Routledge, New York, pp. 183-211.

Halprin, D. 2003, *The expressive body in life, art, and therapy: working with movement, metaphor, and meaning*, Jessica Kingsley Publishers, London.

Hanna, T. 1988, *Somatics: reawakening the mind’s control of movement, flexibility and health*, Addison-Wesley Publishing, Reading, MA.

Hansen, L.A. 2011, ‘Full-body movement as material for interaction design’, *Digital Creativity*, vol. 22, no. 4, pp. 247-62.

Hansen, L.M. 2013, ‘Making do and making new: performative moves into interaction design’, *International Journal of Performance Arts and Digital Media*, vol. 9, no. 1, pp. 135-51.

Harrison, S., Tatar, D. & Sengers, P. 2007, ‘The three paradigms of HCI’, *Proceedings of the Alt. Chi. Session at the SIGCHI Conference on Human Factors in Computing Systems*, San Jose, CA, pp. 1-18.

Haseman, B.C. 2007, ‘Rupture and recognition: identifying the performative research paradigm’, *Practice as research: approaches to creative arts enquiry*, pp. 147-57.

Hashimoto, S. 1997, ‘KANSEI as the third target of information processing and related topics in Japan’, in A. Camurri (ed.) *Proceedings of the International Workshop on KANSEI: The technology of emotion*, AIMI (Italian Computer Music Association) and DIST University of Genova, Italy, pp. 101-4.

Hatten, R.S. 2004, *Interpreting musical gestures, topics, and tropes: Mozart, Beethoven, Schubert*, Indiana University Press, Bloomington, US.

Hatten, R.S. 2006, ‘A theory of musical gesture and its application to Beethoven and Schubert’ in A. Gritten & E. King (eds), *Music and gesture*, Farnham, Ashgate, pp. 1-23.

Herr, K. & Anderson, G.L. 2005, *The action research dissertation: a guide for students and faculty*, Sage, Thousand Oaks, CA.

Hewitt, D. G. 2013, ‘eMic: developing works for vocal performance using a modified, sensor based microphone stand’, *CHI ‘13 Extended Abstracts on Human Factors in Computing Systems*, ACM, Paris, France, pp. 2943-6.

Hewitt, D.G. 2011, ‘Choreographic approaches to music composition for a new musical interface: the eMic’, *Proceedings of the International Symposium on Performance Science 2011*, European Association of Conservatoires (AEC), Belgium, pp. 169-74.

Hewitt, D.G. 2003, ‘EMIC-Compositional experiments and real-time mapping issues in performance’ in L. Vickery (ed.), *Proceedings of the Australasian Computer Music Association Conference* – Converging Technologies, ACMA, Perth, Australia, pp. 96-104.

Hewitt, D.G. 2006, ‘Compositions for voice and technology’, PhD Thesis, University of Western Sydney.

Hornecker, E. & Buur, J. 2006, ‘Getting a grip on tangible interaction: a framework on physical space and social interaction’, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Montréal, Québec, pp. 437-46.

Howard, D.M. & Rimmell, S. 2004, ‘Real-time gesture-controlled physical modelling music synthesis with tactile feedback’, *Journal on Applied Signal Processing*, vol. 7, pp. 1001-6.

Hummels, C., Overbeeke, K.C.J. & Klooster, S. 2006, ‘Move to get moved: a search for methods, tools and knowledge to design for expressive and rich movement-based interaction’, *Pers Ubiquit Comput*, vol. 11, pp. 677–90.

Hummels, C., Smets, G. & Overbeeke, K. 1998, 'An intuitive two-handed gestural interface for computer supported product design', *Gesture and sign language in human-computer interaction*, Springer, pp. 197-208.

Hunt, A. & Kirk, R. 2000, ‘Mapping strategies for musical performance’ in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 231-58.

Hunt, A., Wanderley, M. & Kirk, R. 2000, ‘Towards a model for instrumental mapping in expert musical interaction’, *Proceedings of the International Computer Music Conference (ICMC’2000)*, ICMA, Berlin, pp. 209-12.

Hunt, A. & Wanderley, M.M. 2002, ‘Mapping performer parameters to synthesis engines’, *Organised Sound*, vol. 7, no. 2, pp. 97-108.

Hurtienne, J. &Blessing, L. 2007, ‘Design for intuitive use – testing image schema theory for user interface design’, *Proceedings of the 16th International Conference on Engineering Design (ICED’07)*, CD-ROM, Ecole Centrale, Paris, pp. 1–12.

Hurtienne, J. & Israel, J. 2007, ‘Image schemas and their metaphorical extensions: intuitive patterns for tangible interaction’ in B. Ullmer, A. Schmidt, E. Hornecker, C. Hummels, R.J.K. Jacob, & E. van den Hoven (eds), *Proceedings of the 1st International Conference on Tangible and Embedded Interaction (TEI’07)*, Baton Rouge, LA, pp. 127-134.

Husserl, E. 1901, *Logical Investigations*, trans. J. N. Findlay, Routledge & Kegan Paul, London.

Husserl, E. 1962, *Ideas: a general introduction to pure phenomenology*, trans. B. Gibson, Colliers Macmillan Publishers, New York.

Ihde, D. 2007, *Listening and voice: phenomenologies of sound*, 2nd edn, State University of New York Press, Albany, NY.

Ihde, D. 2013, 'Embodiment: technologies and musics', in H. De Preester (ed.), *Moving Imagination: explorations of gesture and inner movement*, John Benjamins Publishing, Amsterdam, pp. 101-12.

Imaz, M. & Benyon, D. 2007, *Designing with blends: conceptual foundations of human-computer interaction and software engineering*, MIT Press, Cambridge, MA.

Ishii, H. 1998, 'Reflections: 'The last farewell': traces of physical presence', *Interactions*, vol. 5 no. 4, pp. 56-57.

Iyengar, B.K.S. 2005, *Light on yoga*, Harper Collins, London, Foreword by Y. Menuhin.

Jaques-Dalcroze, E. 1930, *Eurhythmics, art, and education*, Ayer, New York.

Jaques-Dalcroze, E. 1967, *Rhythm, music and education*, trans. H. F. Rubinstein Dalcroze Society, London.

James, D.D. 2003, 'A working model for postgraduate practice based research across the creative arts', *Proceedings of the 3rd Doctoral Education in Design Symposium (DED3),* Design Research Society, Tsukuba, Japan, pp. 15-24.

Jensenius, A.R. 2013, 'An action–sound approach to teaching interactive music', *Organised Sound*, vol. 18, no. 02, pp. 178-89.

Jensenius, A. R., Wanderley, M. M., Godøy, R. I., & Leman, M. 2010, 'Musical gestures concepts and methods in research', in R. I. Godøy & M. Leman (eds), *Musical gestures: sound, movement and meaning,* Routledge, New York, pp. 12-35.

Jessop, E.N. 2009, 'The Vocal Augmentation and Manipulation Prosthesis (VAMP): a conducting-based gestural controller for vocal performance', *Proceedings of the 9th International Conference of New Interfaces for Musical Expression (NIME'09)*, Carnegie Mellon School of Music, Pittsburgh, US, pp. 256-9.

Jessop, E.N. 2010, 'A gestural media framework: tools for expressive gesture recognition and mapping in rehearsal and performance', MA Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Jessop Nattinger, E. 2014, 'The body parametric: abstraction of vocal and physical expression in performance', PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Johnson, M. 1987, *The body in the mind: the bodily basis of meaning, reason and Imagination*, University of Chicago Press, Chicago.

Johnson, M. 2005, ‘The philosophical significance of image schemas’, in J.E. Grady & B. Hampe (eds), *From perception to meaning: image schemas in cognitive linguistics*, Walter de Gruyter, Berlin, pp. 15-33.

Johnson, M. 2007, *The meaning of the body*, University of Chicago Press, Chicago.

Johnston, A. 2009, ‘Interfaces for musical expression based on simulated physical models’, PhD Thesis, University of Technology, Sydney.

Jones, J. L. 2006, ‘Introduction: performance ethnography, performing ethnography, performance ethnography’, in D.S. Madison & J. Hamera (eds), *The Sage handbook of performance studies*, Sage, Thousand Oaks, CA, pp. 339-47.

Jordà, S. 2003a, ‘Interactive music systems for everyone: exploring visual feedback as a way for creating more intuitive, efficient and learnable instruments’ in R. Bresin (ed.), *Proceedings of the Stockholm Music Acoustics Conference (SMAC’03)*, KTH Royal Institute of Technology Sound and Music Computing Group, Stockholm, Sweden, pp. 171-4.

Jordà, S. 2003b, ‘Sonigraphical instruments: from FMOL to the reacTable’, *Proceedings of the 3rd International Conference on New Interfaces for Musical Expression (NIME’03),* McGill University, Montreal, Canada, pp. 70-6.

Jordà, S. 2004, ‘Instruments and players: some thoughts on digital lutherie’, *Journal of New Music Research*, vol. 33, no. 3, pp. 321-41.

Jordà, S., Geiger, G., Alonso, M. & Kaltenbrunner, M. 2007, ‘The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces’, *Proceedings of the 1st International Conference on Tangible and Embedded Interaction*, ACM, Bonn, Germany, pp. 139-46.

Jordan, S. 2011, ‘Choreomusical conversations: facing a double challenge’, *Dance Research Journal*, vol. 43, no. 1, pp. 43-64.

Juntunen, M. & Hyvönen, L. 2004, ‘Embodiment in musical knowing: how body movement facilitates learning within Dalcroze Eurhythmics’, *Journal of Music Education*, vol. 21, no. 2, pp. 199-214.

Kalatha, E. & Caridakis, G. 2013, ‘Natural, affect aware interfaces: gesture and body expressivity aspects’, *Proceedings of the 8th International Workshop of Semantic and Social Media Adaptation and Personalization (SMAP’13),* IEEE, Los Alamitos, CA, pp. 97-102.

Kaptelinin, V. & Nardi, B. 2006, *Acting with technology – activity theory and interaction design*, MIT Press, Cambridge, MA.

Karam, M. 2006, ‘A framework for research and design of gesture-based human computer interactions’, PhD Thesis, University of Southampton, UK.

Kendon, A. 2000, ‘Language and gesture: unity or duality’, in D. McNeill (ed.), *Language and gesture*, Cambridge University Press, Cambridge, UK, pp. 47-63.

Kendon, A. 2004, *Gesture: visible action as utterance*, Cambridge University Press, Cambridge, UK.

Kimura, M., Rasamimanana, N. & Bevilacqua, F. 2012, ‘Extracting human expression for interactive composition with the Augmented Violin’, *Proceedings of the International Conference of New Interfaces for Musical Expression (NIME’12),* University of Michigan, Ann Arbor, US, pp. 99-102.

Kirsh, D. 2013, ‘Embodied cognition and the magical future of interaction design’, *ACM Transactions on Human Computer Interaction*, vol. 20, no. 2, pp. 1-30.

Kjölberg, J. 2004, ‘Designing full body movement interaction using modern dance as a starting point’, *Proceedings of the Conference on Designing interactive systems: processes, practices, methods, and techniques 2004*, ACM, Cambridge, MA, pp. 353-6

Kleinsmith, A., Fushimi, T. & Bianchi-Berthouze, N. 2005, ‘An incremental and interactive affective posture recognition system’, *Proceedings of the International Workshop on Adapting the Interaction Style to Affective Factors*, Edinburgh, UK, pp. 378-87.

Knutzen, H., Kvifte, T. & Wanderley, M.M. 2014, ‘Vibrotactile feedback for an open air music controller’ in M. Aramaki, O. Derrien, R. Kronland-Mertinet & S. Ystad (eds), *Sound, music and motion, lecture notes in computer science,* Springer, Berlin Heidelberg, pp. 41-57.

Kossak, M. 2015, *Attunement in expressive arts therapy*, Charles C Thomas, Springfield, IL, US.

Krueger, M.W. 1974, *VIDEOPLACE* videostill, Medien Kuntz Net, viewed 15 August 2015, <http://www.medienkunstnetz.de/works/videoplace/images/1/>.

Krueger, M.W. 1977, ‘Responsive environments’, *Proceedings of the AFIPS 46 National Computer Conference*, AFIPS Press, Motvale, NJ, pp. 423-33.

Krueger, M.W. 1983, *Artificial reality*, Addison-Wesley, Reading, Mass.

Krueger, M.W., Gionfriddo, T. & Hinrichsen, K. 1985, ‘VIDEOPLACE—an artificial reality’, *ACM SIGCHI Bulletin*, vol. 16, ACM, pp. 35-40.

Kuhlman, L.M. 2009, ‘Gesture mapping for interaction design: an investigative process for developing interactive gesture libraries’, PhD Thesis, Ohio State University.

Kurtenbach, G. & Hulteen, E.A. 1990, 'Gestures in human-computer communication', *The art of human-computer interface design*, pp. 309-17.

Kvifte, T. 2008, ‘On the description of mapping structures’, *Journal of New Music Research*, vol. 37, no. 4, pp. 353-62.

Kvifte, T. & Jensenius, A.R. 2006, ‘Towards a coherent terminology and model of instrument description and design’, *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME’06)*, Ircam, Paris, France, pp. 220-5.

Laban, R. 1963, *Modern educational dance*, Macdonald & Evans Ltd., London.

Laban, R. 1988, *The mastery of movement*, Northcote House, Plymouth, UK.

Laban, R. & Lawrence, F.C. 1974, *Effort*, Macdonald & Evans, London.

Lähdeoja, O., Wanderley, M.M. & Malloch, J. 2009, 'Instrument augmentation using ancillary gestures for subtle sonic effects' *Proceedings of the 6th Sound and Music Computing Conference (SMC'09)*, Casa da Música, Porto, Portugal, pp. 327-30.

Lakoff, G. & Johnson, M. 1980, *Metaphors we live by*, University of Chicago Press, Chicago.

Lakoff, G. & Johnson, M. 1999, *Philosophy in the flesh: the embodied mind and its challenge to western thought*, Basic Books, New York.

Larson, S. 2012, *Musical meaning and interpretation : musical forces : motion, metaphor, and meaning in music*, Indiana University Press.

Larssen, A.T., Robertson, T., Loke, L. & Edwards, J. 2007, 'Introduction to the special issue on movement-based interaction', *Personal and Ubiquitous Computing*, vol. 11, no. 8, pp. 607-8.

Leavey, P. 2010, 'Performance-based emergent methods', *Handbook of emergent methods*, The Guildford Press, New York, pp. 343-58.

Leigh-Post, K. 2014, *Mind-body awareness for singers: unleashing optimal performance*, Plural Publishing, San Diego.

Leman, M. 2008, *Embodied music cognition and mediation technology*, MIT Press, Cambridge.

Leman, M. 2010, 'Music, gesture and the formation of embodied meaning' in R. I. Godøy & M. Leman (eds), *Musical gestures: sound, movement, and meaning*, Routledge, New York, pp. 126-53.

Leman, M. & Camurri, A. 2006, 'Understanding musical expressiveness using interactive multimedia platforms', *Musicae Scientiae*, vol. 10, no. 1, supplement, pp. 209-33.

Leman, M. & Godøy, R.I. 2010, 'Why study musical gestures?', in R. I. Godøy & M. Leman (eds), *Musical gestures: sound, movement, and meaning*, Routledge, New York, pp. 3-11.

Leman, M., Styns, F. & Bernardini, N. 2008, 'Sound, sense and music mediation: a historical-philosophical perspective', in P. Polotti & D. Rocchesso (eds), *Sound to sense, sense to sound: a state of the art in sound and music computing*, Logos Verlag, Berlin, pp. 15-46.

Leman, M., Lesaffre, M., Nijs, L. & Deweppe, A. 2010, 'User-oriented studies in embodied music cognition research', *Musicae Scientiae*, vol. 14, no. 2, supplement, pp. 203-23.

Levin, G. 2000, 'Painterly interfaces for audiovisual performance', PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Levin, G. 2005, 'A personal chronology of audiovisual systems research', *Proceedings of the 5th International Conference on New Interfaces for Musical Expression (NIME'05),* University of British Columbia, Vancouver, Canada, pp. 2-3.

Levin, G., Liberman, Z., Blonk, J. & La Barbara, J. 2003, *Messa di voce*, viewed 16 August 2015 <http://www.tmema.org/messa/messa.html>.

Levisohn, A.M. 2007, 'The body as a medium: reassessing the role of kinesthetic awareness in interactive applications', *Proceedings of the 5th International Conference on Multimedia '07*, ACM, New York, pp. 485-8.

Levisohn, A. & Schiphorst, T. 2011, 'Embodied engagement: supporting movement awareness in ubiquitous computing systems', *Ubiquitous Learning: An International Journal*, vol. 3, pp. 97-111.

Levitin, D., McAdams, S. & Adams, R.L. 2002, 'Control parameters for musical instruments: a foundation for new mappings of gesture to sound', *Organised Sound*, vol. 7, no. 1, pp. 171-89.

Linnane, M., Doyle, L. & Furlong, D. 2011, 'Embodied schemas for cross-modal mapping in the design of gestural controllers', paper presented to *The 17th International Symposium on Electronic Art (ISEA 2011)*, Istanbul, viewed 11 August 2015 <http://isea2011.sabanciuniv.edu/paper/embodied-schemas-cross-modal-mapping-design-gestural-controllers>.

Livingstone, S.R., Mühlberger, R., Brown, A.R. & Loch, A. 2007, 'Controlling musical emotionality: an affective computational architecture for influencing musical emotions', *Digital Creativity*, vol. 18, no. 1, pp. 43-53.

Loehr, D. 2007, 'Aspects of rhythm in gesture and speech', *Gesture*, vol. 7, no. 2, pp. 179-214.

Loke, L. 2009, 'Moving and making strange: a design methodology for movement-based interactive technologies', PhD Thesis, University of Technology, Sydney.

Loke, L., Larssen, A.T., Robertson, T. & Edwards, J. 2006, 'Understanding movement for interaction design: frameworks and approaches', *Personal and Ubiquitous Computing*, vol. 11, no. 8, pp. 691-701.

Loke, L., Khut, G.P., Slattery, M., Truman, C., Muller, L. & Duckworth, J. 2013, 'Re-sensitising the body: interactive art and the Feldenkrais method', *International Journal of Arts and Technology*, vol. 6, no. 4, pp. 339-56.

Luck, G. & Thompson, M.R. 2011, 'Exploring relationships between pianists' body movements, their expressive intentions, and structural elements of the music', *Musicae Scientiae*, vol. 16, no. 1, pp. 19-40.

Macaranas, A., Antle, A.N. & Riecke, B.E. 2015, 'What is intuitive interaction? Balancing users' performance and satisfaction with natural user interfaces', *Interacting with Computers*, col. 27, no. 3, pp. 1-14.

Machover, T. 2004, 'Shaping minds musically', *BT Technology Journal*, vol. 22, no. 4, pp. 171-9.

Maes, P.J., Leman, M., Lesaffre, M., Demey, M. & Moelants, D. 2010, 'From expressive gesture to sound', *Journal on Multimodal User Interfaces*, vol. 3, no. 1, pp. 67-78.

Mailman, J. B. & Paraskeva. 2013, 'Continuous movement, fluid music and expressive immersive interactive technology: the sound and touch of Ether's Flux' in M. Wyers & O. Glieca (eds), *Sound, music and the moving-thinking body*, Cambridge Scholars Publishing, UK, pp. 35-51.

Magnusson, T. 2014, 'Improvising with the Threnoscope: integrating code, hardware, GUI, network, and graphic scores', *Proceedings of the 14th International Conference on New Interfaces for Musical Expression* (*NIME'14)*, Goldsmiths, University of London, UK, pp. 19-22.

Malloch, J., Birnbaum, D., Sinyor, E. & Wanderley, M.M. 2006, 'Towards a new conceptual framework for digital musical instruments', *Proceedings of the International Conference on Digital Audio Effects (DAFx'06)*, McGill University, Montreal, Canada, pp. 49-52.

Malloch, J.W. 2008, 'A consort of gestural musical controllers: design, construction, and performance', PhD Thesis, McGill University, Montreal, Canada.

Mandanici, M. & Sapir, S. 2012, 'Disembodied voices: a kinect virtual choir conductor'. *Proceedings of the 9th Sound and Music Computing Conference (SMC 2012)*, Aalborg University, Copenhagen, Denmark, pp. 271-6.

March, N. 2009, *Diversions*, Piano Solo, Hornetmusiq Press, viewed 16 August 2015, < https://soundcloud.com/hornetmuziqpress/diversions-solo-piano-piece>.

Marrin, T. 1996, 'Toward an understanding of musical gesture: mapping expressive intention with the digital baton', MA Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Marshall, M.T. 2008, 'Physical interface design for digital musical instruments', PhD Thesis, McGill University, Montreal, Canada.

Marshall, M.T. & Wanderley, M.M. 2011, 'Examining the effects of embedded vibrotactile feedback on the feel of a digital musical instrument', *Proceedings of the 11th International Conference on New Interfaces for Musical Expression (NIME'11),* University of Oslo, Oslo, Norway, 399-404.

Mason, P.H. 2012, 'Music, dance and the total art work: choreomusicology in theory and practice', *Research in Dance Education*, vol. 13, no. 1, pp. 5-24.

Mauss, M. 1973, 'Techniques of the body', *Economy and Society*, vol. 2, no. 1, pp. 70-88.

McClary, S. 1995, 'Music, the Pythagoreans, and the body', in S. L. Foster (ed.), *Choreographing history*, Indiana University Press, Bloomington, US, pp. 82-104.

McNeill, D. 2000, *Language and gesture*, Cambridge University Press, Cambridge, UK.

McNeill, D. 2005, *Gesture and thought*, The University of Chicago Press, Chicago.

McNeill, D., Brown, E. & Anderson, A. 2006, ‘Gesture: a psycholinguistic approach’ in E. Brown & A. Anderson (eds), *The Encyclopedia of Language and Linguistics*, Elsevier, Amsterdam, Boston, pp. 1-15.

McNutt, E. 2003, ‘Performing electroacoustic music: a wider view of interactivity’, *Organised Sound*, vol. 8, no. 03, pp. 297-304.

Melo, J., Gómez, D. & Vargas, M. 2012, ‘Gest-O: performer gestures used to expand the sounds of the saxophone’, *Proceedings of the 12th International Conference on New interfaces for Musical Expression (NIME’12),* University of Michigan, Ann Arbor, US, pp. 262-5.

Merleau-Ponty, M. 1964, *Signs*, trans. R. C. McCleary, Northwestern University Press, Evanston.

Merleau-Ponty, M. 1999, *Phenomenology of perception*, trans. C. Smith, Routledge, London.

Merrill, D.J. 2004, ‘FlexiGesture: A sensor-rich real-time adaptive gesture and affordance learning platform for electronic music control’, PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Mewburn, I.B. 2009, ‘Constructing bodies: gesture, speech and representation at work in architectural design studios’, PhD Thesis, The University of Melbourne.

Michael, S.T., Odowichuk, G., Driessen, P., Schloss, W.A. & Tzanetakis, G. 2012, ‘Non-invasive sensing and gesture control for pitched percussion hyper-instruments using the Kinect’, *Proceedings of the 12th International Conference on New Interfaces for Musical Expression (NIME’12)*, University of Michigan, Ann Arbor, US, pp. 222-5.

Miranda, E.R. & Wanderley, M.M. 2006, *New digital musical instruments: control and interaction beyond the keyboard*, vol. 21, AR Editions, Middleton.

Moen, J. 2006, ‘KinAesthetic movement interaction: designing for the pleasure of motion’, PhD Thesis, University of Stockholm, Sweden.

Moeslund, T.B., Hilton, A. & Krüger, V. 2006, 'A survey of advances in vision-based human motion capture and analysis', *Computer vision and image understanding*, vol. 104, no. 2, pp. 90-126.

Momeni, A. & Henry, C. 2006, ‘Dynamic independent mapping layers for concurrent control of audio and video synthesis’, *Computer Music Journal*, vol. 30, no. 1, pp. 49-66.

Moog, R. 1967, ‘An Interview with Clara Rockmore’, *Theremin.info Archives*, viewed 11 August 2015, <http://www.theremin.info/-/viewpub/tid/10/pid/28>.

Moore, F. R. 1998, ‘The dysfunctions of MIDI’, *Computer Music Journal*, vol. 12, no., pp. 19-28.

Mulder, A. 1989, ‘Design of virtual three-dimensional instruments for sound control’, PhD Thesis, Rijks Universiteit Groningen, Netherlands.

Mulder, A. 1996, 'Getting a GRIP on alternate controllers: addressing the variability of gestural expression in musical instrument design', *Leonardo Music Journal*, no. 3, pp. 33-40.

Mulder, A. 2000, 'Towards a choice of gestural constraints for instrumental performers' in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 315-35.

Mullins, E.C. 2006, 'Performative somaesthetics: principles and scope', *The Journal of Aesthetic Education*, vol. 40, no. 4, pp. 104-17.

Murray-Browne, T. 2012, 'Interactive music: balancing creative freedom with musical development', PhD Thesis, Queen Mary University of London.

Murray-Browne, T., Mainstone, D. & Bryan-Kinns, N. 2011, 'The medium is the message: composing instruments and performing mappings', *Proceedings of the 11th International Conference on New Interfaces for Musical Expression (NIME'11),* University of Oslo, Oslo, Norway, pp. 56-9.

Murray-Browne, T., & Plumbley, M. 2014, 'Harmonic Motion: a toolkit for processing gestural data for interactive sound, *Proceedings of the 14th International Conference on New Interfaces for Musical Expression (NIME'14),* Goldsmiths, University of London, UK, pp. 213-6.

Nakra, T. M. 2000, 'Inside the Conductor's Jacket: analysis, interpretation and musical synthesis of expressive gesture', PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Nardi, B.A. 1996, *Context and consciousness: activity theory and human-computer interaction*, MIT Press, Cambridge, MA.

Nelson, R. 2009, *The jealousy of ideas: research methods in the creative arts*, Goldsmiths, University of London, UK.

Newland, I. 2014, 'Instrumental gesture as choreographic practice: performative approaches to understanding corporeal expressivity in music', *Choreographic Practices*, vol. 5, no. 2, pp. 149-68.

Newlove, J. & Dalby, J. 2004, *Laban for all*, Routledge, London.

Nicolls, S. 2010, Interacting with the piano - absorbing technology into piano technique and collaborative composition: the creation of 'performance environments', pieces and a piano', PhD Thesis, Brunel University, London.

Nijs L., Lesaffre M., Leman M. (2009). 'The musical instrument as a natural extension of the musician', *Proceedings of the 5th Conference of Interdisciplinary Musicology*, LAM-Institut jean Le Rond d'Alembert, Sorbonne University, Paris, France, pp. 132–133.

Noë, A. 2004, *Action in perception*, MIT Press, Cambridge, MA.

Noland, C. 2008, 'Motor intentionality: gestural meaning in Bill Viola and Merleau-Ponty', *Postmodern Culture*, vol. 17, no. 1053-1920.

Noland, C. 2009, *Agency and embodiment: performing gestures/producing culture*, Harvard University Press, Cambridge, MA.

Norman, D.A. 2002, *The design of everyday things*, Basic Books, New York.

Norman, D.A. 2010, ‘Natural user interfaces are not natural’, *Interactions*, vol. 17, no. 3, pp. 6-10.

Norman, D.A. & Nielsen, J. 2011, *Gestural interfaces: a step backwards in usability*, viewed 11 August 2015, <http://www.jnd.org/dn.mss/gestural_interfaces_a_step_backwards_in_usability_6.html>.

Nunez-Pacheco, C. & Loke, L. 2014, ‘Crafting the body-tool: a body-centred perspective on wearable technology’, *Proceedings of the 2014 Conference on Designing Interactive Systems (DIS’14)*, ACM, Vancouver, pp. 553-66.

O’Modhrain, S. 2000, ‘Playing by feel: incorporating haptic feedback into computer-based musical instruments’, PhD Thesis, Stanford University, CA.

O’Modhrain, S. 2011, ‘A framework for the evaluation of digital musical instruments’, *Computer Music Journal*, vol. 35, no. 1, pp. 28-42.

Odam, G. 1995, *The sounding symbol: music education in action*, Nelson Thornes, Cheltenham, UK.

Orio, N. 1999, ‘A model for human-computer interaction based on the recognition of musical gestures’, *Proceedings of the 1999 IEEE International Conference on Systems, Man, and Cybernetics (SMC’99)*, vol. 4, IEEE, Tokyo, pp. 333-8.

Ostertag, B. 2002, ‘Human bodies, computer music’, *Leonardo Music Journal*, vol. 12, pp. 11-4.

Overholt, D. 2009, ‘The musical interface technology design space’, *Organised Sound*, vol. 14, no. 2, pp. 217-26.

Overholt, D., Roads, C. & Thomspon, J. 2003, ‘On musical gestures and new performance interfaces for electronic music’, *Proceedings of the 5th International Gesture Workshop*, University of Genova, Italy, pp. 9-12.

Overholt, D., Thompson, J., Putnam, L., Bell, B., Kleban, J., Sturm, B. & Kuchera-Morin, J. 2009, ‘A multimodal system for gesture recognition in interactive music performance’, *Computer Music Journal*, vol. 33, no. 4, pp. 69-82.

Paine, G. 2015, ‘Interaction as material: the techno-somatic dimension’, *Organised Sound*, vol. 20, no. 01, pp. 82-9.

Paradiso, J.A. 1997, ‘Electronic music: new ways to play’, *Spectrum, IEEE*, vol. 34, no. 12, pp. 18-30.

Pedrosa, R. & MacLean, K. 2008, ‘Perceptually informed roles for haptic feedback in expressive music controllers’, *Haptic and audio interaction design*, Springer, Berlin, pp. 21-9.

Peters, D. 2012, ‘Introduction’, in D. Peters, G. Eckel & A. Dorschel (eds), *Bodily expression in electronic music: perspectives on reclaiming performativity*, Routledge, New York, pp. 1-14.

Pierce, A. 2007, *Deepening musical performance through movement: the theory and practice of embodied interpretation*, Indiana University Press, Bloomington, US.

Polanyi, M. 2009, *The tacit dimension,* The University of Chicago Press, Chicago.

Ponce, J.B. 2007, *Fractured bodies: gesture, pleasure and politics in contemporary computer music performance*, ProQuest, Ann Arbor, US.

Puckette, M. 2012, 'Does your computer sound like you, or does it sound like your computer?', keynote speech presented at the *Australasian Computer Music Conference*, Brisbane, Australia.

Reed-Danahay, D. 1997, *Auto/ethnography*, Berg, New York.

Rico, J., Crossan, A. & Brewster, S. 2011, 'Gesture-based interfaces: practical applications of gestures in real world mobile settings', in D. England (ed.), *Whole body interaction, human-computer interaction series*, Springer-Verlag, London.

Richardson, L. 1994, 'Writing. A method of inquiry' in N. K. Denzin & Y. S. Lincoln (eds), *Handbook of qualitative research*, Sage, Thousand Oaks, CA.

Roads, C. 1996, *The computer music tutorial*, MIT Press, Cambridge, MA.

Rockmore, C. 1998, *Method for theremin*, trans. D. Miller & J. McFarland-Johnson, Viewed 15 August 2015, <http://www.electrotheremin.com/claramethod.html>.

Rodet, X., Gosselin, F. & Mobuchon, P. 2005, 'Study of haptic and visual interaction for sound and music control in the Phase project', *Proceedings of the 5th International Conference on New Interfaces for Musical Expression (NIME'05)*, University of British Columbia, Vancouver, Canada, pp. 109-14.

Roddy, S. & Furlong, D. 2013, 'Rethinking the transmission medium in live computer music performance', paper presented to the *Irish Sound Science and Technology Association (ISSTA) Convocation*, Dún Laoghaire Institute of Art, Design and Technology, Dún Laoghaire, viewed <http://issta.ie/wp-content/uploads/ISSTC-2013-RODDY.pdf>.

Rodger, M.W. 2010, 'Musicians' Body Movements in Musical Skill Acquisition', PhD Thesis, Queen's University, Belfast.

Rokeby, D. 1998, 'The construction of experience: interface as content' in C. Dodsworth (ed.), *Digital illusion: entertaining the future with high technology*, Addison-Wesley Publishing Company, pp. 27-47.

Rokeby, D. 2010, *David Rokeby*, viewed 15 August 2015, <http://www.davidrokeby.com/vns.html>.

Rosa-Pujazón, A., Barbancho, I., Tardón, L. & Barbancho, A. 2013, 'Conducting a virtual ensemble with a Kinect device', *Proceedings of the Sounds and Music Computing Conference (SMAC)*, KTH Royal Institute of Technology Sound and Music Computing Group, Stockholm, Sweden, pp. 284-291.

Rosen, C. 2002, *Piano notes: the hidden world of the concert pianist*, Penguin Books, London.

Rosenberg, H.S. & Trusheim, W. 1989, 'Creative transformations: how visual artists, musicians and dancers use mental imagery in their work', in J.E. Shorr, P. Robin, J.C. Concella & M. Wolpin (eds), *Imagery: current perspectives*, vol. 5, Springer, New York, pp. 55-75

Rovan, J. & Hayward, V. 2000, 'Typology of tactile sounds and their synthesis in gesture-driven computer music performance', in M. M. Wanderley and M. Battier (eds), *Trends in gestural control of music*, Ircam, Paris, France, pp. 297-320.

Rovan, J.B., Wanderley, M.M., Dubnov, S. & Depalle, P. 1997, 'Instrumental gestural mapping strategies as expressivity determinants in computer music performance', *KANSEI, the Technology of Emotion. Proceedings of the Associazione di Informatica Musicale Italiana (AIMI) International Workshop*, Genoa, Italy, pp. 68–73.

Rovan, J.B., Wechsler, R. & Weiß, F. 2001, '*Seine Hohle Form*: artistic collaboration in an interactive dance and music performance environment', P*roceedings of COSIGN*, vol. 1, pp. 43-7.

Rowe, R. 1993, *Interactive music systems*, MIT Press, Cambridge, MA.

Ryan, J. 1991, 'Some remarks on musical instrument design at STEIM', *Contemporary Music Review*, vol. 6, no. 1, pp. 3-17.

Saffer, D. 2008, *Designing gestural interfaces: touchscreens and interactive devices*, O'Reilly Media, Sebastopol, CA.

Saintilan, N. 2008, 'In search of the inner voice: a qualitative exploration of the internalised use of aural, visual, kinaesthetic, and other imagery in the perception and performance of music', PhD Thesis, University of Wollongong, NSW, Australia.

Salter, C. 2012, '*JND:* An artistic experiment in bodily experience as research' in D. Peters, G Eckel & A. Dorschel (eds), *Bodily expression in electronic music: perspectives on reclaimed performativity*, Routledge, New York, pp. 181-199.

Sapir, S. 2002, 'Gestural control of digital audio environments', *Journal of New Music Research*, vol. 31, no. 2, pp. 119-29.

Sawada, H., Ohkura, S. & Hashimoto, S. 1995, 'Gesture analysis using 3D acceleration sensor for music control', *Proceedings of the International Computer Music Conference (ICMC'95)*, ICMA, Beijing, China, pp. 257-60.

Schacher, J.C. 2010, 'Motion to gesture to sound: mapping for interactive dance', *Proceedings of the 10th International Conference on New Interfaces for Musical Expression (NIME'10)*, University of Technolology, Sydney, pp. 250-254.

Schacher, J.C. 2012, 'The body in electronic music performance', *Proceedings of the 9th International Sound and Music Computing Conference (SMC'12)*, Aalborg University, Copenhagen, Denmark, pp. 194-200.

Schacher, J.C. 2013, ‘Hybrid musicianship – teaching gestural interaction with traditional and digital instruments’, *Proceedings of the 13th International Conference on New Interfaces for Musical Expression (NIME’2013)*, KAIST (Korea Advanced Institute of Science and Technology, Daejeon, South Korea, pp. 55-60.

Schacher, J.C. & Stoecklin, A. 2011, ‘Traces – body, motion and sound’, *Proceedings of the 11th International Conference on New Interfaces for Musical Expression (NIME’2011)*, University of Oslo, Oslo, Norway, pp. 292-5.

Schiphorst, T. & Kozel, S. 2002, 'Pulp fashion | wearable archi [ves] tectures', *Proceedings of the V2-anarchiving? Conference,* Rotterdam, (online essay), viewed 21 August 2015 <http://v2.nl/archive/articles/pulp-fashion-wearable-archi-ves-tectures>.

Schiphorst, T. 2009, ‘Body matters: the palpability of invisible computing’, *Leonardo*, vol. 42, no. 3, pp. 225-30.

Schiphorst, T. & Andersen, K. 2004, ‘Between bodies: using experience modeling to create gestural protocols for physiological data transfer’, *Proceedings of CHI 2004 Fringe, ACMCHI’04*, ACM, Vienna, pp. 1-8.

Schön, D. A. 1996, *The reflective practitioner: how professionals think in action*, Ashgate, Aldershot, UK.

Schloss, W.A. 2003, ‘Using contemporary technology in live performance: the dilemma of the performer’, *Journal of New Music Research*, vol. 32, no. 3, pp. 239-42.

Schroeder, F. & Newland, I. 2013, ‘The musical body: devising a choreo-musical interpretation of *Tierkreis* (1974-75) by Karlheinz Stockhausen’, in S. Reeve (ed.), *Nine ways of seeing a body,* Triarchy Press, Devon, UK, pp. 99-132.

Schroeder, F. & Rebelo, P. 2009, ‘The Pontydian performance: the performative layer’, *Organised Sound*, vol. 14, no. 02, pp. 134-41.

Schutz, M. & Manning, F. 2012, ‘Looking beyond the score: The musical role of percussionists’ ancillary gestures’, *Music Theory Online*, vol. 18, no. 1067-3040.

Scrivener, S. & Chapman, P. 2004, ‘The practical implications of applying a theory of practice based research: a case study’, *Working papers in art and design*, vol. 3, viewed 11 August 2015, <https://www.herts.ac.uk/__data/assets/pdf_file/0019/12367/WPIAAD_vol3_scrivener_chapman.pdf>.

Sheets-Johnstone, M. 1999, *The primacy of movement*, John Benjamins Publishing, Amsterdam.

Sheets-Johnstone, M. 2010, ‘Body and movement: basic dynamic principles’ in D. Schmicking & S. Gallagher (eds.), *Handbook of phenomenology and cognitive science*, Springer, Netherlands, pp. 217-234.

Sheets-Johnstone, M. 2013, 'Bodily resonance', in H. De Preester (ed.), *Moving imagination: explorations of gesture and inner movement*, John Benjamins Publishing, Amsterdam, pp. 19-36.

Shusterman, R. 2009, 'Body consciousness and performance: somaesthetics east and west', *The Journal of Aesthetics and Art Criticism*, vol. 67, no. 2, pp. 133-45.

Sloboda, J.A. 2005, *Exploring the musical mind: cognition, emotion, ability, function*, Oxford University Press, Oxford, UK.

Smith, A. *Fit to play: musicians and their bodies,* audio podcast, The Body Sphere Radio National, ABC Radio, Sydney, 21 December 2014, viewed 16 August 2015, <http://www.abc.net.au/radionational/programs/bodysphere/fit-to-play/5788058>.

Spool, J. 2005, 'What makes a design seem intuitive?', *User Interface Engineering*, viewed 20 August 2015, <http://www.uie.com/articles/design_intuitive/>.

Spry, T. 2001, 'Performing autoethnography: an embodied methodological praxis', *Qualitative Inquiry*, vol. 7, no. 6, pp. 706-32.

Stock, C. 2014, 'Writing embodied practice from the inside: outside the exegesis', in L. Ravelli, B. Paltridge & S. Starfield (eds), *Doctoral writing in the creative and performing arts*, Libri Publishing, Oxfordshire, pp. 297-318.

Stockhausen, K. & Maconie, R. 1989, *Stockhausen on music: lectures and interviews*, Marion Boyers, London.

Strachan, S., Murray-Smith, R. & O'Modhrain, S. 2007, 'BodySpace: inferring body pose for natural control of a music player', *CHI'07 Extended Abstracts on Human Factors in Computing Systems*, ACM, San Jose, CA, pp. 2001-6.

Tanaka, A. 1993, 'Musical technical issues in using interactive instrument technology with application to the BioMuse', *Proceedings of the International Computer Music Conference (ICMC)*, ICMA, San Fransisco, CA, pp. 124-6.

Tanaka, A. 2000, 'Musical performance practice on sensor-based instruments', in M. M. Wanderley and M. Battier (eds.), *Trends in gestural control of music*, Ircam, Paris, France, pp. 389-405.

Tanaka, A. 2010, 'Mapping out instruments, affordances, and mobiles', *Proceedings of the 10th International Conference on New Interfaces for Musical Expression*, University of Technology, Sydney, Australia, pp. 88-93.

Tanaka, A. & Knapp, R.B. 2002, 'Multimodal interaction in music using the electromyogram and relative position sensing', *Proceedings of the 2nd International Conference on New Interfaces for Musical Expression,* National University of Singapore, Singapore, pp. 1-6.

Tarabella, L. 2004, 'Handel, a free-hands gesture recognition system', *Computer Music Modeling and Retrieval (CMMR 2004)*, Springer, Esbjerg, Denmark, pp. 139-48.

Tarabella, L. & Bertini, G. 2000, ‘Giving expression to multimedia performance’, *Proceedings of the 2000 ACM Workshop on Multimedia*, ACM, Los Angeles, CA, pp. 35-8.

Tarabella, L. & Bertini, G. 2004, ‘About the role of mapping in gesture-controlled live computer music’ in U. K. Wiil (ed.), *Computer Music Modeling and Retrieval*, Springer-Verlag, Berlin Heidelberg, pp. 217-224.

Taylor, R., Boulanger, P. & Torres, D. 2006, 'Real-time music visualisation using responsive imagery', *Proceedings of the 8th International Conference on Virtual Reality (VRIC 2006)*, ACM, Laval, France, pp. 26-30.

Theremin, L. 1999, ‘Recollections’ in M. Battier (ed.), *Aesthetics of live electronic music*, Harwood Academic Publishers, St. Helier, pp. 1-8.

Thompson, M.R. & Luck, G. 2012, ‘Exploring relationships between pianists’ body movements, their expressive intentions, and structural elements of the music’, *Musicae Scientiae*, vol. 16, no. 1, pp. 19-40.

Todoroff, T., Bettens, F., Chu, W.Y. & Reboursière, L. 2008, ‘Dancing Viola’ in T. Dutoit & B. Macq (eds), *QPSR of the numediart research program*, vol. 1, no. 4, pp. 129-46.

Tolman E.C., 1948, ‘Cognitive maps in rats and men’, *Psychological Review*, vol. 55, no. 4, pp. 189–208.

Underbelly Arts Festival 2008, *Underbelly arts festival*, viewed 17 August 2015, <http://underbellyarts.com.au/about/>.

Van Eck, C. n.d., *Song no 3 - singing through gestures*, viewed 20 August 2015, <http://www.cathyvaneck.net/gallery/song-no-3/>.

Van Manen, M. 1990, *Researching lived experience: human science for an action sensitive pedagogy*, State University of New York Press, Albany, New York.

Van Manen, M. 2007, ‘Phenomenology of practice’, *Phenomenology & Practice*, vol. 1, no. 1, pp. 11-30.

Van Nort, D. 2010, ‘Modular and adaptive control of sound processing’, PhD Thesis, McGill University, Montreal, Canada.

Van Nort, D., Wanderley, M.M. & Depalle, P. 2004, 'On the choice of mappings based on geometric properties', *Proceedings of the 4th 2004 Conference on New Interfaces for Musical Expression (NIME’04)*, Shizuoka University of Art and Culture, Hamatsu, Japan, pp. 87-91.

Varela, F.J. & Shear, J. 1999, ‘First-person methodologies: what, why, how’, *Journal of Consciousness Studies*, vol. 6, no. 2-3, pp. 1-14.

Varela, F.J., Thompson, E. & Rosch, E. 1992, *The embodied mind: cognitive science and human experience*, MIT Press, Cambridge, MA.

Varèse, E & Wen-chung, C. 1966, ‘The liberation of sound’, *Perspectives of New Music*, vol. 5, no. 1, pp. 11-19.

Veitch, S., Veitch, J., & West, S.J. 1991. ‘3-dimensional interactive space (3DIS)’, *Nuclear Materials Management,* vol. 20, pp. 875-878.

Verfaille, V., Wanderley, M.M. & Depalle, P. 2006, 'Mapping strategies for gestural and adaptive control of digital audio effects', *Journal of New Music Research*, vol. 35, no. 1, pp. 71-93.

Vines, B., Wanderley, M., Krumhansl, C., Nuzzo, R. & Levitin, D. 2004, 'Performance gestures of musicians: what structural and emotional information do they convey?', *Gesture-based communication in human-computer interaction: 5th International Gesture Workshop*, GW 2003, vol. 2915, Springer Verlag, Berlin,, pp. 468-78.

Waisvisz, M. 1985, 'The Hands, a set of remote MIDI controllers, *Proceedings of the International Computer Music Conference (ICMC),* ICMA, Simon Fraser University, Canada, pp. 313-8.

Waisvisz, M. 1999, 'Riding the Sphinx - lines about 'live'', in M. Battier (ed.), *Aesthetics of live electronic music*, Harwood Academic Publishers, St. Helier, pp. 119-26.

Wanderley, M.M. 1999, 'Non-obvious performer gestures in instrumental music', *Gesture-based communication in human-computer interaction*, Springer-Verlag, Berlin Heidelberg, pp. 37-48.

Wanderley, M. 2001, 'Performer-instrument interaction. Application to gestural control of sound synthesis', PhD Thesis*, Université Paris*, France.

Wanderley, M. 2002, 'Quantitative analysis of non-obvious performer gestures', in I. Wachsmuth & T. Sowa (eds), *Gesture and sign language in human-computer interaction*, Springer-Verlag, Berlin Heidelberg, pp. 241-53.

Wanderley, M.M. & Depalle, P. 2001, 'Gesturally-controlled digital audio effects', *Proceedings of the COST-6 Conference on Digital Audio Effects (DAFx-01)*, University of Limerick, Ireland, pp. 165-9.

Wanderley, M.M. & Depalle, P. 2004, 'Gestural control of sound synthesis', *Proceedings of the3rd IEEE International Conference on Sensors*, vol. 92, no. 4, Vienna University of Technology, Vienna, Austria, pp. 632-44.

Wanderley, M.M. & Orio, N. 2002, 'Evaluation of input devices for musical expression: borrowing tools from HCI', *Computer Music Journal*, vol. 26, no. 3, pp. 62-76.

Wanderley, M.M., Schnell, N. & Rovan, J. 1998, 'Escher - Modeling and performing composed instruments in real-time', *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics (SMAC'98),* vol. 1, IEEE, San Diego, CA, pp. 1080-4.

Ward, P., Hodges, N.J., Williams, A.M. & Starkes, J.L. 2004, 'Deliberate practice and expert performance' in A.M. Williams & N. J. Hodges (eds), *Skill acquisition in sport: research, theory and practice*, Routledge, London & New York, p. 231-58.

Ward, N., Penfield, K., O'Modhrain, S. & Knapp, R.B. 2008, 'A study of two thereminists: towards movement informed instrument design', *Proceedings of the 8th International Conference on New Interfaces for Musical Expression (NIME'08)*, University of Genova, Italy, pp. 117-21.

Wechsler, R. 2006, ‘Artistic considerations in the use of motion tracking: practices of virtual embodiment and interactivity’, in S. Broadhurst & J. Machon (eds), *Performance and technology: practices of virtual embodiment and interactivity*, Palgrave Macmillan, Hampshire, pp. 60-77.

Wechsler, R., Weiß, F. & Dowling, P. 2004, ‘EyeCon--a motion sensing tool for creating interactive dance, music, and video projections’, *Proceedings of the Society for the Study of Artificial Intelligence and the Simulation of Behaviour (SSAISB)'s convention: Motion, Emotion and Cognition*, Citeseer, Leeds, England, viewed 11 August 2015, <http://www.palindrome.de/content/pubs/leeds.pdf>.

Wessel, D. 2006, ‘An enactive approach to computer music performance’, in Y. Orlarey (ed.), *Le feedback dans la creation musical*, Studio Gramme, Lyon, France, pp. 93–98.

Wessel, D. & Wright, M. 2002, ‘Problems and prospects for intimate musical control of computers’, *Computer Music Journal*, vol. 26, no. 3, pp. 11-22.

Wessel, D., Wright, M. & Schott, J. 2002, ‘Intimate musical control of computers with a variety of controllers and gesture mapping metaphors’, *Proceedings of the 2nd International Conference on New Instruments for Musical Expression (NIME'02),* MediaLabEurope, Dublin, Ireland, pp. 1-3.

Wexelblat, A. 1995, 'An approach to natural gesture in virtual environments', *ACM ransactions on computer-human interaction (TOCHI)*, vol. 2, no. 3, pp. 179-200.

Whitehouse. M. 1995, ‘The Tao of the body’ in D. Johnson (ed.), *Bone, breath & gesture: practices of embodiment*, North Atlantic Books, Berkeley, CA.

Wigdor, D. & Wixon, D. 2011, *Brave NUI world: designing natural user interfaces for touch and gesture*, Morgan Kauffman, Burlington, MA.

Wilde, D. 2011, ‘Swing that thing: moving to move: the poetics of embodied engagement’, PhD Exegesis, Monash University, Melbourne, Australia.

Wilde, D., Schiphorst, T. & Klooster, S. 2011, ‘Move to design/design to move: a conversation about designing for the body’, *Interactions*, vol. 18, no. 4, pp. 22-7.

Wilkie, K., Holland, S. & Mulholland, P. 2013, ‘Towards a participatory approach for interaction design based on conceptual metaphor theory: a case study from music interaction’ in S. Holland, K. Wilkie, P. Mulholland & A. Seago (eds), *Music and human-computer interaction*, Springer-Verlag, London, pp. 259-70.

Wilkie, K., Holland, S. & Mulholland, P. 2010, ‘What can the language of musicians tell us about music interaction design?’, *Computer Music Journal*, vol. 34, no. 4, pp. 34-48.

Wilson-Bokowiec, J. & Bokowiec, M.A. 2006, ‘Kinaesonics: the intertwining relationship of body and sound’, *Contemporary Music Review*, vol. 25, no. 1-2, pp. 47-57.

Winkler, T. 1995, ‘Making motion musical: gesture mapping strategies for interactive computer music’, *Proceedings of the 1995 International Computer Music Conference (ICMC),* University of Michigan Press, Ann Arbor, MI, pp. 261-4.

Winkler, T. 1998, *Composing interactive music: techniques and ideas using Max*, MIT Press, Cambridge, MA.

Winkler, T. 2010, 'Audience participation and response in movement-sensing installations', paper presented to the *10th International Symposium on Electronic Art (ISEA2000)*, Paris, France, pp. 194-9.

Wright, M., Freed, A., Lee, A., Madden, T. & Momeni, A. 2001, ‘Managing complexity with explicit mapping of gestures to sound control with OSC’, *Proceedings of the 2001 International Computer Music Conference (ICMC),* International Computer Music Association, San Fransisco, CA, pp. 314-7.

Wu, J.C. 2015, ‘The Expressionist: a gestural mapping instrument for voice and multimedia enrichment’, *The International Journal of New Media, Technology and the Arts*, vol. 10, no. 1, viewed 11 August 2015, <https://www.mat.ucsb.edu/Publications/A14-c_49652_Body.pdf>.

Wyers, M. 2013, ‘Shaping music, shaping you: optimising music performance potential through body movement/dance’ in M. Wyers & O. Glieca (eds), *Sound, music and the moving-thinking body*, Cambridge Scholars Publishing, UK, pp. 59-69.

Yang, Q. & Essl, G. 2012, ‘Augmented piano performance using a depth camera’, *Proceedings of the International Conference of New Interfaces for Musical Expression (NIME’12),* University of Michigan, Ann Arbor, pp. 252-255.

Yoo, M. J., Beak, J. W. & Lee, I. K. 2011, ‘Creating musical expression using Kinect’, *Proceedings of the 11th International Conference on New Interfaces for Musical Expression (NIME’11)*, University of Oslo, Norway, pp. 324-5.

Young, I. M. 1980, ‘Throwing like a girl: a phenomenology of feminine body comportment motility and spatiality’, *Human Studies*, vol. 3, pp. 137-56.

Young, M. 1988, *The metronomic society: natural rhythms and human timetables*, Harvard University Press, Cambridge, Mass.

Zbikowski, L.M. 2002, *Conceptualizing music: cognitive structure, theory and analysis*, Oxford University Press, New York.

Zhao, L. 2001, ‘Synthesis and acquisition of Laban movement analysis qualitative parameters for communicative gestures’, PhD thesis, University of Pennsylvania, Philadelphia, PA.