On the hunt for feedback: Vibrotactile feedback in interactive electronic music performances

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For Manto

Related Publications

Some of the work contained within this thesis has appeared in the following publications. All publications appear in Appendix A.

- Bullock, J., Coccioli, L., Dooley, J., & Michailidis, T. (2013) Live Electronics in Practice: Approaches to training professional performers. *Organised Sound,* Vol 18(2), pp. 170–177.

- Polydorou, D., Michailidis, T. & Bullock, J. (2015) Communication through Haptic Interaction in Digital Performance. In Popat, S. & Salazar, N. (eds), *Digital Movement: Essays in Motion Technology and Performance*. Hampshire: Palgrave Macmillan.

- Michailidis, T., Polydorou, D. & Bullock, J. (2013) A multimodal integration of sensory feedback modalities for dance performers. In *proceedings of the FASCINATE Conference*, Falmouth University, UK.

- Michailidis, T. & Bullock, J. (2011) Improving Performers' Musicality Through Live Interaction With Haptic Feedback: A Case Study. In *Proceedings of Sound and Music Computing Conference (SMC)*, Padova, Italy.

- Michailidis, T. & Berweck, S. (2011) Tactile Feedback Tool: Approaching The Foot Pedal Problem In Live Electronic Music. In *Proceedings of the International Computer Music Conference (ICMC),* University of Huddersfield, UK, pp. 661–664.

Abstract

The expressivity of musical performance is highly dependent on the feedback relationship between the performer and the instrument. Despite current advances in music technology, performers still struggle to retain the same expressive nuances of acoustic instruments. The capacity of performative musical expression in technologically-driven music is mitigated by the limitations of controllers and other sensor-based devices used in the performance of such music.

Due to their physical properties, such devices and components are unable to provide mainly the haptic and vibrotactile experience between the instrument and the user, thus breaking the link with traditional musical performance. Such limitations are apparent to performers, suggesting often the existence of an unnatural barrier between the technology and the performer.

The thesis proposes the use of vibrotactile feedback as means to enhance performer's expressivity and creativity in technology mediated performances and situate vibrotactile feedback as part of the tradition of instrumental musical playing. Achieved through the use of small controllable electric motors, vibrotactile feedback can nourish communicative pathways between the performer and technology, a relationship that is otherwise limited or non-existing. The ability to experience an instrument's communicative response can significantly improve the performer-instrument relationship, and in turn the music performed. Through a series of case studies, compositions and performances, the dissertation suggests ways in which vibrotactile feedback may be applied to enhance the experience between the technology and the performer. As a result performers are able to develop expressive nuances and have better control of the technology during performance.

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4. *Live Mechanics*

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CHAPTER One
Introduction

The relationship between technology and music is the key theme of this thesis. It reflects my long-term fascination with the use of technology as an integral part of creating and performing music. A fine line separates what I will describe as *correct* and *incorrect* practice in technology-mediated performances. The ways we experience and respond to technology as performers is problematic and can significantly diminish the expressiveness of a performance and the artistic intentions of the composer. The lack of haptic feedback as a part of the musical experience when performing with technology is substantial to the point that it may cultivate and sustain incorrect performance approaches. This thesis examines how artificially embedded devices with vibrotactile feedback can support and enhance both the composer's intentions and the performer's interpretation of the technology. For the composer, vibrotactile feedback suggests creative pathways within this field of music and for the performer it brings additional communicative channels and access to further expressive nuances in performance.

I cannot say if there was a definitive turning point for me, but I was always intrigued by the way rock guitarists could just press the distortion pedal and uplift the crowd. There was something magical and mysterious in the way technology could alter my perception: seeing the same person and instrument sounding out of the ordinary with the click of a button. It was this cause and effect relationship that I felt was missing in the experience of most *live electronics* music, a term which I will discuss later on, and the reason why I am seeking to bring its absence to the attention of performers and composers alike. We respond to this connection, whether we are music makers or audiences. From this early stage, when I took an interest in computer music, I was curious to understand how the technology involved in performances could have such a fundamental influence on the musical experience, very often hard to detect and other times highly engaging and visibly intriguing. This curiosity had to do with the way performers could perform and *present* the technology on stage and how it affected the music heard. It was obvious that technology played a major role, not only musically but also at a more perceptual level on the listener. As a performer and composer, I tried to consider and understand these aspects that have turned out to become an inseparable part of my creative and aesthetic process.

As I became more experienced, a wider range of practical and theoretical issues became apparent. In what ways, and to what extent, does technology on the stage impact on the listener experience? Do we listen in a different way when technology is involved? Why do performers often struggle to engage with technology, yet remain comfortable with an acoustic instrument? How can composers enhance the expressiveness of their music through technology? What makes a good performance when technology is involved? Are we using technology in the wrong way? I soon realised that such issues were not dependent entirely on me and were more universal. I was convinced that there was a drawback when it comes to performing music with technology and undertook a personal exploration to examine further how and why a distinction between good and bad music technology performances practice should be made. I took on a mission to look deeper into the origins of these problems, why they exist and how they may be approached to enable and support my own creative practice, discovering in the process ideas that are applicable more generally in the domain of music technology.

As an integral part of this discussion I examine a range of terms concerning music technology practice to provide a wider and unified understanding among performers, composers and the audience. This is however, a difficult task. The interchangeable meaning of music technology terms used often creates confusion with regards to musical understanding and the experience. *Computer Music* for example, is a broad term that assumes the use of a combination of a wide range of hardware and/or software to facilitate artistic expression. Nonetheless, there is a tendency from the audience, the performer and the composer to understand it not only as the medium for the creation of music but also as a genre of music in its own right which encompasses other artistic implications and assumptions. This hybrid combination between the genre and the medium allows variable levels of uncertainty to exist when analysing and discussing computer music. In live performances this becomes even more complicated. The term *Live Electronics* often addresses the essence of such performances. It includes to some extent, the live formation, transformation and transmission of sound through a performer and a computer device. Live electronics as a term is problematic and there is an urgent need to reconsider its meaning, role and functionality within the wider framework of performance with technology. In the following chapters I will discuss further both terms, *Computer Music* and *Live Electronics*, in an attempt to identify and examine their relationship with this dissertation.

To understand more deeply the role of technology in performances and compositions, my focus turned to what defines live music and how its properties can be reflected and maintained within the wider field of computer music performances. In acoustic music we can examine what may be considered as live by studying three interconnected components: the performer, the composer, and the listener. By examining the relationships between them it is possible to arrive at a basic understanding of how *liveness* may exist. The audience receives the way in which the performer, through her instrument, interprets the composer's score and as a result without the performer there is no live music. There are some underlying universal similarities amongst instrumentalists regardless of the genre they perform noticeably how performers act on similar acoustic principles towards the instrument. The energy of the performer's actions allows vibrating components of the instrument to transform the air molecules into acoustic pressure waves thus enabling the formation of sound. The performer-instrument relationship has an uninterrupted association with the produced sound, suggesting a mutual dependency between the two. The harder one depresses the keys on the piano the louder it will sound and this comes as *de facto* to all performers. The performer-instrument relationship is intimate, stable and personal and provides composers with an established framework to compose and present the music.

Instruments used in technology-mediated performances can have different functions and roles from those found in traditional musical instruments. This creates an elusive relationship between the composer, performer and the listener. Such instruments do not come with fixed associations but rather present a blank canvas on which the composer, and very often the performer, must create, develop and sustain a bond with the instrument and the composition. By far the greatest difference in this association is the disembodiment of sound from the instrument, contrary to what occurs naturally with the mechanical production of sound. To consider and examine the *liveness* in technology driven performances, one should consider and view the *instrument,* as a separate component, may affect and influence the relationship between the performer, the composer and the listener. The instrument, in this case, refers to the overall use and applications of technology in music performances including the use of computers, sensors, controllers and other software and electronic hardware devices. The instruments are no longer solely an extension of the performer's body but part of a framework of technological possibilities. This separation between the instrument and the body resulted in problematic performance experience.

1.1 Haptic and Vibrotactile Feedback

The term *vibrotactile* refers to the vibrating sensation and experience on the skin, muscles and bones of the body received through touch. The skin is a complex organ and such vibrating sensations should be considered as a part of a wider sensory experience that comprises other touch-related factors such as temperature, roughness of surface and force feedback. The broader sensory experience sensed by the skin, including tactile and kinaesthetic experience, could be defined as *haptics*. Paterson refers to haptics as the 'new mechanical channel' that is related to the production of touch (Paterson, 2007, p. 128). Cholewiak and Collins portray the complexity of the skin as an orchestra where different instruments, referring to different functions of the skin, contribute their voices, each in its own fashion (Cholewiak and Collins, 1991).

Feedback is involved in every action taken consciously and subconsciously throughout our lives. We continuously monitor feedback within our body's organs and the outer physical world as the information we obtain before, during and after an activity. This information reaches our senses as multilevel packets that include readings of the activity we have experienced.[1] There are two classifications of feedback: *intrinsic feedback* and *extrinsic feedback* (Utley and Astill, 2008), (Schmidt and Lee, 2011). Intrinsic feedback is associated to a greater extent with the direct sensory information gained from an individual's movements or actions. For example, plucking the string of the violin provides physical resistance and friction, as well as sound, which can be received as feedback. Extrinsic feedback, on the other hand, takes place when additional information is provided for an action that enhances or augments the intrinsic feedback. This may include the conductor's cues to an orchestra. Feedback is essential to both the human learning process as well as for all physical activities that require or benefit from real-time monitoring and adjustment.

[1] Multilevel packets refer to variable perceptual information that is received from all the senses at the same time.

In this thesis, feedback specifically refers to the sensory information that has arisen as the result of performed actions. Such feedback is considered *closed* when all possible sensory types (e.g., auditory, tactile, visual) are retuned to the instrumentalist during performance, allowing for performance nuances. A closed feedback loop returns confirmation of an action back to the user. In Chapter Three I examine the integration of multiple senses in the development of a coherent understanding of interactive electronic performances and how instrumentalists experience feedback information during performance.

Vibrotactile feedback was not originally designed for use in a musical context. Its use in such a context however, compensates for the lack of a suitable feedback loop in music performances using technology. It enables an additional communication channel between the performer and technology. The feedback loop in this case is the outcome of the interaction with a system and provides the user with meaningful information on how they are doing. Such finely detailed information gained through vibrotactile feedback and haptics is vital for performers working with technology. Through physical experience it provides a framework for the performer's expressivity.

Acoustic instruments have been developed and transformed over their long history, thus enabling instrumentalists to establish a defined and complex habitual relationship through performing. Performers interact with the mechanical properties of their instruments through a rich and intimate bidirectional relationship and trained to sense their instrument beyond its sound. The complete picture from the feedback information enables them to reflect on the status of their performance at a micro level (Chafe, 1993), (Winold *et al.*, 1994), (O'Modhrain, 2000). In technology-driven music performances the feedback is often inadequate but it is a necessary step forward in completing the ambition of fine control and musical expression found in acoustic instruments.

Performing music with the help of controllers, sensors and other computer devices does not currently include expressive and communicative properties that can be found in acoustic instrumental performances. The most widely used technologies for music performances cannot provide a similar sensory experience to allow for expressive nuances. This is not to assume that electronic and digitally created instruments follow the same performance techniques and experiences as those of acoustic instruments but it is necessary to acknowledge the underlining differences between the two.

The technology used does not rely on mechanical properties but on digitally defined functions through hardware and software. This creates a problematic relationship between the performer and the instrument that is often weak and incomplete, making it difficult to establish a habitual link for musical expression. The role of feedback and how it is perceived has been a major concern in the design of interactive music systems and controllers (Cadoz *et al*., 2003), (Bongers, 2000), (Paradiso and O'Modhrain, 2010). Through the implementation of vibrotactile feedback it is possible to create a closed feedback loop and to convey a familiar haptic experiences to the performer.

The work of Ernst Heinrich Weber between 1830-1870 can be seen as the initiation of a scientific approach to haptic research within experimental psychology. His experiments explore the anatomical and physiological characteristics of the senses including visual resolution, inhabitation and adaptation in sensory systems, selective attention and the binocular combination of colours (Prytherch and McLundie, 2002). In his most famous work, dated 1838, Weber observed that a threshold in haptic sensitivity exists before an increase in the intensity of the stimulus can be detected (Weber, 1996). This is known as 'Weber's Law'.[2]

Another important landmark in haptic research appears in David Katz's work *Der Aufbau der Taswelt* (The World of Touch) in 1925. Katz underlines the significance of touch and the nature by which vibrating sensation is highly involved in surface and object exploration (Krueger, 1982), (Katz, 1989), (Gillespie, 2001), (Paterson, 2007), (Grunwald and John, 2008). Since then philosophers and researchers such as James J. Gibson and Maurice Merleau-Ponty as well as others including Roberta Klatzky, Jack Loomis and Susan Lederman have provided further research into the influential role of touch and haptics within the fields of psychology and human perception (Gibson, 1950), (Gibson, 1962), (Lederman *et al*., 1982), (Loomis and Lederman, 1986), (Merleau-Ponty, 2002), (Klatzky *et al*., 2005), (Romdenh-Romluc, 2011).

Haptic feedback including vibrotactile feedback enables us to appraise the experience of objects in our everyday life. The significant properties of haptics have been applied since the early stages of tele-operation, the operation of a device or a machine from a distance. Raymond Goertz developed the first modern master-slave manipulator in the late 1940s for the safe handling of radioactive isotopes (Goertz and Thompson, 1954),

[2] Weber's Law states that there is a constant ratio between the background intensity and the threshold. For example, when holding a weight of 2.0 kg and then you add weights, you will only notice the difference for weights above 0.2 kg.

(Yong *et al.,* 1998). The successful relationship between the *master* and *slave* came from the ability to provide haptic feedback to the human user to experience the actions undertaken by the slave. Under the communicative fabric of tactile feedback Frank Geldard argued about the ability to train our skin to do substantially what the tympanic membrane does in the ear.[3] After a 35-hour training period, the subject was able to receive five-letter words with 90-per-cent accuracy (Geldard, 1960). Likewise, James Graig addressed the communicative possibilities of tactile feedback through the Optacon device, **Op**tical **Ta**ctile **Con**verter (1977). The portable device scans written letters through a small camera controlled by the right hand and translates that into a 6x24 actuating grid of tiny mechanical pins for the reader to touch (figure 1). Studies from the use of the Optacon suggest how feedback is actively involved in the learning and communicative process.[4] Due to its tactile feedback functionality the device is able to achieve effective results in a relatively short time (Efron, 1977), (Graig, 1977). The Optacon device has many similarities with the way musicians and instruments function together. Muscular control, spatial orientation, two-hand coordination, tactile sensitivity and mechanical control are required for using the Optacon, something that can be found when performing an instrument.

[3] Air received on the tympanic membrane vibrates the eardrum affecting the ossicles of the middle ear and the cochlea that create and provide electrical signal to the brain.
[4] *Optacon Teaching Guidelines*. [Online] Telesensory Systems, Inc. Available at: <http://www.freedomscientific.com/fs_downloads/optacon/OPTACON%20Teaching%20Guidelines.pdf > [Accessed 22 November 2014].

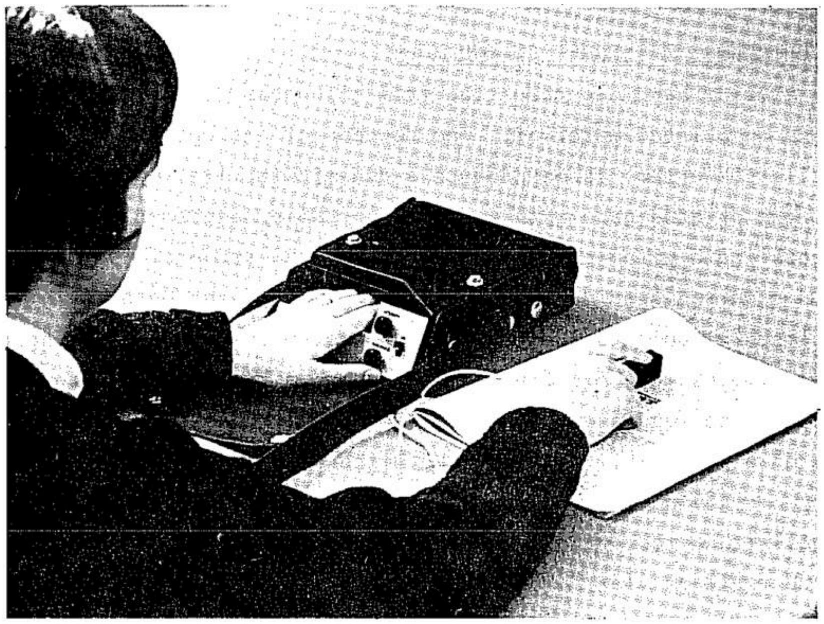

Figure 1 - The Optacon in use. The left hand senses the tactile visualisation of the letters from the camera on the right hand (copied from *Optacon Teaching Guidelines*, p 2).

With the advent of robotics and other computer technologies developed in the 1970s and 1980s haptics developed further guiding the user towards the best possible experience when interacting with a system. Such a significant development had implications on a variety of fields including handling nuclear, subsea and outer space exploration, medical and military applications (Burdea, 1996), (Goethals, 2008). Other disciplines acknowledge these developments within an array of interactive applications including media, design, video games, handheld and computer devices (Saddik *et al*., 2011). The ability to provide communicative and expressive qualities through haptics has impacted on experimental artistic practice through sculpture, painting, interactive installations, dance, music and theatre.

1.2 Aims of this Research

The fundamental issue of feedback and how performers register it through their senses serves as the underlying core of my thesis. I do not aim to demonstrate any finite solution on how to facilitate expressiveness in technology-mediated performances through the addition of vibrotactile feedback. I will however, propose a wider understanding of the intimate relationship that performers and technology have on stage.[5] The underlying factors of such feedback relationship are examined in an attempt to demonstrate similarities that exist between acoustic instrumental performance and technology-driven music performance. In that respect, vibrotactile feedback experience can enhance composers' creativity and performers' expressivity in computer-mediated performances.

Before addressing the research questions it is important to examine briefly the relevant existing research around vibrotactile feedback and how can be implemented in music. Bird *et al.* suggest the use of vibrotactile feedback to examine augmented perception based on three different scenarios: driving a car, playing a game, and performing music (2008). The music scenario uses a 6x8 grid of vibrating motors providing musicians with the experience of tactile feedback as the representation of the harmonic relationship during performances.[6] Lauren Hayes and Christos Michalakos created the *NeVIS,* (Networked Vibrotactile Improvisation System). The vibrating cue-based system between the two performers needs to be *composed* prior the performance and allows a 'more integrated and polished performance' between the two (Hayes and Michalakos, 2012). A similar work has been employed in a co-located musical performance in which vibrotactile feedback provided an additional communication path between performers over the network (McDonald *et al*., 2009). Through the use of a force feedback device, Hayes looks at the expressiveness in musical performance and at the different ways that the system communicates and interacts with the performer (Hayes, 2011), (Hayes, 2012). Marshall, Giordano and Wanderley discuss how vibrotactile feedback can be embedded within Digital Musical Instruments (DMIs), allowing substantial confidence and suggesting creative outcomes by the performer (Marshall and Wanderley, 2006), (Marshall, 2008), (Marshall and Wanderley, 2011), (Giordano and Wanderley, 2013). There is extensive research concerning the use of vibrotactile and force feedback as means of communication and learning aids for music performances (Beamish *et al*., 2004), (Modler and Myatt, 2007), (Berdahl *et al*., 2009), (Ciglar, 2010), (Giordano and Wanderley, 2011), (Papetti *et al*., 2011). Holland *et al.,* carry out experiments in polyphonic rhythm and with multi-limb haptic guidance (2010). Similarly, Grindlay examines the effects of haptic and auditory guidance on learning in a musical

[5] I assume here that most technology mediate performances will include a computer as a part of their performance.
[6] Using Simon Holland's Harmony Space system. More information at <http://mcl.open.ac.uk/hsp>. [Accessed 22 November 2014].

percussion performance context (2008).

This dissertation focuses specifically on solo performers of acoustic instruments where vibrotactile feedback is included in the creation, processing and control of computer systems. We know little about the impact of vibrotactile feedback when used by instrumentalists with no or little knowledge and experience of performing with technology. It is a necessity to examine how its use may affect the creativity and expressivity of musicians. Embedding vibrotactile feedback establishes a physical and intimate relationship that reinforces the performer-technology communications channels bringing back similar habits of music experience and expressiveness during performance. Through compositional and performance practice I will examine and demonstrate the effectiveness of vibrotactile feedback and how this is manifested through my personal artistic development. I will look at the theoretical understanding, how performers experience instrumental feedback as well as examining how this can be realised through the embodiment of vibrating motors. The aim of such integration, of the vibrotactile feedback, is to facilitate any non-existent or limited communicative channels between the computer and the performer. From the technical point of view, while such integration introduces more hardware to the already complex setup of performing with technology, it also enables an underlying simplicity and facilitates confidence in the performer's interaction with the technology. A discussion of the compositions created for the thesis reflects the intersection of theory and practice. Four case studies are presented to support and demonstrate the approaches taken during the compositional process. The case studies focus primarily on the way performers felt and experienced the vibrotactile feedback system while performing. They serve as an initial point for the creative outcomes derived from the performers' views and experiences. The compositions reflect on the case studies and develop their own artistic approach during the process; thus, the case studies are an integral part of the composition process.

The following research questions became apparent and crucial from the start of this research:

- In what ways does vibrotactile feedback allow expressiveness to emerge in technology-mediated music performances and compositions?
- How could vibrotactile feedback be used in the compositional process?
- How are performers able to form and establish a habitual relationship with their instrument through vibrotactile feedback, and in what ways is it most effective?

I do not intend to claim that vibrotactile feedback must be included in all computer-driven performances, nor that the same haptic experience can be recreated as with acoustic instruments. We cannot assume that the use of vibrotactile feedback will result in better compositions or performances. As a tool of technology, vibrotactile feedback acquires credibility only through the way it is implemented and approached within the compositional process. As discussed further in this thesis, vibrotactile feedback provides sensory information that may not be appropriate or useful for all acoustic instruments due to technical or practical constraints as well as the nature of the performance.

The proposed approach has elements of custom-made electronic hardware and programming. Detailed technical aspects of the electronic hardware will not be discussed in depth but some of the discussion will be of a technical nature in order to understand the technology's potential for application in this context. Even though vibrotactile feedback as a communicative tool has implications on education and learning this will not be discussed at length.[7] I shall focus instead on the way in which vibrotactile feedback may facilitate a simpler approach and a wider understanding of interactive computer music for future musicians. These crucial questions and concerns will be addressed through the case studies and the analysis of the compositions.

1.3 Methodology

My research uses a practice-led methodology. The compositions and performances are driven by my own artistic practice and the outcomes of the case studies. The research undertaken and the theory are examined and reflected through the case studies. Haseman

[7] For the interested reader the following research has demonstrated the potential of vibrotactile feedback in education (Grindlay, 2008), (Holland *et al.*, 2010).

discusses how practice-led research may not have a problem-solution approach similar to scientific research.

> [Many] practice-led researchers do not commence a research project with a sense of ‘a problem’. Indeed they may be led by what is best described as ‘an enthusiasm of practice’: something which is exciting, something which may be unruly, or indeed something which may be just becoming possible as new technology or networks allow (but of which they cannot be certain) (Haseman, 2006).

To understand the essence and significance of vibrotactile feedback in music, we have to step back for a moment and look at the performers’ experience. In what ways is tactile feedback able to influence the performer’s understanding of the music performed? The overall haptic experience including vibrotactile is personal and intimate. The haptic and tactile experience is an essential part of the instrument playing that enables performers to convey the expressiveness and enjoyment of music to the audience. Thus it is necessary to examine and monitor how a performer engages and realise the role and use of vibrotactile feedback. The case studies address different aspects of how vibrotactile feedback behaves and is understood in a live performing environment. The compositions demonstrate further creative implications of the findings.

The thesis provides three main strands within the proposed practice-led framework. First, an examination of the senses of the human body provides us with the framework to address relationships in the experience of the user and allow us to identify further how the instrumentalist experiences technology in performance. This leads us towards the embodiment of vibrotactile feedback within the wider multisensory experience. Second, we examine the embodied interaction and its phenomenological importance of bodily experience. Merleau-Ponty’s views on perception and the body as the centre of experience as well as his views on habit and tools as the extension of the body allow us to form a new phenomenal body as performers (Merleau-Ponty, 2002). The proposed vibrotactile feedback can be part of our new phenomenal bodies in the computer-performer relationship. Third, through the case studies and the compositions we are able to investigate further the theory, practice and creative outcomes of vibrotactile feedback and propose a new approaches towards music performance.

This research project took place over several years at Birmingham Conservatoire, where I was able to reflect on my own personal experience as a practitioner in this field. I had the opportunity to organise many music technology concerts and I was also involved in research projects exploring the relationship between instrumentalists and computers. This included a range of concerts ranging from students to internationally renowned performers and composers such as Louis Andriessen, Heiner Goebbels, Nick Collins, Garth Knox, Barbara Lüneburg, Xenia Pestova and Krista Martynes among others. In addition, I was able to collaborate with students on their way to becoming professional musicians, allowing me to have a closer understanding of their existing relationships with computers, how they use them and their opinion on the role of computers in musical performance. I had the opportunity to work at the Integra Project as a research lab assistant.[8] Apart from the research carried out by the lab, I was acting as an electronics musician and technician in preparing and delivering the technologies involved in compositions and performances for concerts and festivals around Europe. In particular, I collaborated with composer Hilda Paredes and assisted her in the creation of the electronics of her composition *Revelación.*[9]

1.4 Layout

This chapter has introduced the research topic through my own artistic concerns as well as in the context of other research. Following an introduction, the aim and research questions are posed and the relationship between the case studies and my compositions is addressed, the methodology of my research is then discussed.

Chapter Two explores the theory and practice of computer music performances. In particular, I examine the various drawbacks of technology in live performances. I look at current issues with terminology and the practice of live electronics and I propose the use of the term *Interactive Electronics*. This suggested subcategory of *live electronics* is an attempt to narrow the scope of the genre focusing towards the artistic intentions of the composer and performer originated from the interaction with the technology. Furthermore, I discuss the role of feedback and the performer's perception and sensing experience through haptic, aural and visual information, allowing me to establish a

[8] Integra (2005-2012) was a €3.1M project to promote live electronic music funded by the Culture programme of the European Union and led by Birmingham Conservatoire, <http://www.integralive.org>
[9] More information at <http://www.hildaparedes.com>

working definition of interaction in computer music performance.

Chapter Three examines the theoretical background within the cross-modality and phenomenology of perception through the work of Maurice Merleau-Ponty. Other fundamental issues arise from the discussion, such as the role of habit and tools as well as the relationship of time in the feedback experience. The chapter examines also how Gibson's concepts of affordance and active touch are reflected in music. I examine the utilisation of vibrotactile and haptic feedback applications in different systems, including music applications, to provide a coherent and sensible approach towards a human interaction with the digital.

In Chapter Four I discuss the case studies and how vibrotactile feedback is applied and demonstrated, and I show the relationships between the case studies and my compositions.[10] Case Study One, *The Gloves*, involves six trumpet players unfamiliar with performing in the field of live electronics. The subjects go through a series of short melodies to examine the effect that vibrotactile feedback has while performing. In particular, the case study looks at how vibrotactile feedback allows performers to sense the applied pressure of a pressure sensor glove and thus control the music.

Case Study Two, *Footpedal*, examines a common problem among performers and composers while using footpedals, the inability to know when the computer receives a successful pedal trigger. A bespoke device, named *Tactile Feedback Tool-TfTool*, was created in order to transform the incoming pedal signal into vibrating pulses for the user to experience. A vibrating pulse informs the performer of a successful trigger.

Case Study Three, *Cross-modality,* examines a combination of different performing approaches that focus on the creative implications of vibrotactile feedback and the perception of cross-modality of the senses during performances. While similar case studies and experiments looked at cross-modal perception, the approach taken here is through the performer's experience in a live performance context.

Case Study Four, *Performing Electronics,* looks at the long-term effects of vibrotactile feedback. Through the process of monitoring the learning of a new interactive electronics piece as well as through discussions and interviews with the performer, the case study examines how confidence emerges from understanding the role of the technology and in particular how vibrotactile feedback may influence such confidence

[10] Figure 3, page 74, shows the relationships between the four case studies and the four compositions.

and habit.

The case studies and the compositions provide an artistic overview of the discussed theory and show a practical understanding of the use of vibrotactile feedback as a creative component. The compositions themselves and the performers provide insights towards the practice-led methodology.[11]

Chapter Five goes on to analyse my four compositions: *Barbaróphonos, Big Bang…, …Big Crunch,* and *Live Mechanics.* The analysis looks at the creative use of technology in the pieces, focusing on the implementation of vibrotactile feedback and its notation. All composition software files including video recordings of performances are included in the USB flash drive.

Finally, Chapter Six provides an overview of the thesis and how vibrotactile feedback through the case studies and compositions, creates an environment where the performer is able to nourish expressivity when performing with technology. Future work and creative approaches are put forward in an attempt to suggest the use of vibrotactile feedback in the context of other performing arts.

[11] All subjects included in the case studies and the performers have granted permission to use their likeness and any rehearsal discussion that took place, ensuring that my work conforms with the standard research guidelines.

CHAPTER Two
Interactive Electronics

Chapter Two examines two main themes. First, I will examine different approaches to performing with technology with particular reference to *Live Electronics*. Throughout its history the meaning of the term live electronics has been very confusing amongst performers and composers. There is an underlying tendency to address performances that use even the most basic electronic technology as live electronics performances. This might include any setup ranging from simple audio playback to live sound processing. With such a vague meaning and description, I will argue that live electronics reached a point that no longer stands out as a genre of music but rather as a concept in music. I propose that *Interactive Electronics* can be a subcategory of Live Electronics. It addresses a performance approach where interaction between the performer and the technology is an integral part of the composition and the performance. It is necessary to examine further how feedback channels including vibrotactile, are involved in the interactive process of a music performance. In the second part of this chapter I provide an overview of common feedback modalities: auditory, visual and tactile. The examination of these sensory feedback modalities will allow us to clarify further the role of feedback in music performances.

Examination of these topics suggests that the integration of multisensory feedback experience has expressive implications for the music performed. Vibrotactile feedback has a significant role in the formation of expressive nuances, especially in technology-mediated performances. This allows us to make further assumptions about the relationships between feedback and interaction in music and how interactive electronics could benefit from that.

2.1 Defining Music Technology

When performing with technology, questions arise when audiences finds it difficult to understand its artistic intentions and meanings. It is important to examine two interrelated genres where technology plays a prominent role in the realisation and performance of a composition. This will allow us to understand the role of technology in composing and performing music.

First we look at the term *Live Electronics.* It describes the practice and use of computers and electronic technologies in live performances. The performer, through the act of performance, promotes the *liveness* of the *electronics*, hardware and software. Emmerson and Smalley define live electronics as follow:

> In live electronic music the technology is used to generate, transform or trigger sounds (or a combination of these) in the act of performance; this may include generating sound with voices and traditional instruments, electroacoustic instruments, or other devices and controls linked to computer-based systems (Emmerson and Smalley, 2001).

The definition from Emmerson and Smalley encompasses a wide range of technology-oriented activities where the presence of a human performer on stage is involved in the act of performance. In a later definition Emmerson points out that the definition of live electronics is only suggested for the time being as it has the ability to evolve its underlying meanings and purposes through time (Emmerson, 2007, pp. 89-90). There is no defined line about what should be included or not under the term live electronics and very often this becomes an opportunity for composers and performers to *abuse* the term. Over the years the term has reached a point where its overused meaning has collapsed and it has became acceptable to describe most technology driven performance practices as live electronics. It is time to rethink the term live electronic and consider it as a concept in music rather than a genre.

Secondly, we look at *Computer Music*. Collins defines Computer Music as the 'music that involves a computer at any stage of its life cycle' excluding the music created without microprocessors involved (Collins, 2010, p. 1). I will add to that definition that it is the music that involves the *creative use* of a computer at any stage of its life cycle. It should include the process of decision making by the user throughout its performative music life span. Eric Lyon, even though restrictive in his description, gives a more pragmatic approach. He defines computer music as the 'music created using a computer that could not have been made without the use of a computer' (Lyon, 2006). Lyon suggests that computer music is rather an instrumental definition somewhat analogous to the category of *piano music* where the category refers to the tools rather than to its musical outcome (Lyon, 2006). Other technologically driven music styles, such as DJing, share similar characteristics where the term refers to the tool and the process rather than its musical outcome. The technology used to perform music becomes an uninterrupted part of how the music is created and perceived. According to Samson, the definition of music genres shifted after the mid-1960s from being the 'nature of artworks to the nature of aesthetic experience' (Samson, 2013). The hardware used for DJing; the turntables, support the way music may function from a physical and performative point of view; however, it does not necessarily define further any musical outcomes and other artistic possibilities and experience therein. Audiences are able to create their own views and assumptions based on the context that is implied through a familiar music experience and the act of performance. The technology becomes a part of the framework that enables the performed music and its artistic outcomes to exist.

Apart from a wide range of underlying assumptions in music performance, it is important to acknowledge ways in which technology, including hardware and software reflect perceptually to listeners and musicians. Composers and performers working with technology have to consider the way technology influences and conveys familiar assumptions through the listener's perception. The creative intentions of the composer should be the result of how technology is integrated with the music performed and how audiences are able to experience that.[12] Our listening experience changed through the use of technology and thus a shift in the experience of the music and consequently the composers' creativity and approach.

[12] It is beyond the scope of this thesis to examine in depth any interconnected variables that may exist regarding the enjoyment of music through technology.

> The sound of big opera ensembles can be fitted onto a windsurfing board, and the sound of a nylon-stringed guitar can fill a football stadium; one can listen to march music in the bathtub and saloon music in the mountains [...] Not long ago, one was obligated to go to the opera to hear opera, and the only way to hear the guitar was to sit rather close to the performer (Stockfelt 2004, p. 90).

The ability to enjoy music everywhere through portable electronic devices for example, has shifted our listening experience (Chambers, 2004). Music acquires influences through our everyday exposure to our cultural technological framework. This affects the way audiences, composers and performers are able to create an abstract representation of the music through the technology involved. Today's overwhelming interaction with technologies such as touch-screens, accelerometers, WiFi, Bluetooth and other sensor technologies suggests to the audience as well as the performer an *inexperienced familiarity*. This familiarity with the technology affects our perception and expectations in music performances and often distracts the audience from the essence of music. Composers and performers should incorporate technologies in a creative way that will introduce and guide the listener towards their artistic intentions.

2.2 Some Issues with Technology

The performed technology should be in a position to support and sustain the composition. Audience must somehow overcome the technological framework set up by the composer and the overall technological culture to fully interpret and appreciate the performance. This is different from how the piece affects the listener through its harmony, melody, articulation and other music functions. When technology is involved, composers should assume equilibrium between the technology used and how it is combined with any acoustic instruments. With this in mind, there is no predefined equilibrium as this is based on the artistic intentions of the composer and cannot be justified or described in qualitative or quantitative terms. Equilibrium here suggests a framework in which the context of technology is balanced within the performance and the artistic intentions. It often intersects between what it is familiar and even embeds habitual qualities around the experience of the composer, the performer and the listener. For example, when a mobile phone is used in performances, it is impossible to justify the underlying meaning and influence that it may have on the listener's perception. The purpose of a mobile phone is to communicate, at least for the majority of people, thus the use of such non-music related technology can often disturb the way in which audiences might perceive the composers' intentions. Composers, in this case should be able to artistically justify the use of the mobile phone within the context of the composition.[13] Kim Cascone suggests that being part of a wider competitive market, all necessary systems of economics, promotion and presentation must co-exist and as a result there are unpredicted influences on the listeners (Cascone, 2003).

Frequently, comments arise when performers perform behind a laptop screen with seemingly untraceable actions. This motionless action, one that the audience is not used to experiencing, may direct them into the *clichéd* speculation that the performer may as well have 'just been checking his email' (Parkinson, 2012). This is often the case when the listener is in a situation where visual cues are not in a position to support the aural information and vice versa. In a laptop performance, the *technology* is hidden behind the laptop screen and within the software used for the audio processing transformations. Through the laptop the performer on stage transforms, creates and controls different aspects of the sound. Such a minimalistic approach, far from what is often anticipated, can easily disturb the said equilibrium that the audience may expect in a performance. Audiences are expecting the performer to *perform.* The performer, after all, is part of a communicational framework in performance (Leman, 2008), (Paine, 2008). It is important to acknowledge that not all listeners are *disturbed* by laptop performances. This is possibly due to the familiarity and previous experiences of those listeners that in their increasing frequency, may facilitate a different appreciation of the music, that results into moving away from the mainstream need and expectation to have the performer physically and actively engaged on stage.

Many suggestions have been put forward to overcome this issue when performing with technology. Caleb Stuart argues that the audiences need to shift their understanding from a visual focus into that of aural *performativity* when it comes to the live, computer-mediated digital audio environment (Stuart, 2003). Cascone suggests how the audience perception and expectations can play a significant role in the enjoyment of a laptop performance:

[13] Look at the composition by Julio d'Escriván (2009), *Ayayay!* Concerto for iPhone, pianola and orchestra.

> The more skill (hence authority) the performer can demonstrate, the more value is received by the audience. However, it is difficult for an audience to perceive the value of a performance where the artist could simply be playing back sound files on a device more suited for an office cubicle than a stage (Cascone, 2003).

Electro-acoustic or acousmatic music has a different approach towards the listener's experience. The term refers to use of electronic technology, mostly computers, to access, generate and explore sound material, digitally created or prerecorded, in which the loudspeaker is the main medium of transmission (Emmerson and Smalley, 2001).[14] Since there is no human performer on stage to perform any music, in the traditional sense, it is suggested that one may abandon any prior historical listening references that can interfere and alter the experience of the listener (Smalley, 1996). In that sense, the artistic intentions of the composer and the overall electro-acoustic genre are to introduce a new listening approach away from the performer-audience relationship. This approach benefits the views of those arguing for the necessity to shift towards an alternative listening mode. However, such transformation in our listening modes and habits is not something that can be addressed easily. Already over a decade ago, according to Cascone, this utopian proposition of radically changing gears in our listening mode has been a necessity (Cascone, 2003). When it comes to performance with performers on stage we should reconsider the way in which music and technology is presented and acknowledged by the audience. Performing with technology requires a performer with the ability to deliver what is intended in the composition. It is no longer the case that the audience must be educated in unfamiliar sounds or how the technology is use but rather the performers' ability to demonstrate the music through the technology towards the audience.

With the presence of a human performer on stage the audience is not only interested in just listening to the music as expected by electro-acoustic music. The listener wants to be influenced by the visual experience of that performance and see how the technology is integrated within the composition. It enables a communicative framework in performance with technology (Leman, 2008). In an interview with Anthony Huberman, Kaffe Matthews discusses her performance approach.

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[14] The terms electro-acoustic and acousmatic music are often interchangeable within the performance practice. Other terms also used such as *tape* and *fixed media*. For consistency, I will use the term 'electro-acoustic' throughout this thesis.

> When I'd been playing violin, people had looked at me as if they were watching this performing monkey: Oh God, look at that girl with the violin and all that technology! All I wanted was for people to turn their eyes off and get down to some listening. "No, there's nothing to watch here! (Huberman, 2004).

According to Emmerson, 'to be live is to have to respond because there are people listening' (Emmerson, 2007, p. 113). There is a need to respond to the audience in a way that the liveness can be justified within the composition and the technology used. This is well established in instrumental performances where the *performance* refers to the liveness itself and the audience is experiencing the performance as a whole rather than only the sounding music. Matthews continues by putting forward the importance of performance nuances when it comes to technology-mediated performances.

> It's funny because for a few years I'd been going, "Don't watch me, shut your eyes and listen. There's nothing to watch." But everybody does watch me. Well, a lot of people do. And I'm always saying that there's nothing to watch and gradually I've learned that there is. They watch my face. They watch me get surprised, fed up, angry and then excited. They stand over my shoulder and watch my computer screen. It all actually gives them a way into what's going on (Huberman, 2004).

In a live performance, sound and visual experience create a complex perceptual phenomenon that cannot be separated. With the traditional seating placement facing the stage, the audience is more likely to focus also on visual aspects of the performance. Traditional musical performances include visual experiences as well as audible. There is an inherent need to tighten visual and aural experiences to allow a coherent understanding of the causality of sound. With the absence of the stage performer in electro-acoustic music concerts listeners straggle to move away from their habitual experience of the causality of sound and music. Audiences often focus, where possible, towards the mixing desk, where the diffusion performer attempts to reintroduce the elements of *liveness* within the composition (Croft, 2007). We should rethink the role of technology in a similar way as in an operatic work that can be seen 'as a new and strategic attempt to integrate media of expression' (Leman, 2008, p. 139).

Controllers, for example, are most likely to have a very simple performance technique such as pressing switch buttons or moving faders. Due to the simplicity involved, composers often assume that most musicians are able to perform with the technology to the same extent as with their instruments.[15] Perhaps composers look at the technology being disconnected from having abstract musical properties due to the limited acoustic properties of the controller. The physical properties of controllers play a significant role in the way performers are able to establish, develop and sustain any musical and performative connection with it. Acoustic instruments can sustain fine audio-haptic feedback information to the performer. In doing so, the performer feels the responses of the instrument through aural and haptics modes based on the energy provided. Feedback from acoustic instruments creates a closed feedback loop system that allows expressive nuances in performances. The user is able to adapt and fine-tune future actions. A guitarist, for example, is able to tune the guitar through listening, judging and adjusting the strings accordingly. Figure 2 below shows a closed feedback loop system adapted to demonstrate the process of performing an instrument. The right hand side shows a generic process of the closed feedback loop described by Schmidt and Lee (2011). The referencing mechanism refers to the device or the object able of providing feedback. The executing level is when energy is applied to that object, and the effector level refers to the feedback result of that process. On the left hand side, the feedback from an instrument includes sound as well as tactile feedback from the vibrations of the body of the instrument. Such relationships, while fundamental to a performer's interaction with an instrument and the functionality of a musical instrument, receive little or no attention when performing with controllers and other technological devices.

[15] Case Study One, discussed in Chapter Four, provides evidence that this is far from being true.

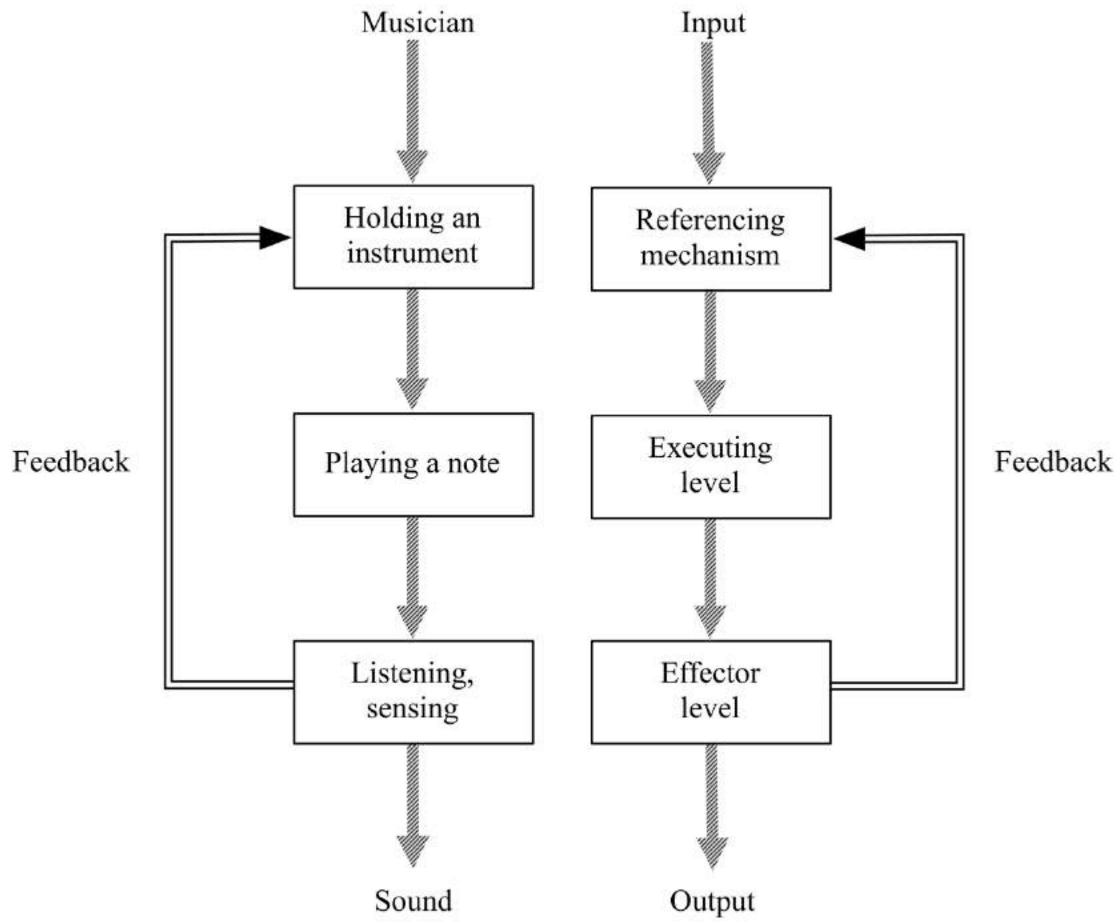

Figure 2 – The right hand-side depicts a generic closed loop system with everyday objects and the left depicts a closed loop system with a performer and an instrument (adapted from Schmidt & Lee, 2011, p. 136).

Through practice, performers create a habitual understanding of the closed feedback loop allowing them to experience fine changes embedded in the action-feedback relationship. Different hardware components of an instrument such as the mouthpiece, the reed or the strings are often noticeable by instrumentalists when changed. Any musician simply performing on a different instrument, even if it is the same brand and model, will be able to sense the fine difference within the haptic and aural domain. The feedback integration that exists naturally with acoustic instruments cannot be separated (Chafe, 1993). Instruments produce both acoustic and haptic feedback to the user and one cannot be experienced without the other. Interestingly, current technologies used in music performances such as sensors, foot switches and other controllers, have no *musical* tactile feedback properties. They are able to decouple aural from tactile feedback disturbing any formed habitual relationships. Due to the material used within such technologies, primarily plastic and metal, such devices are not able to have a vibrating and responsive function like acoustic instruments. Unsatisfactory tactile feedback is problematic for the trained instrumentalist as it contradicts the experience learned over years of practicing.

Mapping is another important factor when performing with technology. Mapping strategies are interchangeable between software and hardware allowing the composers to map any action of the performer to any musical function imaginable (Hunt and Kirk, 2000), (Hunt *et al.*, 2003). Whilst employing mapping strategies in a composition opens new creative possibilities, it does however create one complex problem from the performer's point of view. The performer struggles to establish a habitual relationship between the controller's functions and the musical expression. For example, a switch foot pedal controller may activate an envelope function for the reverb effect, or control the volume, or start the playback of a prerecorded audiofile. Even though all functions have very different and distinct sound results, the tactile feedback experience of pressing the pedal remains constant. In that manner, pressing the foot pedal is not engaging with the performer's actions. Being unable to engage with the device consequently results in impeding the formation of perceptual habitual relationships with the device as it happens naturally in acoustic instruments.

There is a need to create more natural experiences when using technology in an attempt to create a more expressive framework between the technology and the performer.

2.3 When Performing Computer Music

The role of the performer with technology has been shifted and it is unable to sustain a coherent meaning as it does in acoustic performances. There are some common characteristics that enable a wider understanding of the terms instrument and instrumentalist.[16] The physical presence of the performer on stage, the view of the instrument and the cause-effect relationship are justifiable through the audiences' eyes and ears. However, with technology audiences are presented with a mystery to solve about the role and function of the performing musician.

It is important to examine how performance practices with technology are acknowledged and how they are experienced fro their aesthetic and artistic views. *Live*

[16] A pianist is the person playing the piano and a cellist is the person playing the cello.

Coding, *DJing*, and *Laptop performances* have accepted practices with specific idioms and approaches through the embedded functions of the technology they use. Laptop performances for example, address not only the use of the instrument, the laptop, but also include other metaphors of artistic intentions that are embedded and exist through the act of performance.[17] In Live Coding, the term puts forward the practice of coding on the fly and it is unlikely for audiences to hear something not digitally created. The successful application of terminology and practice of those sub-genres is due to the way their artistic intentions are embedded within the technology able to establish a performance practice, a practice that embraces the use of technology, hardware and software, through its artistic musical outcomes.

In recent years there has been an increase of successful bespoke instruments, interfaces and controllers enabling expressive nuances while performing with technology (Marshall and Wanderley, 2006).[18] The majority of those new interfaces, instruments and controllers often suggest new performance paradigms that enable the composer to become the performer and the performer to become the composer (Waisvisz, 1985), (Nichols, 2002), (Palacio-Quintin, 2003), (Overholt, 2005), (Räisänen, 2008), (Ciglar, 2010). In a similar manner, the instrument provides a framework that allows performers to be transformed and become a part of the instrument and the instrument to become part of the performer. Instrumentalists can offer insights about their performance practice with the technology and are often required by composers to help them understand how the technology can be performed (Nicolls, 2010). Performers can provide composers with the technical and physical limitations of how the instrument performs with the technology. The ability to integrate the technology with the artistic intentions of the composer suggests the creation of a new type of performer, the *hybrid performer*.[19]

Furthermore, Leman suggests how listeners could possibly have in mind a representation of the symbolic structure of the music that they are then able to use as a reference to compare and decode expressive performance nuances (Leman, 2008, p.143).

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[17] For instance audio material will most likely be heavily processed, loud and noisy as the artistic metaphors are focused around the ways composers/performers can combine, transform and manipulate sounds live on stage in an artistic manner through the laptop.

[18] New Interfaces for Musical Expression (NIME) and International Computer Music Conference (ICMC) welcome such unique interfaces.

[19] In the composition, *Barbaróphonos* discussed in Case Study Four, the performer is actively involved in the creative process. *Live Mechanics*, a composition for piano and interactive electronics discussed in Chapter Five is a showcase of the new *hybrid* approach, where composer, performer and the instrument are part of the same.

He goes on to propose the ways in which the expressive intentions of the performer may be also decoded through corporeal resonances implied within the sonic moving form of the performance. A similar assumption can be made when examining technology-driven performance. Listeners often struggle to decode such symbolic structure and the corporeal sonic movement within the performance-technology framework. With the absence of a defined performance practice in live electronics, as happens with other music genres such as Live Coding or DJing, the audience struggles to decode any symbolic or artistic meaning from the music. With ever increasing bespoke instruments and controllers the audience is not able to reference and compare the role of the performer and the instrument as there is nothing prior to that with which to compare it. In addition, decoding body movement as expressive metaphors in computer mediated performance is not straightforward. The individuality of the composition allows the performer to become a part of the instrument that can provide and suggest other aesthetic references in music experience. This prompts us to propose new ways of experiencing the expressiveness of such hybrid performances by the audience.

Further examination of the nature of live electronics provides us with a coherent view of the performing aspects and the relationship that exist between the performer and the technology. To do this, it is necessary to touch upon similarities with how electroacoustic music is reflected to the composer and the audience. This discussion will lead us to understand why live electronics should be acknowledged as a concept in computer music and not as a music genre. The term *Interactive Electronics* is my attempt to distinguish and clarify the performer's role and performance practice of the compositions that form part of this thesis.

2.3.1 Similarities with Electro-acoustic Music

Even though both fields of electro-acoustic and live electronics have similar use of technical creative tools including the reproduction and transmission of sound, they are very different in terms of performing practice. The main difference between the two is the lack of human performers on stage. The human presence on stage carries its own dynamics, historical referencing and ecological background, which should always be under consideration. However, in live electronics the communicative role of the stage performer is often underestimated.

As discussed earlier, Smalley suggests the need to change our listening habits and aesthetic approaches when listening to an electro-acoustic composition (Smalley, 1996). He argues that abandoning any prior musical reference originating from the causality of sound is required and acceptable because the music exists only within the medium of the loudspeaker (Smalley, 1996), (Emmerson, 2007). Due to its nature, the genre does not necessarily require the presence of a piano and pianist in order to hear the piano sound. The listener should only focus her listening to that sound as a sound like any other and not referring to prior knowledge and assumptions about the way that piano sound might have been produced. Smalley says that by renouncing any prior reference outside the transmitting technology, the loudspeaker, one can convey different listening experiences and artistic approaches that are required to appreciate and understand this musical genre. While this is true, it is at the same time a huge task for a new listener. Listeners cannot immediately abandon any prior knowledge and experience of sound and the creation of sound or at least the familiarity of sounds produced on stage through visual observation and listening. Perhaps it is assumed that time constraints are involved within that statement. Over the long-term it is possible to calibrate and readjust our ears into new listening modes through habit and experience and other extrinsic listening influences.

> A piece of music is not a closed, autonomous artefact: it does not refer only to itself but relies on relating to a range of experiences outside the context of the work. Music is a cultural construct, and an extrinsic foundation in culture is necessary so that the intrinsic can have meaning. The intrinsic and extrinsic are interactive (Smalley, 1997).

Previous listening experiences and influences from other cultural and technology-related experiences, impact the perceptual understanding and experience of the music. Similarly in the context of live electronics cultural, technological and aesthetic concerns should be digested within the compositional process. There is a need to recalibrate and readjust our performance practice experience under which live electronics mostly depends.

A prime difference between electro-acoustic and live electronic music performances is the stage at which the audience actively has to look. The *stage* brings with it the whole history of performance practice especially when acoustic instruments are involved. Moreover, the performer's gestures are a powerful and meaningful tool that can nourish the audience with further nuances of musical enjoyment making the visual reference a necessity (Leman, 2008). John Croft describes both the difficulties in electro-acoustic music and in live electronics.

> This acousmatic character is often cited as one of the difficulties with the reception of acousmatic music – not, it has to be said, so much because it erases the labour of production, but more often because ‘there is nothing to look at’… In short, we expect a sound proportionate to the energetic characteristics of the performer’s action …[...] we expect the sound to have a more or less transparent relation to the properties of the sounding body we see before us (Croft, 2007, pp. 61-62).

In electro-acoustic music the difficulty for the audience comes through the absence of the labour of production of sound that excludes visual representation and gestures in creating that sound. In live electronics the music often *suffers* from the *bad labour* of performance, the technology is not directly linked with how the sound is created and transformed on stage. Croft describes further the multiplicity of approaches in live electronic music, suggesting a more detailed taxonomy of five different paradigms derived from the performance and compositional practices (Croft, 2007). This proposed approach offers variable levels of interaction between performer and technology, where all paradigms include a performer on stage.

- ***Backdrop***: Computer electronic sounds function as background. Even though they might have reference points between the two (performer and computer), these are not perceived as causal of each other.

- ***Accompanimental***: Sound from the loudspeaker functions as a kind of a passive accompaniment. This might include triggered sound files and/or live processing of an accompanimental nature (such as harmonisation).

- ***Responsorial/proliferating***: Sound from the loudspeaker functions as a kind of an active accompaniment with the acoustic sound. This might include treated precomposed events or/and live processing of the acoustic sound.

- ***Environmental***: The creation of acoustic environments (real and unreal) through electronic means such as reverberation, delay, resonators.

- ***Instrumental***: The performer plays the instrument providing an interactive relationship with the electronics. The electronics may include, footpedals, button switches, sensors or other custom made and commercial controllers embedded on the instrument or becoming part of the performer’s movement (Croft, 2007).

These paradigms can be combined offering a coherent classification of live electronic music performances. The *Instrumental* paradigm is by far the most interesting from the point of view of the performer, composer and audience. Composers are open to unlimited combinations based on the instrumentation, the computer's sound processing ability, the use of the other taxonomies, and the overall mapping approach. Such a plethora of combinations can become a limitation for composers. One may consider this as analogous to the limitations of an acoustic instrument. Joel Ryan describes how such limitations have always been considered as an initiating factor for creativity.

> From the Serialists to John Cage to the experimentalists of the post war generation, the project has been to deny the habitual or the hackneyed by developing techniques to restrain or condition the immediate process of choice. Whether the problem was seen to be the limitations of traditional technique or the excesses of romantic self expression, the solutions were either to adopt a formal method to distance choice or to choose a medium for which there was no existing habit. With computer music you get both: the distance comes for free but a distance which can only be viewed as problematical. (Ryan, 1991, p. 3)

The *problematic* flexibility of the *Instrumental* taxonomy as described by Croft allow us to propose a sub-genre within the concept of live electronics. *Interactive electronics* make possible the wider formation of role and experiences through interactivity between the system and the instrumentalist.

2.3.2 Interactive Electronics

The suggested interactive electronics term may exist as a performance practice within the live electronics concept. Interactive electronics assumes and values interaction as an important and integral part of the compositional and performing process. This includes the way composers and performers address interaction with the computer system. It puts forward the idea and the ideal of performing music through interacting with the technology.

On the contrary, live electronics refers to the idea and ideal of performing music with the support and use of technology including hardware and software. In a concert labelled as *Live Electronics Concert* held at Birmingham Conservatoire in October 2012, one could clearly notice through the programme notes the ambiguity allowed by the term.[20] Composers taking part in the concert titled their pieces in a variety of ways trying to impart their own compositional and performance practice based on the technology integrated in the piece. This included wordy composition titles specifying *for clarinet, piano and electronics*, *for piano and fixed media*, *for piano and tape*, *for piano and SuperCollider*. For the unfamiliar audience these affixed titles can only confuse. With no hardware technology that can be associated entirely with live electronics, the audience struggles towards creating an abstract meaning of the performance and the music. The open-ended performance practice diminishes the formation and support of live electronics as a music genre.[21] The term live electronic has been used and debated since the 1960s within variable modifications (Emmerson, 1991), (Manning, 2004). We should rethink its interpretation as it may provide a coherent understanding of today's compositional and performance practice in the wider technology-mediated performance. Clarifying and redefining the term is necessary not only for this thesis but also to point out the significance of interaction and the instrumental taxonomy within the computer music framework. We need to provide a term that could reinterpret and pinpoint the performance practice in computer music thus enabling better description of the functionality of the electronic and computerised components.

The word *live* in live electronics impacts the purpose and meaning of the performances. Perhaps live lost its energetic *liveness* and became a description of simply being alive on stage, which has no underlying musical meaning since being on stage requires a living performer. Replacing the word live with interactive, one can make assumptions of a basic interactive relationship between the live stage performer and the computer system. Such interaction might be bidirectional interactive relationships through aural, haptic or visual. Similarly, referring to an interactive installation, for example, there is an underlying assumption that suggests the use of interactive elements and functions as a part of the installation. The word interaction incorporates an assumed liveness as an integral part of the human experience as to be human is to be interactive. On the contrary, the term *live installation* could assume how the artist is crafting the installation live during the performance. Furthermore, Live Coding manifests and defines its context and creative practice through the ability to code live on stage.

[20] Recital Hall, Birmingham Conservatoire, Birmingham City University, 22 October 2012.
[21] Music genre refers to the principle of repetition through the context, function and community validation within the social domain and not simply on formal and technical regulations (Samson, 2013).

Live electronics throughout its history has been undoubtedly the ideal descriptor for shifting towards the new idea of performing practice with technology.

> By the early 1960's, two additional branches had been added to electronic music, "computer music" and "live electronic music." Both appear to have developed as reactions to the limitations and slow pace of tape realization, with its necessary requirements of splicing, mixing, and re-recording (Cross, 1968).

Composers and performers of that period started using technologies to create music. They presented the underlying meaning of the term and were able to reflect the social and cultural needs of the period they were in. This enabled a common language and understanding between the musicians and the audience but also in the search for any artistic and creative implications that are embedded in performance. According to Cross (1968), *electronic music* referred to the electrical elements that were embedded within the devices they used. Today, the term *electronic music* refers to the digital creation and manipulation of sounds with computers and often addresses styles and genres of music such as techno, house and electronic rock. Early approaches on the use of technology from the 1960s, such as the *Stockhausen Ensemble* and *Gentle Fire*, would comprise the use of electronic hardware devices that would enable them to treat sounds live on stage (Emmerson, 1991), (Emmerson, 2000), (Davies, 2001). Hugh Davies in the 1970s described live electronics as the transformation of electronic sounds whose sources fall into four categories as follows:

- sounds played on conventional instruments or quasi-conventional invented instruments;
- on found or adapted objects or equivalent noise-making invented instruments;
- on electronic oscillators or instruments which, like synthesizers, may incorporate their own modification devices and;
- sound replayed from earlier recordings which more recently would include samplers (Davies, 2001).

These categories were focused mainly on the way physical production of sounds takes place through the instruments rather than the performer. In David Behrman's piece from 1966, *Wave Train* for piano resonances and feedback, the composer placed guitar pickups on the strings of the piano and connected to guitar amplifiers under the piano's soundboard (Collins, 2007). By controlling the created feedback loop with the audio signal, it was possible to perform and control different sound textures.[22] Gordon Mumma built his own circuit boards allowing them to 'produce and process sound in reaction to input from acoustic sources and electronic controls' (Collins, 2007, p. 42).[23] Electronic devices and electric circuits were physically presented to the performers and the audience. The use of electronic hardware *live* on stage had an underlying social validity towards the listener's perception. Whilst live electronics initially addressed the use of electronic devices live on stage today such meaning is blurred and unable to describe a rational performance practice.

Emmerson debated on a similar issue between the live and real time performance approaches in his article titled '*Live* versus *real-time*' (Emmerson, 1994). The debate and argument was apparent with the upcoming technology of the computer's sound processing and its ability to transform sounds in 'real-time' and the increasingly abstract meaning of 'live' in performance. Twenty years later the term 'real time' is rarely used to describe a performance practice or the used hardware. I argue once again the liveness in live electronics and how it has shifted from being initially a performance practice to becoming a performance concept.

2.4 Interactions and Feedback

In accepting the term interactive electronics we must consider feedback as an integral part of the interaction process. Feedback is a vital component that allows any form of musical interaction to exist. Interaction in music is undoubtedly a necessity; however, first we need to establish a working definition of the word *interaction*, what it meant and how it is realised. The intention is not to provide a definitive statement about what is interaction, but rather to examine the wider relationship between feedback and interaction in music making. Examining these meanings within the interactive electronics framework will enable us to set boundaries for the artistic aims of the genre and how it might be applicable to performers and composers.

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[22] The composition requires two performers, the pianist and the controller of the feedback loop. Both are on stage and visible to the audience.
[23] See composition *Hornpipe* (1967) by Gordon Mumma.

‘Interaction is a two-way street’ (Winkler, 1998, p. 3). This short description captures the essence and meaning of interaction in music in a comprehensive way. The interaction should take place between at least two agents within specific time duration. In this case, that is the latency between the initiation from performer and the computer processing. To simplify the underlying meaning of interaction in music we should step back and examine interaction through the feedback experience.

Feedback and the response time within an interactive process have a significant role in the relationship between the initiator and the recipient. There are variable time thresholds that can indicate whether the initiated interaction has had any effective consequence. This is commonly referred as *response-produced* feedback where the initiated action serves as a trigger in a chain sequence (Schmidt and Lee, 2011, p. 178). Time in such a sequence of events is important as it allows the chain reaction that forms interaction. In a situation where the feedback chain is not important time has little or no significance; for example, when a conductor provides verbal feedback to musicians about the rehearsal, time is insignificant in that respect as it does not affect the music directly. Feedback might have been for the rehearsal that took place the day before or ten minutes ago. Depending on the context of interaction, time affects overall process and the result. When asked for directions, one is expected to reply within a certain time frame otherwise the response might be considered irrelevant. A delay of 200-300 milliseconds is common in a conversation as this delay relates to the time needed for the listener’s sensory system to get the relevant aural information to the brain (Dix, 2008). Response time is important in the way feedback is understood and affects our actions.

In performance the expressiveness of music cannot exist without feedback. Without immediate feedback from the instrument, musicians would be lost and unable to monitor their actions and expressive decisions would not be possible. In music technology and in particular in interactive electronics, feedback has a significant role. The composition should make available those elements that can retain important feedback qualities, enhancing the experience of the performer. It is important to examine further how vibrotactile feedback and haptics are applied within the performance framework.

2.4.1 Haptic Senses

William Schiff refers to haptic perception as the ‘acts of reaching, touching, grasping and manipulating’ (Schiff and Foulke, 1982, p. 82). Within the field of Human Computer Interaction (HCI) haptics describe the mechanical signal able to stimulate human kinaesthetic experience and touch channels (Hayward *et al*., 2004). Haptics in HCI often simply refer to information that is not visual or auditory (MacLean and Hayward, 2008). Such actions, in particular when handling physical objects, require a closed loop system as the feedback results will determine precision and fine detail adjustments. The term haptics includes the functionality of the receptive organs of the human body. Hsiao and Yau suggest examining haptics under two categories:

(a) proprioception or kinaesthetic awareness
(b) information sensed via the skin (Hsiao and Yau, 2008).

Kinaesthetic awareness refers to the knowledge of position, state and movement of the human body: one’s position in space as well as the position of arms and legs in relation to the body. It is the knowledge of the internal state of the body, through information gained from the vestibular system, muscle receptors (including the muscle spindles and the Golgi tendon organs), joint receptors, and the cutaneous receptors (Oakley *et al*., 2000), (Hsiao and Yau, 2008), (Utley and Astill, 2008), (Schmidt and Lee, 2011). The perceptual experience acquired from the skin is significant to the haptic process. It may include information concerning temperature, pain, pressure and vibrations (Verrillo and Gescheider, 1992), (Burdea, 1996). In addition, touch and tactile feedback provides information about the direction and movement of an object as well as the ability to signal simultaneously separate information to the body such as pain, pressure, heat, cold and other chemical stimuli (Schmidt and Lee, 2011, p. 156).

These two categories, kinaesthetic and tactile, even though we are able to separate and address them in different contexts, should not be understood as two separate sources of information but as things that tend to overlap and influence each other. Von Békésy, demonstrates that vibrations can be sensed through deeper receptors in the joints proposing that the perception of vibrations is a variation of kinesthesia (Krueger, 1982). Loomis and Lederman, suggest that due to the ability of tactile and kinaesthetic senses to overlap and influence each other, they should be considered as a single separate sensory entity: the 'haptic perception' (Loomis and Lederman, 1986), (Lederman and Klatzky, 2009).

Physical contact with objects provides both fine detail information about their texture gained from the tactile senses such as roughness and temperature as well as information about shape and weight derived from the kinaesthetic senses. The same process takes place when performing music. Physical contact with the instrument provides information about size, weight, material, texture and temperature, all of which comprehend a coherent view towards the instrument-performer relationship. The brain interprets bodily perceptions from internal and external organs to create a coherent understanding of the surroundings. According to Damasio this has further implications in our emotional and social behaviour:

> Under no normal condition is the brain ever excused from receiving continuous reports on the internal milieu and visceral states, and under most conditions, even when no active movement is being performed, the brain is also being informed of the state of its musculoskeletal apparatus. The brain is truly the body's captive audience as I noted. (Damasio, 2000, p. 150)

The interpretations of bodily perceptions are constantly adjusted and reexamined, and thus constantly affecting our perceptual understanding. For the performer this constant haptic information from the instrument enables the control of detailed expressive nuances during performance.

2.4.1.1 Motor Learning Through Tactile Feedback

Performers' gestures may include visual cues with similar structural information as the generated sound, including phrasing and tension that the audience perceives as a part of the performance experience (Lazzetta, 2000), (Vines *et al*., 2003). The experience of a musical performance does not imply only sound in that respect, but also elements from the visual feedback. Performing music involves expressive nuances that come from the kinaesthetic and tactile perception of the instrument-performer relationship. Learning an instrument includes the development and control of the received tactile feedback information from the instrument that allows for the creative execution of phrasing, articulation and other stylistic details. Xenia Pestova, a concert pianist, discusses the necessity of such expressive nuances in performance:

> The ability to be creative with phrasing, articulation and stylistically acceptable breathing or flexibility are just some of the elements that make for an expressive performance and create a satisfying experience for both the performer and the audience. Compositions that allow for these components to be structurally integrated tend to be the most satisfying to play (Pestova, 2008, p. 68).

The challenges in terms of tactile expressiveness such as articulation and phrasing, are fundamental for a satisfying performing experience. Such a claim can be demonstrated with the countless available performances of Johann Sebastian Bach's *Well-tempered Clavier*. All expressive nuances are left to the decision of the performer. The different articulations, phrasing and other expressive approaches by the performer's stylistic personality are reflected on the audiences' enjoyment of the performance. As a listener, the satisfaction is not only gained through the harmonic and melodic relationships of the piece but also through the way the performer interprets these expressive nuances.

Apart from the tactile feedback experience received by the instrument, augmented feedback contributes to the development of a musician, providing an indirect relationship with the tactility of the instrument. Visual and auditory feedback can be taken in consideration as an integral part of the motor learning approach. Such an overlap of tactile feedback with visual and auditory feedback in musical pedagogy can have substantial results on professional development. Music teachers were able to notice more sustainable learning outcomes for students that record the way they practice and perform, both audio and video, in order to discuss it later as a form of augmented feedback (Sloboda and Howe, 1991), (Hallam *et al*., 2012).

Furthermore, we should examine how feedback from other senses can substantially overlap and augment the sense of perception in an instrumental performance. Visual and auditory senses will be discussed as to the ways they augment and supplement each other and in particular the tactile sense.

2.4.2 Augmenting the Senses

We have an underlying ability to prioritise certain sensory information over others. Vision is able to provide information about movement, placement and shapes of objects in the environment including the perception of movement of one's body. In low-light conditions there may be a significant limitation in undertaking visually-oriented tasks. The limited visual information received subconsciously awakens other facilities such as the haptic and aural senses. For example, in a dark room, one subconsciously extends her hands to *see* what is in front of her, creating a mental representation of the space.

2.4.2.1 Visual and Auditory Experience of the Surroundings

The perception of one's body and its surroundings comes from the visual and tactile impressions of 'something that is uniquely and continually *here'* (Gibson, 1950, p. 228). James J. Gibson, one of the twentieth century's leading figures on visual reception, suggests that through vision we can *feel* the visual scene and the environment around us. We are able to gauge distances in a room or how fast an object is travelling through visual perception. According to Gibson, spatial perception is directly related to the tactile and kinaesthetic senses (Gibson, 1950). He argues that objects, through experience, embody a truth that is capable of being grasped, pushed and touched. He mentions that 'we learn to trust our vision of the table as being there, for instance, because we can always go over and touch it' (Gibson, 1950, p. 223). Montagu provides a similar illustrated example.

> What we perceive through the other senses as reality we actually take to be nothing more than a good hypothesis, subject to the confirmation of touch. Observe how often people will respond to a sign reading, 'Wet Paint'. Quite frequently they will approach and test the surface with their fingers for themselves (Montagu, 1986, p.100).

Such *visual trust* about the reality of the surroundings comes through the tactile feedback experience. This experience may take many forms as the overall haptic experience is a combination of different sensations. When *Virtual Reality* (VR) became possible in the early 70s, one of the striking observations was how it was possible to distort one's perception through visual perception, such as walking in the streets with two-metre long hands (Burdea, 1996). This egocentric approach of knowing the self and the body comes from what is known as visuo-tactile integration, the concept that visual senses are enhanced when integrated with the tactile and kinaesthetic senses (Damasio, 2000), (Saxe *et al*., 2006).

The sense of hearing has an equally important role in the overall perception of spatial understanding. Aural perception provides information about our surroundings, and particularly objects that we encounter, in a similar manner as visual perception. Auditory perception can provide information about different states of the environment. For example, the sounds of footsteps when jogging provide subconscious information concerning the type of the terrain or the height of stairs (Schmidt and Lee, 2011). Auditory perception can also be associated to physical and tactile actions. An increasing number of handheld electronic devices such as mobile phones and tablets provide artificial audible feedback in an attempt to mimic the audible feedback that may occur naturally from those actions. When typing on a touchscreen device, there is no auditory feedback from the physical contact as found with the traditional typewriter or with computer keyboards. The auditory feedback enhances and confirms the actions of the user. Similarly, this applies to the artificial sound of a shutter on a portable digital camera. The sound of the open/close shutter is artificially produced as there is no mechanical component within a digital camera to produce that sound. The shutter sound informs the user and others around her that a photo was taken. The auditory associations that were previously established with pre-digital cameras are maintained. Both of these examples demonstrate the importance of auditory feedback in relation to our actions. The auditory feedback associated with one's action is similar to what Gibson describes as the combination of tactile and kinaesthetic senses with visual perception. In ta similar manner, auditory perception has a bidirectional influence with tactile and kinaesthetic senses. The human ability to correlate actions with sounds is fundamental in musical performance experience and in particular within technology mediated performances. For a convincing performance, time differences in the action–reaction relationship between aural, tactile and visual cues are essential (Emmerson, 2007, p. 109).

Apart from the ability to associate sounds with actions, the sense of hearing is able to localise sounds in space as well as able to understand the different sizes and types of spaces we inhabit. Knowing where the sound is coming from is an important feature of feedback information in relation to our surroundings. For instance, through vision one must actively look in the same direction where an event is taking place, in contrast with aural sense, where one can perceive the position of the event without looking. Aural perception is as important as vision in its own right and should not be compared as there are different qualities that are driven by each sense.

Whilst visual, aural and haptic senses retain different characteristics and qualities, all of them contribute to our perceptual understanding. It is important not to examine these senses as different entities but through the ways in which they gain information from an action. Music performance, especially with technology, depends upon a specific set of the senses. The style of the performance and the intentions of the composer determine how multimodality of the senses takes place.

2.5 Active and Passive Interaction

Performing music is an interactive art. Interactive agents associated with music performances can be addressed as either *passive* or *active*. Passive agents within an interactive system encompass all musical instruments, computer programming and hardware that cannot initiate the process of interaction. An active agent is the performer himself with the ability to make decisions within the system, influence and be influenced through the interactive processes as well as to self-initiate an action. For example, the violin as an instrument is not able to initiate any form of interaction unless the performer applies energy to it. A computer program cannot self-initiate unless it is programmed to do so. Bongers suggest that cognition within a system makes the difference between a reactive and interactive system (Bongers, 2000).

> Interaction can be defined as 'mutually influential', that is, both partners in the discourse (whether machine or human) will have changed state, frame of mind, or views after the interaction (Bongers, 2006, p. 186).

Even though musical instruments are considered passive agents and thus reactive, the physical material and structure of the instrument often supports complex mapping responses of the produced sound. These endless reactive possibilities by the instrument support an interactive relationship between the two, the active (human) and the passive (instrument) agent. Joel Chadabe, as early as 1975, suggested similar metaphors in terms of active and passive computer systems.

> If a computer is used to perform a previously finished composition, it is not a variable in a composing system because is not used in composing. If a computer is to function as a variable it must have an identity. Its role must be *active* rather than *passive* (Chadabe, 1975) [*my italics*].

It is necessary to examine further how the active and passive agents are formed within the proposed music genre of interactive electronics.

2.5.1 Musical Interaction

Earlier discussion suggests how live electronics should be viewed as a concept of computer music under which interactive electronics may exist. Whilst *live* suggests an abstract meaning of being present and live on stage, interactive electronics may suggest the interactivity between two or more agents and the liveness that arise as a product of that interaction. Guy Garnett suggests two approaches to achieve the desired interaction between performers and computers. He addresses interaction as a process in which 'the performer's actions affect the computer's output or the computer's actions affect the performer's output' (Garnett, 2001). Even though this is a general and simple approach, it immediately shifts the meaning and purposes between the active performer and the passive computer on stage to incorporate a bidirectional interactive relationship. The computer system here refers to all electronic components and controllers used to control the computer processing functions.

Instrumental music, as a performing art, assumes interactivity between performers as an integral part of the process. According to Jordà, there should be a similar *self-evident* interactivity with computers (Jordà, 2007, p. 91). An instrumentalist controls every musical nuance of the instrument physically. Every small or large variation of control can affect the sound of the instrument; however, the instrumentalist is able to achieve such a high level of control due to the fixed mechanical structure of the instrument. The process of systematic practice provides a framework in which habitual relationships are established and defined. With computers, all the musical nuances by no means have a fixed relationship with the performer's actions. On the contrary, the mapping strategies constantly change between controllers, functions and processing, making mapping a creative and compositional feature within computer music performances (Hunt and Kirk, 2000), (Hunt *et al*., 2003), (Fiebrink *et al*., 2010). Mapping strategies employed in any computer music system determine the formation and the succession of musical interactions. From the performer's point of view the creative role of mapping does not allow the development of sustainable habitual relationships. The interchangeable strategies between functions and the produced sound weaken the relationships between the technology and the performer.

In interactive electronics, the performer's physical effort should be demonstrated in a way to communicate to the audience the artistic and abstract relationships derived from the composition. Composers should be able to provide the performer with clear cause-effect link of the *emerged* sound since time is essential for the audience to establish interaction through the abstract relationship between visual and aural information (Emmerson, 2007, p. 109). This brings back the significance of time as discussed earlier. From the audience point of view, instrumental performance has always been very clear considering the cause-effect relationship. The movement of the performer is tightly related to the formation of sound where cause-effect already exists with the instrument.

Shiau-uen Ding points out the necessity of synchronisation and cues when performing piano pieces with fixed media (Ding, 2007). Fixed media compositions that rely on performer's listening judgment for initiation should not be considered as interactive electronics as the performer's input has no effect on the resulting sound. Belet comments that fixed electronic sounds are relentless and unforgiving as they simply play on regardless of the state of the performer (Belet, 2004). Other performers find the fixed media approach unnatural as this is only a one-way interaction with no influential feedback components. On the subject of interactivity the flautist Elisabeth McNutt points out how fixed media and instrumental pieces create a *temporal prison* (McNutt, 2003).

> For the player, performing with fixed accompaniment is like working with the worst human accompanist imaginable: inconsiderate, inflexible, unresponsive and utterly deaf (McNutt, 2003).

Such a passive form of interaction carries problems of integrity of the performer's actions towards the listeners. The aim here is not to judge any compositional approaches but rather to clarify the essence of human-computer interaction under the confines of technology mediated performances music presented in this thesis.

Through interactive electronics performers are able to interact with the computer system in a non-predetermined way that allows them to creatively interpret the music. To do so vibrotactile feedback is vital in sustaining a closed feedback loop between the computer system and the performer. For composers, the ability to interpret and use feedback not only as byproduct of interaction between the performer and the system, but also as a communicative and dynamic component proposes new compositional techniques within interactive electronics. Through the felt vibrations performers and composers are able to create abstract meanings and representation of the musical interaction with the technology, thus suggesting new ways of realisation of the music.

CHAPTER Three

Perception and Vibrotactile Feedback

Chapter Three examines further how perception and in particular how vibrotactile sense can become an organic parts of expressivity and creativity in music performance. The theory and practice of sensory feedback presents a framework in support of interactive electronics performances.

Firstly, through the work of Maurice Merleau-Ponty and Don Ihde, the phenomenology of perception will be examined and the way in which technology is reflected in bodily experience. The role of habit will also be discussed, looking at how latency is involved in the formation of habit, feedback experience and interactive relationships. Furthermore, J.J. Gibson's affordance theory will be examined considering how tools and objects can have interchangeable qualities through their feedback and habit properties. Secondly, vibrotactile and haptic applications will be studied to provide us with a coherent approach when interacting with the technology.

Different theories around this field will be examined while looking at some examples within the confines of human perception. This conversation will lead us to a broad understanding of the significance of feedback and vibrotactile feedback in our everyday experience and interaction as well as the importance of feedback in specialised activities like performing music.

3.1 Cross-modality of Perception in Technology

Technology-mediated performance and in particular interactive electronics may benefit from incorporating vibrotactile feedback rather than relying on visual and aural feedback alone. For performers, visual feedback from a computer screen is not considered as important as haptic and aural feedback and often can be a distraction during performances (Berweck, 2012). However, this is far from the case for many technology-driven performance genres such as *Laptop Performances* and *Live Coding* where the focus is primarily on the computer screen or a projector screen.

Visual distractions are evident in other performance-oriented tasks outside music that include the handling and use of technology. When flying an aeroplane, which requires high levels of concentration, it is vital to balance the visual information in the cockpit making sure that warning signals and alerts are most effective. Interestingly, when vibrotactile feedback is embedded as a part of the warning signal, it can help to *balance* a situation of overwhelming visual feedback (Gray *et al.*, 2009). Research conducted by Gray *et al.* demonstrates how tactile and auditory cues may reorient visual attention more effectively than visual warnings alone and thus contribute to the decrease of the reaction time from the user (Gray *et al.,* 2009). A study by Tan *et al.* shows how vibrotactile cues, placed on the user's back, can reorient the visual attention with the reaction time decreased by an average of 41% (Tan *et al.,* 2003). Additionally, McGarth *et al.* illustrate how the *Tactile Situation Awareness System* (TSAS) is able to increase pilot's *Situation Awareness* (SA) as well as decrease the visual workload in complex flight conditions (McGarth *et al.,* 2004). The integration of visual and tactile feedback modalities encourage higher and more effective performance levels.

Similarly, aural and tactile feedback modalities enable improvements of operations on handheld electronic devices over entirely visual feedback (Poupyrev and Maruyama, 2003), (Chang and O'Sullivan, 2005). Hoggan *et al.* argue that all touchscreen devices should incorporate vibrotactile feedback as it significantly improved finger based text entry (Hoggan *et al.,* 2008). The study suggests that overall performance can be improved even further with high specification of vibrotactile actuators. Looking at music performances, Hayes uses vibrotactile feedback in her composition *kontroll* that allows her to become *free*, staying away from the computer screen and focusing more on performing the piano. Through vibrotactile feedback she retains the information needed from the computer system to perform (Hayes, 2011). Whilst the computer screen instantly provides a variety of meaningful information about the performance status, it is not always the best option for the performer.[24]

The environment and the surroundings provide information that affect our experience. Hoggan *et al.* discuss how different environments, particularly those with extensive noise and vibrations, affect feedback information obtained from the use of mobile phone devices (Hoggan *et al*., 2009). Environmental feedback, including a non-initiated feedback, can mask and override the received feedback information that results in what we might call a *non-normal* feedback experience. In a live performance when the performer on stage is not able to hear what they perform there is tendency to play louder than normal to restore the *non-normal* feedback experience.[25] Hoggan *et al.* goes further to suggest a solution based on the currently available technologies. Sensors found on mobile phone devices, such as accelerometers, gyroscopes and microphones, can be used to monitor the state of the environment at any given time in order to calibrate and provide the most suitable and effective feedback information to the user (Hoggan *et al*., 2009). In essence, the technology should be able to receive, judge and engage based on environmental feedback. What is interesting here is how the proposed *solution* for the apparent *problem* is in essence to solve the technology *with* technology.

The way one may experience such cross-modality of perception may not always be intentional and selective. The well known *Cocktail Party Effect* examines the non-selective ability to block sounds from the environment (Mitchell *et al.,* 1971) This is mainly due to the ability of our auditory sensitivity to detect time differences between the two ears (Mitchell *et al.,* 1971). When holding a conversation in a noisy environment we ignore noises from the crowd but also try to focus our hearing while looking at the face and lips of the speaker to gain additional information (Wassenhove, 2004). Our senses can shift focus and attention to allow the best possible integrated feedback experience as well as provide a coherent understanding of our environment. We do not have two

[24] Case Study Three examines, from the performer's perspective, different performing approaches and practices that are often employed within the context and concept of live electronics involving the use of a computer screen.

[25] An everyday example would be a two-person conversation at a construction site. The noise from the environment masks the voices and the tendency will be to speak louder in order to be heard.

separate experiences from our senses such as sound and vision, instead we experience an integration of the senses. A dog's bark produces visual as well as auditory feedback as a result of the same activity. We do not experience the opening of the mouth and the sound of the bark as two perceptions of the same thing but rather as one entity (Romdenh-Romluc, 2011, p. 67). This natural characteristic, being able to experience two phenomena as one, is due the way we can relate such phenomena through time and latency thresholds that are embedded in the senses of the human body.[26]

The *McGurck Effect* illusion is another example that clearly shows how our senses, while working in conjunction to provide us with a coherent meaning, also allow for a possible misreading of the given information. McGurk and McDonald demonstrated the possibility to overcome the given sensory information through the following experiment. Subjects heard the word *Ga* with their eyes closed. When seeing the person's mouth on a video screen, producing the word *Ba,* they could hear the word *Ba* even though the sound remained unchanged to the sounding *Ga* (McGurk and MacDonald, 1976), (McGurk and MacDonald, 1978).[27]

Music also is affected by these cross-modal relationships of perception. The cross-modality of the senses plays an important role on how performers and the audience perceive a musical performance. What follows is a view of a philosophical perspective on cross-modality and its applications in musical performativity. From this argument, we can highlight the significance of vibrotactile feedback in the context of live electronics music and in particular in interactive electronics.

3.2 Phenomenology of Perception

So far we have looked at how the senses have been explored and studied through a comprehensive physiological approach, and how bodily senses are perceived. To create a complete picture, we need to focus on the phenomenology of the body and the embodiment relationship that exists through the use of technology. Such relationships will be appraised to provide us with a better understanding of the role that vibrotactile

[26] Later in this chapter the effect of latency on our perception is examined with examples from networked musical performance.
[27] The video link demonstrates the effect. Available at http://youtu.be/G-lN8vWm3m0 [Accessed 22/10/2014]

feedback plays, and to what level affects the embodiment between the performer and the technology.

Maurice Merleau-Ponty is an influential figure in phenomenology looking at bodily experiences and perceptions as well as the spatiality and motility of objects and the body. Merleau-Ponty refers to the body as the *phenomenal body*. He points out that we do not have to look in order to locate a specific part of our own body. Merleau-Ponty argues that the 'phenomenal hand (reaches) a certain painful spot on his phenomenal body' (Merleau-Ponty, 2002, p. 121). When the hand reaches to pick up the scissors, for example, there is no need to look at the fingers, hands, arm because 'they are not objects to be discovered in the objective space' like scissors are (Merleau-Ponty, 2002, p.121). What we perceive visually as the object (the scissors) already mobilises our phenomenal body in order to locate, reach and use them. In essence, while the body has spatial properties, as it physically enraptures the space around it, at the same time other relationships emerge that reflect towards a personal *body schema*. We do not move our objective body in space but rather move our phenomenal body with the potential objects to be grasped.

The senses address the body schema capable of determining external properties and functions of the environment and the objects. This may include assessing how near or far an object may be, how large or small, heavy or light, high or low. Through our body schema we can distinguish and make sense of the variations in the objects we encounter. In music the ability to distinguish variations is paramount to the instrumentalist and an inseparable part of performing. The instrumentalist forms and develops her body schema through a systematic experience of the tactile and the overall haptic feedback experience. The body schema cannot be evolved through visual and aural feedback alone where the physical experience with the instrument is vital.

Merleau-Ponty introduces the importance of *habit* and *skills* and how they impact, perceptually on the body schema when it comes to manipulating objects. Through the process of acquiring skills the body schema changes thus altering further the potentialities of carrying out an action. Through such a process, unfamiliar objects become familiar tools that are incorporated and act as an augmentation of the phenomenal body. Motor skills are involved in the development of the body schema, which relies on feedback experience. Merleau-Ponty gives an example of a woman wearing a hat with a feather. The woman is able to *sense* the end of the feather avoiding obstacles that might break it off. Even though this is not a very descriptive example and invites discussion, it suggests how through handling objects, we might engage with the world around us.[28] Another example is when we drive a car in a narrow passage, we do not need to measure the width of the car against the width of the passage. *Our new phenomenal body*, the body with the extension of the hat or the car, is compared with the other objects, in this case the height of a door or the width of a passage.

Examining further these relationships we encounter Don Ihde. Ihde, addresses how we may establish a relationship with the world through the tools and the technology we use (Ihde, 1979), (Ihde, 1990). For Ihde there are different modes to consider when interacting and initiating relationships with the technology and the world we experience. These relationships extend the ideas of Merleau-Ponty further; particularly, how instruments become an extension of one's body. The distinction between the two, even though both theories can be seen as complementary, is that Merleau-Ponty places the body experience within the environment and the object, whereas Idhe propose that the body responds and experiences the objects as embodied artefacts (Brey, 2000). Ihde introduces four central phenomenological approaches to the human experience derived from the human-technology *Relations*: the *Embodiment*, the *Hermeneutic*, the *Alterity* and the *Background.*

The *Embodiment Relations* refer to the created artefacts of technology we encounter through the environment. The telescope enables an *embodiment relation* that allows the user to experience and make observations about the solar system. Without the technology to amplify the visual experience it would have been impossible to make any discoveries about the solar system. The instrument becomes the reality in which it is possible to *see through* and consider the experience as 'real' by the user (Ihde, 1997). Similarly, Merleau-Ponty refers to this as the *new phenomenal body.* The telescope, whilst it allows a *magnified* view of the moon, it narrows and *reduces* the visual field to a specific area. Through instruments, we aim towards an amplification of a particular task and as a result other sensory input information may be reduced. With acoustic instruments such

[28] In later section *3.2.2 Instruments as Tools,* I am referring to this example looking at the feedback information provided by the hat as a tool.

limitations and advances are well known.[29] Instruments perform in their own unique way through the way they are built that allows certain aspects to be *amplified.*

The *Hermeneutic relations* do not necessarily extend sensory-bodily functions but rather aim towards the 'linguistics and interpretive capacities' of the technology (Ihde, 1991, p. 75). The technology is distant from the user, as it happens with embodiment relation and requires a degree of interpretation and understanding about the functionality or the end result. This is similar to reading a text where the technology is the text and the reader needs to interpret its meaning.

> There must be a pre-existing fore-knowledge or framework from which the reading takes place. There must be a movement from the initially more ambiguous to the later more specific through the interpretive process, and there must be, again, the gestalt insight which is then the favoured reading (Ihde, 1997, p. 79).

The technology is the medium and we must decode its meaning. Ihde provides an example from an X-ray photograph taken from deep space. While we cannot see beyond the spectrum of the human vision, it is possible to interpret what is out there through the technology alone. We need to decode the X-ray photograph in an understandable form within our visual spectrum.

Ihde's *Alterity Relations* are different from *Embodiment* and *Hermeneutic* relations. The technology here is presented as the *quasi-other*: we relate to it from a distant perspective. Automated or intelligent computer systems such as video games, in-car GPS systems or voice recognition systems are defined as *Alterity relations* (Pierce and Paulos, 2011). From a musical point of view, this reflects on how digital musical instruments are able to perform on their own through algorithms, allowing a distance between the humans and the technology.

The last relationship is formed by the *Background relations* where the technology has a 'present absence' quality. The experience is not direct and at the same time can give some structure to direct experience. The technology has the ability to perform

[29] Take for example the double bass in contrast with the violin. Both have different aspects that are magnified and others that are reduced without making one instrument better than the other.

automatically after an initial setup but we need to refer back to the technology during its active states. An example is when an oven-cooking timer is set and we need to .[30]

Through the work of Merleau-Ponty and Ihde a wider view emerges about the relationships formed when we encounter technology. In *Embodiment* relations the amplified end result through technology is the main focus. In *Hermeneutic* relations the instrument becomes a part of the focus together with the ability to interpret how the end result, the music, is represented. In this respect, vibrotactile feedback can be interpreted as having both *Embodiment* and *Hermeneutic* relations towards the performer. The augmentation of an instrument through vibrations reflects on a perceptual and physical level further extending the potentiality of the technology as well as allowing the performer to interpret the vibrations as a part of expressivity. At the *Hermeneutic* level the performer is free to interpret the symbolic representation of the vibrating feedback sensation through its representational modality.

This discussion continues further to question, from the performer's view, the ways in which it is possible to augment the body through our actions. Gibson's affordance theory, the dissemination between objects and tools as well as the formation and effect of habit will be discussed next to elaborate my thoughts on perception and experience of the body.

3.2.1 Affordance of Things

Musical instruments can be seen as *objects* or *tools* depending on the context. A piano, for example, is an amazing *tool* in the hands of a skilled pianist and a beautiful *object* often used as a lamp table. Gibson introduces the concept of affordance to describe relationships concerned with visual perception (Gibson, 1950). Gibson's affordance looks at the actor-environment mutuality by removing any subjective and objective barriers between the two.

> The theory of affordances rescues us from the philosophical muddle of assuming fixed classes of objects, each defined by its common features and then given a name. You do not have to classify and label things in order to perceive what they afford (Gibson, 1979, p. 134).

[30] Thor Magnusson's Ph.D examines in depth these relationships from the digital musical instrument perspective and their difference from acoustic and other analogue musical devices (Magnusson, 2009).

Donald A. Norman proposes an extension of Gibson's concept where the object itself embeds inherent affordances (Norman, 1998). Norman describes how the information received from an object suggests affordances about its functions. A chair affords sitting but not long distance travelling. Even though the term has been used widely within psychology it is nonetheless applied in other areas such as HCI, neuroscience, design and robotics (Norman, 1998), (Sahin, 2007). Apart from the affordances provided through its design, other cultural and environmental backgrounds are able to influence how we understand them.

The significance of affordances in electronic music steams from the functionality of hardware and software as musical instruments. Magnusson incorporates such affordances to design screen-based musical instruments (Magnusson, 2006). The performer has a metaphorical relationship that reflects creatively on how compositional ideas are formulated (Magnusson, 2009). Tanaka *et al.* provide a comparative study of three controllers and their affordance relationship using four different instrumental sounds (Tanaka *et al.*, 2012). The subjects, knowing the nature of the instrumental sounds, were able to associate gestural functions with the controllers.

The context in which an object, function or a system is presented makes possible the formation of an abstract relationship and musical meaning. Performer and composers are able, through the affordance theory, to *transform* objects into musical tools. Listeners also make use of affordance in music performances enabling an abstract understanding and appreciation of music. Cook and Pullin argue about the affordances of everyday objects such as a TV set or a tree branch and how they can become musical instruments (Cook and Pullin 2007). The circuit bending approach of Nicolas Collins, the *Global String* by Atau Tanaka and Kasper Toeplitz and the Modified Toy Orchestra[31] are only a few examples of how affordance is embedded through a creative musical approach (Tananka, 2001), (Collins, 2009).

Music, being a creative performing art, nourishes a never-ending debate on how computers, controllers and the overall technology can be seen as a musical instrument (Paine, 2008), (Tanaka, 2011). A composer should consider how different performing and compositional approaches come together to support such technology-driven affordances.

[31] A performance group performing with electronic toys as musical instruments <http://www.modifiedtoyorchestra.com>.

For example, laptop music performances comprise a collection of software, functions and controllers as the *performance instrument*. The creative process takes place in front of a computer screen away from the eyes of the audience that are left on their own to decode the produced sound. The often limited visual and gestural feedback associations in laptop music performances are a deterrent for the decoding process. The argument here is in what ways the audience can form abstract representations of sound through the presented affordance relationships. Audiences familiar with the cultural background of the genre, often other laptop performers, can develop a mental representation of the performed sound through their own performing experience and practice without the need for any gestural and visual reference. The majority of the audience however, expect some *performative* elements where the output presented on stage is visually and aurally enjoyable. Experience and habit, in that sense, influence the perception and the expectation of how affordances are formed and developed. The concert stage is understood at a subconscious level, as a performance space that includes visual and aural satisfaction such as in theatre, public speaking and talks, cinema, dance, music and so forth. Placing a laptop on stage, where the *effort* of performing music is not related to the visual movement of the performer, contradicts the habitual expectations on what a stage and the laptop can afford. Similarly non-traditional performance stages such as a nightclub, a pub or an art gallery, are free from habit constraints and affordances and make the laptop performance more inviting and acceptable.

Julio d'Escriván argues that electro-acoustic music would have been 'more at home in endless loops as part of sound installations in art galleries, as they could be, in fact, far more sonically interesting than most sound installations' (d'Escrivan, 2006). The affordance of an art gallery as the new *concert stage* for electro-acoustic music suggests a more sonically interesting experience to the listener's ears. When the history and habit of the traditional concert stage is removed, our expectations are freed, giving space to artistic affordances. As discussed earlier, Smalley suggests that we should abandon our habitual reference to the labour of sound in electro-acoustic music and liberate our ears (Smalley, 1996). d'Escriván proposes a distinction between the old and new generation listeners in the ways they appreciate performance skills and the value of effort in performance.

> Since the advent and popularity of the Nintendo™ computer games system in the early 1980s, so many new ways of human computer interaction have sprung forth, that a generation brought up on a diet of videogames is, in my opinion, ready to accept the rupture of what we could call the efforted-input paradigm(…) People of an older generation, may tend to require an old-school paradigm of performing virtuosity, where perceived effort and dexterity on behalf of the performer are paramount to the enjoyment of music (d'Escrivan, 2006).

Even though the video-game diet might distinguish the old and new generation performance paradigms, I would argue that digital and physical effort should be prominent in all performances of electronic music. Video-games have indeed widened our affordances and provided the palette to accept a diversity of performance skills. However, as noted above we are *prisoners* of our senses and perceptual assumptions in our everyday life experiences. Such dependency affects how we may form abstract representations when attending a music concert and in particular how *effort* plays a major role in experiencing music. Perhaps, the views of d'Escriván would have been different after the release of the *Wii* console and the *Wii Remote* from Nintendo™ late 2006. Physical effort and virtuosity in many video games are now a prominent feature.[32]

Ihde suggests that through playing video-games we are connected with the technology through the *Alterity Relations*, described earlier. We are in an immersed state within the video-game's digital world. Pushing the controller's button requires minimum physical effort. However, in a virtual world this may be expressed and translated as a *humanised* and *real* activity through picking up coins, jumping or running. The gamer is immersed within the video-game's digital reality where functions and actions of the virtual character reflect back to the gamer through an abstract representation of the action/reaction relationship. More realistic games include real life scenarios where the character often follows the physical laws being able to run for a certain distance before getting tired or holding her breath for a finite amount of time under water. The properties of the game give the impression of real life scenarios that engage the gamer in such abstract representation.

In computer music, the effort takes place within the computer's programming functions away from the physical production of sound. However, composers and

[32] Today, many gaming consoles such as the Kinect™ by Microsoft™ and the PlayStation-Move™ controller by Sony™ require physical effort from the gamer.

performers should be in a position to provide audiences with affordances of such *digital effort*. Perhaps, Live Coding would have been less popular if video projectors were excluded during performances. The visualisation of *digital effort* while performing (the coding process) engages and stimulates the unfamiliar audience further inviting them to fabricate abstract affordances with the code (Zmolnig and Eckel, 2007). The video screen becomes the new performance stage that enables affordances through meaning of text and numbers to be interpreted by the audience; thus, the audience can accept the unorthodox performer that sits behind the laptop. The new stage enables *digital effort* to take place on screen rather than through the physical actions of the performer.

The main perceived affordance of the vibrating feedback is to inform and provide feedback to users about different states in relation to their actions. Even though vibrotactile feedback might not be analogous to the applied effort when performing with technologies, the performer will be able to make new associations between the actions and the experience. This approach nourishes performative expressiveness between the technology and the performer, a necessity in interactive electronics. It is important to look at how objects can become tools and how we can form a habitual relationship. This supports the idea of vibrotactile feedback as a musical tool that may enable further expressive nuances to be formed and established during performance.

3.2.2 Instruments as Tools

Within the confines of affordance theory we should differentiate tools from objects. Tools are objects that acquire functionality from a user.[33] A piano is an object to a non-musician and an instrument (tool) in a musician's hands. Tools, through their feedback qualities, allow users to create, sustain and develop knowledge and habitual relationships. Tactile feedback is a significant feedback modality supporting the creation of such performative habits, which can reflect further upon experiencing and understanding our new phenomenal body. For an object to become a tool, a certain amount of time is required to allow the user to experience feedback modalities through its exploration. During this time different sensory experiences take place between the body and the tool. The way objects may provide sensory feedback information to the body while in use, affects the duration

[33] The affordance of an object, discussed earlier, suggests how objects can change functionality and meaning depending on how they are understood and expressed by the user.

needed to transform the tool as an extension of the new phenomenal body. With musical instruments, the complexity of feedback embedded in the instrument requires a lengthy development time for the performer. Sergi Jordà, in the search for new digital instruments, examines the instrumental efficiency and the time needed for performers to reach such efficiency (Jordà, 2004). As complexity varies between instruments this also affects the development time needed for establishing a new phenomenal body with the instruments.

Feedback allows us to distinguish objects from tools. When a fixed feedback association exists through an object we are able to form habitual relationships gained from systematic practice. Without fixed associations and feedback, controllers, sensors and other electronic devices are unable to manifest themselves as musical tools. Not being able to experience sufficient feedback affects expressivity in music performances (Michailidis and Bullock, 2011). Incorporating vibrotactile feedback in controllers, sensors and other electronic devices that have no fixed audible feedback associations, may provide a sustainable framework for performers and composers, and a new way of looking at the creative possibilities we have in our domain.

3.2.3 The Habit and Tools

Habit in music refers to the sensory experience and knowledge gained while repeatedly performing on a musical instrument. Habit affects at a perceptual level the relationship between the instrumentalist and the instrument. Due to the vibrating resonance from the material and the mechanics of the instrument, performers develop a coherent understanding of the ways their actions reflect on and respond to the instrument.

Apart from the embodiment of habitual formation concerning how the instrument *feels* and *interacts*, habit can also address repetitive self-initiated actions such as practicing an instrument every day or the habit of playing a scale in an *unconventional* fingering. Having the habit of a *wrong posture* while playing is the outcome of systematic wrong approaches towards the instrument over a lengthy period of time (Williamson, 2012).

> Habits are complex organizations of the self, tools, and materials. Alexander's technique deals initially with the self, restoring functional integrity and bringing about the "harmonious relationing" of the parts of the body. Both physical and mental changes are necessary in order for a change of habit, and as reliable sensory experiences are necessary to form new mental concepts, the individual is often unable to accomplish the changes without assistance (Williamson, 2012).

It is very difficult to form such habitual relationships with the instrument when performing with technology including sensors, controllers and other electronic devices. Bespoke devices often exclude the significance of a humane approach resulting in non-intuitive devices, a factor that contributes negatively towards the formation of habit.

> The ideal humane interface would reduce the interface component of a user's work to benign habituation. Many of the problems that make products difficult and unpleasant to use are caused by human-machine design that fails to take into account the helpful and injurious properties of habit formation (Raskin, 2000).

Humane interface simply refers to an interface that includes prior familiarity with the user or at least some elements of intuitiveness that can provide and sustain a habit formation.[34]

3.2.3.1 Instrumental Performances

Due to the nature of acoustic instruments and the fixed feedback associations, the performer understands and *feels* the instrument. The resonance qualities of an acoustic instrument are responsible for fabricating and sustaining such relationships. A professional musician may be considered an expert when she is able to accumulate entirely the reactive properties that arise from the instrument (Utley and Astill, 2008). Although acoustic instruments are reactive with predictable behaviours, we may consider them as *interactive* within the framework of music performance. A musical instrument is only an object in the hands of a non-performer in the same way that a user is transformed into a performer through the instrument. Such a relationship has been described as emotional and idiosyncratic due to the *liveness* of the instrument. Rebelo goes as far to

[34] With the release of OS Lion 10.7 in 2011, Apple Inc. changed the default direction of the mouse scrolling. The direction of the mouse scrolling had been in use for more than fifteen years and many users formed habit in using it. However, with the introduction and familiarity of touch screen devices, same direction scrolling was intuitive and thus able to break the old scrolling habit.

describe this relationship as *erotic*, where musical instruments are not only seen as tools but as unique entities that carry their own dynamics, expressions, sociality and ecology (Rebelo, 2006). It creates coherence between a musician's actions and performance in an action/reaction feedback dynamic (Tanaka, 2000). Decoupling the tactile from the aural feedback creates an unfamiliar environment for the acoustic instrumental performer (Dahl and Bresin, 2001).

The detachment of the performer from a habitual haptic and aural perception creates a situation where the musical instrument loses its functionality from being a tool and somehow gets demoted into being an object. Without the haptic and aural feedback associations the formed habitual bond is broken. The instrument can no longer function as an instrument.[35]

3.2.3.2 Imperfect Instruments

Instruments come with variable levels of imperfections either from the material used or from the design. Tanaka suggests how such imperfections are vital in order to justify the *personality* and voice of the instrument (Tanaka, 2006). To a further extent there are no imperfect instruments since imperfection is a by-product of the instrumentalist's quest for perfection. The level of imperfection is demonstrated through the instrumentalist. In an essay written by Sally Jane Norman, Michel Waisvisz and Joel Ryan for the first STEIM Touch manifestation in 1998, the authors pointed out the need of physical effort as a result of the limitations of the instrument and how this turns into 'beauty and expressiveness' in the performer's hands (Norman *et al.*, 1998).

> Every instrument has its difficult and easy fingerings, its rough and smooth terrain. A singer's effort in reaching a particular note is precisely what gives that note its beauty and expressiveness. The effort that it takes and the risk of missing that note forms the metaphor for something that is both indescribable and the essence of music (Norman *et al.*, 1998).

The performer's quest for perfection, going beyond her limits, extended techniques, unconventional playing, creates the *imperfect instrument* allowing beauty and expressiveness to take place. On the other hand, programmable computers can potentially

[35] Later we examine how latency affects the formation and functionality of the instrument.

create the *perfect instrument*. Such perfection undermines beauty and expression. Bongers points out how the technologically successful instrument becomes more invincible, less physical and easier to play but harder for the player to nourish expressivity (Bongers, 2006).

> This is because effort is actually often a good thing. When playing the instrument, the physical resistance is a source of information about the process of playing and articulating sound. The lack of physicality must be compensated for, by including haptic design, ie. force feedback and vibrotactile feedback (Bongers, 2006, p. 72).

Whilst vibrotactile feedback focuses on specific aspects of music performances within the wider concept of live electronics, is it nonetheless far from creating a perfect instrument. The vibrating experience brings back the meaning of *effort*: a personal *effort* that bounces off expressive nuances to the audience.

3.2.4 Feedback Phenomenology

The simplicity of feedback makes it hard to define it. Feedback simply provides confirmation about its user's actions. It can be found in every physical action we carry out in our everyday life. Typewriting, for example, exhibits three feedback modalities:

(a) *visual*, while looking at the keyboard and/or the screen for visual confirmation;
(b) *aural,* from the sound produced during typing that confirms a successful entry and;
(c) *haptic*, while pressing the keys.

We create the habit of experiencing all three feedback modalities at different levels. While typing, we interchange our visual attention between the screen and the keyboard and often it feels *unnatural* if we are not able to do so.[36] With regards to the haptic feedback, a study by Hoffman *et al.* shows how a press-resistant keyboard decreases the

[36] As an experiment, try typing a sentence with closed eyes. After a few words there is an urgent need to look at the screen for confirmation.

error correction rates by 46% compared to only visual feedback (Hoffman *et al*., 2009). Interestingly, after a period of three months the experienced user became familiar and embraced responses from the device that contribute in reducing even further the necessary corrections as well as the typing time.

Musicians have similarities with typists when it comes to learning and performing music. Throughout years of practicing, performers establish the necessary skills towards a dynamic relationship with the instrument. This makes it possible to perform an instrument without visual feedback, even without aural feedback for the needs of demonstration, since the years of practicing establish a habitual association of the finger positions and the muscles with the instrument. However, the aural feedback is significant as it is the end result of instrumental performance and music in general.

One remarkable property of habit and sensory feedback is the ability to recalibrate our relationships and the focus of attention from the senses where this is needed. Merleau-Ponty provides an illustrative example of the process of an organist with a new organ just before the performance.

> He sits on the seat, works the pedals, pulls out the stops, gets the measure of the instrument with his body, incorporates within himself the relevant directions and dimensions, settles into the organ as one settles into a house. He does not learn objective spatial positions for each stop and pedal, nor does he commit them to 'memory'. During the rehearsal, as during the performance, the stops, the pedals and manuals are given to him as nothing more than possibilities of achieving certain emotional or musical values, and their positions are simply the places through which this value appears in the world (Merleau-Ponty, 2002, pp. 167-168).

Large instruments, such as the piano and the organ, often serve as house instruments. Thus the pianist and organist establish habit experiences that enable them to recalibrate easier their phenomenal bodies based on the feedback received from the instrument.

Feedback is involved in many interconnected functions that concern the perceptual understanding of our surrounding and the tools we use. From the received feedback we are able to suggest affordances, distinguish objects from tools, develop habitual relationships and recalibrate for different scenarios.

3.3 Time and Feedback

Even though network-based performances are not specifically within the scope of this thesis, they nonetheless serve the purpose of examining the perception of time in feedback perception. Network-based performances have one technical concern: latency. Latency is the time duration needed to communicate or the response time between two points. Points in this context might include performers in two different locations communicating via a network link. There is a vast amount of research regarding the aspects of network performances from the technological as well as the musical use and perception of latency (Chafe *et al*., 2004), (Weinberg, 2005), (Latonero and Renaud, 2006), (Renaud and Robelo, 2006), (Schroeder *et al*., 2007). Experiments conducted regarding the role and functionality of latency in music show a fundamental impact on our perception, skills and performance (Levitin *et al*., 1999), (Dahl and Bresin, 2001), (Maki-Patola and Hämäläinen, 2004), (Olmos *et al.*, 2009). However, here we will focus on how and why we experience latency and its relevance with the vibrotactile feedback experience.

Latency occurs in nature. The way we listen, see and experience the world through the senses as well as any other physical event in the universe, such as light and sound, are all affected by its presence. Light has speed *latency* in the way it behaves, approximately 300,000 km/s in vacuum, but we do not acknowledge it as latency since it is the physical and natural property of light. Our internal and external organs tolerate latency in the way they transmit information to the brain from different sensory inputs. Because we live and experience these physical universal laws from the very first day of our lives it is impossible to perceive and observe the latency embedded in nature, i.e. to experience something other than the physical laws we live in. Michio Kaku refers to this in a similar way the fish experience the world through his pond.

> We live out our lives in our own *pond*, confident that our universe consists of only those things we can see or touch […] our universe consists of only the familiar and the visible (Kaku, 1994, p. 5).

The properties of latency in the physical world are fixed and allow familiarity and unconscious habitual relationships to which we can respond. If the force of gravity changed overnight, car drivers for example, would have difficulty stopping, most likely resulting in traffic accidents. This is due to the new unfamiliar relationship between the car, the driver, and gravity. In the same manner, instruments have fixed latency feedback associations with the performer. When changed, the instrument becomes unperformable.

The latency embedded in computer hardware and networks is not fixed and thus problematic. There are many parameters that contribute to latency in computers and networks. However, it is a never-ending task due to the ever-changing development of hardware technology. In 1996 Stuart Cheshire suggested focusing on eliminating any unwanted latency from software and hardware as well as developing latency-hiding techniques since latency will always exist within networks (Cheshire, 1996). Software applications such as *JackTrip*[37], *LOLA*[38], *eJamming*[39] and *NINJAM*[40] are only a few solutions towards the effective handling of latency within the network (Carot and Werner, 2007), (Cáceres and Chafe, 2009). Limitations in network performances create the imperfect playground and are perceived as creative by performers and composers (Kim-Boyle, 2008). Creativity through the limitations of the apparent technology often comes as a necessity.

Latency is apparent to the user or the audience only if familiar tasks or actions are no longer familiar or unable to embrace habitual experience. An example of this is when video and audio playback are not in sync. As we discussed earlier, the cross-modality of perception allows the experience of events as one entity rather than two, vision and sound. Even though we are familiar with the physical properties of sound and vision, only latencies that do not qualify as habitual will be noticeable.

3.3.1 Responses to Latency

Latency is noticeable when our perceptual understanding of the action/reaction relationship is disturbed. In instrumental performances this has never been a noticeable problem since there is always the same direct relationship between the performer and the instrument. The existing latency from the instrument and the performer becomes a part of the performing act relationship. An organist, for example, will be trained with the variable latencies embedded in different organs as a part of her instrumental relationship.

[37] <http://ccrma.stanford.edu/groups/ soundwire/software/jacktrip/>
[38] <http://www.ict-lola.eu>
[39] <http://www.ejamming.com>
[40] <http://www.cockos.com/ninjam/>

For a pianist, the latencies of the organ might be problematic. Due to the physical interaction with the instrument, performers are able to understand how the energy of the instrument reacts to their own energy and therefore how it behaves haptically and sonically towards the instrumentalist and the acoustic environment.

Dahl and Bresin demonstrated that separating the aural from the tactile feedback exposes the performer, in their case a percussionist, to a problematic performing environment (Dahl and Bresin, 2001). The study showed that 40-55ms could be the break-point where the performer experiences latency and needs to adjust to other strategies for sensory input information to continue playing. Interestingly, the study showed that different musical backgrounds can produce different thresholds for such reliance on aural and tactile coordination. The familiarity in different performance settings, such as an orchestra or a jazz ensemble, suggests that there are variable levels of confidence for the performer in terms of the relationship between tactile and aural feedback (Dahl and Bresin, 2001). Orchestral performers were able to play in tempo with larger delays since long distances between performers exist in an orchestral setting. In a full orchestra the distances between players can be up to 30 meters which results in up to 90ms of latency.[41] Sawchuk *et al.* showed a variable break-point of latency depending on the instrument and piece performed (Sawchuk *et al*., 2003). For instance, they noticed that playing a synthesised accordion the performer could tolerate latency of 25ms and up to 100ms with a synthesised piano.

Adelstein *et al.* examine the threshold relationships between haptic and audio events in order to implement effectively real-time acoustic modelling methods for real and virtual mechanical interactions (Adelstein *et al.,* 2003). In this experiment twelve subjects were measured in relation to their perception of latency in space. The results showed that the average of the Just Noticeable Differences (JNDs) for the tactile-aural relationship is between 18-25ms. Levitin *et al.* showed asynchronies between audio and tactile feedback in the range between −25 and +42ms (Levitin *et al.,* 1999). In the same experiment, when an observer was looking at an actor hitting a drum, he was able to detect latencies of -41ms and 45ms between sound and action. Olmos *et al*. demonstrate how opera singers may perform and interact with the conductor via network communication (Olmos *et al*., 2009). The results suggest that the performer was able to

[41] The speed of sound is roughly 340 meters per second that results in a rough estimation of 3ms per meter.

cope even with latencies above 80ms if there is sufficient time for rehearsal in order to formulate a new association with the latency, i.e. to calibrate and adjust to the new performance setting. Furthermore, performing with vibrato, latencies can reach up to 100ms without notice (Maki-Patola and Hämäläinen, 2004). The organ example given by Merleau-Ponty shows clearly the ability to tolerate latencies. Church organ players can perform fluently with latencies of 100ms (Maki-Patola, 2005).

There is no absolute threshold of latency concerning the ability to perform on a musical instrument since we have to consider the physical limitations of the instrument itself, the environment, the style of the music and the visual nonverbal interaction between performers. By examining latency relationships with the instrumental performer one general conclusion can be observed: performers have an extended ability to recalibrate their performance strategies based on the current needs which can only be acknowledged through feedback.

3.4 Touching Technologies

Haptics senses are important in our experience and perception (Classen, 2005), (Paterson, 2007). When interfacing with computers and in essence with most technological objects, we want to experience the information in a holistic way visually, aurally and haptically. The experience of technology through vision, sound and haptics provides users with a framework of transforming their experience while immersed in digital and virtual spaces. In terms of haptics, Paterson suggests that:

> The goal then is to create the illusion of tangibility through mimetic machines, and the grater fidelity of haptic sensation the grater the user's sense of presence in a virtual space. But mimetic is not representation (Paterson, 2007, p. 129).

In a musical performance the proposed artificial vibrotactile sensation has no intention to present the same vibrotactile and haptic experience of an acoustic instrument. It is possible to implement the feedback experience in a programmable manner that benefits the performer when using the technology.

3.4.1 Haptic Applications

The use of haptic applications goes back as early as the 1950s in what we know as a teleoperator or telemanipulation system where *master* and *slave* could exchange haptic information (Goertz and Thompson, 1954). The consideration of haptic feedback within the context of virtual reality came from the vision of Ivan Sutherland, a pioneer in computer graphics, where his *ultimate display* was to incorporate haptic feedback into a simulated virtual word (Sutherland, 1965), (Grudin, 2008).

> The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked (Sutherland, 1965).

Coming across haptic feedback, one will encounter the developments that occurred in virtual reality (VR) field during the 1970s. The need to incorporate any haptic stimuli in a virtual world comes as a necessity since visual representation alone results into ambiguity, leading to an unwieldy and a non-intuitive method of design and object manipulation (Paterson, 2007, p. 137). Dionisio *et al.* point out the desirable visual-haptic co-location to achieve a believable sense of interaction with visual objects (Dionisio *et al.,* 1997). In addition, the successful illusion of out–of–body experience within a VR environment has been closely related to the synchronicity of the visual and haptic perception (Botvinick and Cohen, 1998), (Slater *et al*., 2010).

Another useful application of haptics focused around medical practice. Doctors can practice real life scenarios without the risk of harming the patient. Matching the variable levels of tissue resistance of the needle, as it penetrates the skin, allows medical practitioners to gain confidence, reduce anxiety through repeated realistic exercises (Jung *et al*., 2012). Such flexibility in educating doctors and nurses goes as far as remote surgery, microsurgery, dental surgeries and rehabilitations (Burdea, 1996), (Ghodoussi *et al*., 2002). In addition, vibrotactile feedback provides support for the visually and hearing impaired, improving the quality of life (Bernstein, 1992), (Saddik *et al*., 2011).

Haptic technologies are now standard in gaming consoles such as Sony's PlayStation, Microsoft's Xbox and Nintendo's Wii. They enhance the gaming experience through force feedback and vibrotactile feedback and allow the player to engage and interact in a more realistic experience and a higher senses of immersion (Chang, 2002). Andrews *et al*. suggest that haptic integration of a 3D game increases its realism, the level of immersion as well as the entertainment value of the game (Andrews *et al*., 2006). New haptic controllers will only continue to emerge as the gaming industry is growing. Haptics will evolve from simple into complex high resolution multi-haptic sensing systems able to deliver rich immersive experience while playing interactive games (Ali Israr, 2012).

Haptics on mobile phones has been taken seriously by phone companies and is something that will eventually catch up with the users through the integration of the new audio-tactile modalities. Even though this will be featured as another function on the latest handheld/wearable device, the user will have a direct sensory channel, the vibrotactile, which will differ from other visual based applications.[42] *ComTouch*, a communication device that supports audio-tactile modality, enhances verbal communication and meaning between users in real-time (Chang *et al*., 2002). The study showed that the lost non-verbal cues, usually present during a face-to-face conversation, can be reintroduced and integrated with a new mode of communication similar to *Braille* and *Morse Code* offering a versatile communication tool. The *CheekTouch* device translates multi-finger gestures from a mobile phone's touch screen into vibrotactile incoming signal received by the other person (Park *et al*., 2010). The *Force Phone*, provides a synchronous haptic communication during phone calls. Users can squeeze the side of the devices to enhance communication with pressure/vibrotactile messages called *pressages* (Hoggan *et al*., 2012).

Artists and designers could not ignore vibrotactile and haptic feedback. The ability to *feel* the artwork through haptics has been an enhancement of the user's perception, specifically under situations where the user has limited access or the artefact is delicate. The *Museum of Pure Form* presents such a novel approach to visitors that allow having a closer and intimate relationship with the artefact by exploring the shape of the pieces otherwise forbidden in conventional museums (Loscos *et al*., 2004). In painting, a 3D haptic brush allows users to have a natural feeling of control with a variety of brushes

[42] By the time of writing this thesis the iWatch device by Apple Inc. just came out on the market (April 2015). A wearable, watch-like device able to provide vibrotactile feedback to the user for a variety of different functions such as directions, alerts and audio cues.

within the digital domain (Baxter *et al.*, 2001). Furthermore, installations and other art forms integrate haptics as a means to redefine human perception and sensing (Schwartzman, 2011). The artist Erik Conrad through his site-specific installation *Palpable City* presents a tactile landscape while exploring the city. Participants wear a vest with custom made electronics and GPS providing different vibrotactile sensations in terms of rhythm and intensity (Conrad, 2006a). The installation provides a form of embodied environmental or spatial awareness through the tactile sensation of the body (Conrad, 2006b). Stahl Stenslie and Kirk Woolford in 1993 created the CyberSM, a system where two participants in remote locations wear special suits that can communicate haptically with each other (Stenslie and Woolford, 1993). By creating their virtual bodies on the computer each participant could allow each other to be *touched* virtually over the network. Each suit was embedded with vibrating motors as well as the ability to provide electrical shock as means of communications (Stenslie, 2010). In a similar fashion Chung *et al.* create a peer-to-peer communication over the network that allow anonymous users to exchange haptic messages (Chung *et al.,* 2009).

Haptics and the use of vibrotactile feedback can be found in a wide range of disciplines such as entertainment, education, medical, military and robotics (Chang and O'Sullivan, 2005), (Cincotti *et al*., 2007), (Ghiani *et al*., 2008). They have been integrated into technologies as to provide a coherent and sensible approach towards a humane interaction. To a great extent the success of such technologies depends on the integration of the functions of the product able to provide a humane resemblance. Tactile perception, even though it is not acknowledged relatively to its impact, is fundamental in the way we experience, understand and learn through digital technologies.

3.4.2 Vibrotactile Feedback

Vibrotactile feedback can provide an intimate and expressive relationship between performers and the technology. Haptic perception allows us to modify and manipulate the world around us (Minogue and Jones, 2006), (Grunwald, 2008). In attempting to find the optimal approach to designing digital instruments for music performance, Bongers suggests a close consideration of the functionality of hands and lips and in consequence haptics (Bongers, 2000).

The vibrating experience can be artificially created and controlled through electronic components. Through prototyping devices such as Arduino, we are able to control the duration and density of vibrations. The motors are similar to those found in mobile phones and can enable discreet vibrotactile sensations on the skin. It is possible to provide feedback information back to the user about different aspects of the technology. However, the artificial vibrotactile experience created from the motors cannot be compared with the complex vibrotactile experience gained when performing an acoustic instrument nor this is the aim and application of the motors. The aim is to provide feedback information through the tactile channel and enable an abstract but meaningful interactive relationship between the performer and the technology.

The feedback provided through vibrations can be described as a tool with communicative properties as it informs the user about her actions maintaining a closed feedback loop. The performer is able to *feel* how the technology senses her actions and interacts accordingly. This opens a wide range of possibilities for musical interactions that brings back the essences of virtuosity in performing with technology. The closed feedback loop characteristic of the vibrotactile feedback suggests an educational standpoint. For instance, vibrotactile feedback was applied for learning rhythms (Bouwer *et al*., 2013), learning relative pitch (Mate-Cid *et al*., 2012) and as a metaphor for notated score through vibrations (Lee *et al*., 2009). It has been addressed as a tool for teaching violin bowing techniques (Linden *et al*., 2011) and supporting performances over the network (McDonald *et al*., 2009).

3.5 Conclusion

This chapter has focused on theories of perception and applications of vibrotactile and haptic feedback. I examined how the integration of the senses is able to provide a perceptual understanding of our actions and their surroundings. The theoretical texts of Merleau-Ponty and Ihde, have shown the way in which objects are seen and experienced as extension of one's body. Ihde suggests four central phenomenological approaches: the *Embodiment*, the *Hermeneutic*, the *Alterity* and the *Background.* Vibrotactile feedback makes use of such approaches, providing the ability to *feel* computer functions as the extension of the performer's body (*Embodiment*) and through the symbolic representation of the felt vibrations that can be interpreted freely by performers (*Hermeneutic).*

The discussion of affordance addressed the role of the technology, including computers, controllers and laptops through the way in which they are employed in music performances. I touched upon how computers are viewed as instruments and how the stage allows affordances to exist and influence performers and audiences. Our habitual experience of what and how a performance *should* be presented on stage makes it difficult, at first, to appreciate interactive electronic music. There is an urgent need to consider habitual expectations of the audience in regards to concert stage, the instrument and the performer. *Digital* and *physical effort* should be explicit for the audience thus encouraging them to make abstract representations of the production of sound. For performers, instruments should be physically *playful* for expressive nuances to exist.

Through the theories of affordance I examined ways physical objects have the ability to transform themselves into musical tools in the hands of performers. The way we understand and experience any object, tool or instrument comes mainly from tactile perception, including vibrotactile. Acoustic instruments, being able to provide fixed feedback associations, allow performers to *feel* and *interact* musically through an established habitual relationship. Any disturbance on the performative habitual equilibrium between the performer and instrument reflects on the performability of the instrument.

A fundamental aspect of feedback is the role of latency and how it alters our perception and cognition including the formation of habitual relationships. The example of networked performance illustrates how habit and feedback are of vital importance in the way we perform and express music. I examined the broader implication of haptics and how it allows users to experience and interact with the technology.

Vibrotactile feedback suggests its function as a communicative tool that can compensate for the lack of physicality in technology-oriented performance. The ability to manipulate and control how vibrotactile feedback is felt on the performer's body creates additional means of communication moving away from visual and sound. The following chapters discuss how vibrotactile feedback is employed in performances and compositions.

CHAPTER Four

Case Studies

Chapter Four examines the relationship of vibrotactile feedback with the performer. A series of case studies and compositions examine and explore how vibrotactile feedback functions, and what its implications on interactive electronics performances and compositions may be. It explores, through creative and reflective practice, features and characteristics of vibrotactile feedback in music performances. Four case studies are presented that are either directly associated and influenced creatively the compositions or embrace other indirect relationships. All compositions are discussed in Chapter Five. The following diagram shows a visual representation of the existing relationships.

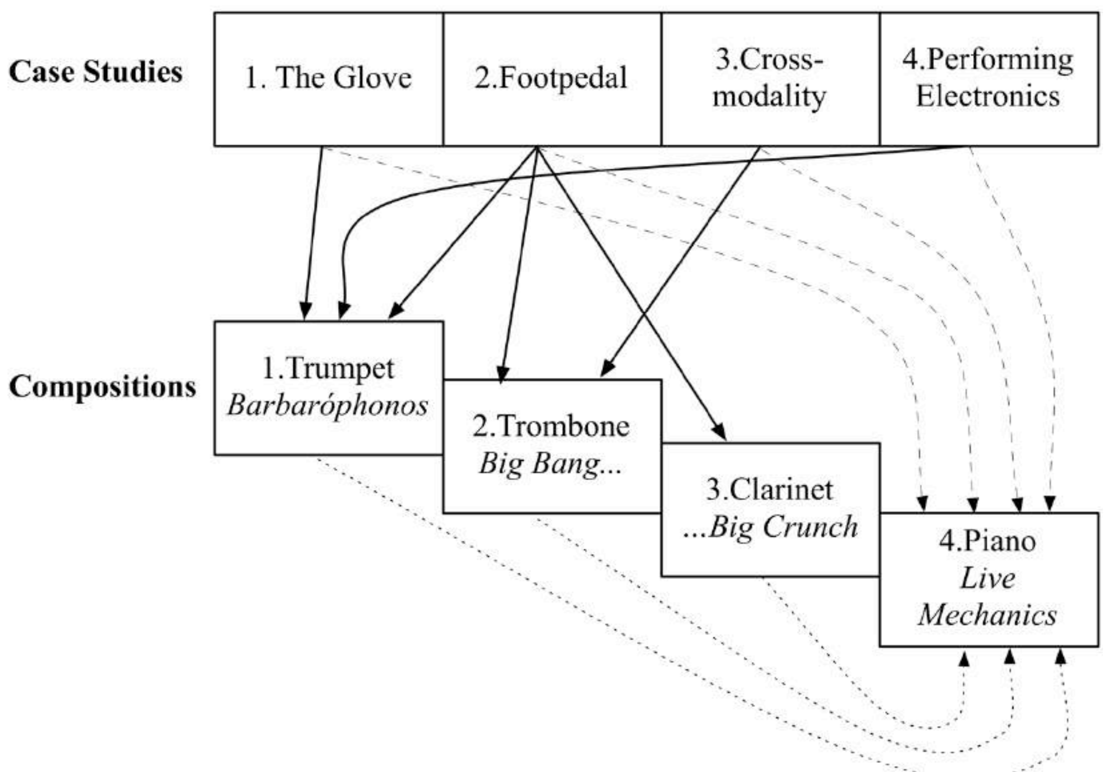

Figure 3 - Diagram showing the relationships between the case studies and the compositions.

The case studies are presented in a chronological order as they have been conducted throughout the research. The first composition, *Barbaróphonos* includes evidence of direct influences from three case studies where the fourth composition, *Live Mechanics,* has no direct influence from the case studies. The process of creating the compositions and the outcomes from the case studies indirectly influenced *Live Mechanics*.

4.1 Case Study One - Trumpets

Case Study One examines if and how instrumentalists can improve the overall control, perception and musicality when performing with technology. Through vibrotactile feedback performers receive confirmation about different states of the technology. They are able to introduce and broaden expressive nuances that are often undeveloped in controllers and other electronic devices employed in live electronic performances.

A common practice for composers is to combine acoustic instrumental performances with computers and other bespoke controllers (Croft, 2007). Performers, however, often lack performativity and expressivity through the use of technology. It is often assumed that performers can adapt and perform with new controllers and the overall technology at a similar level as they do with acoustic instruments. We should however, consider performer's ability to perform with the technology different from that when performing with acoustic instruments. It is argued that through the introduction of vibrotactile feedback in rehearsals and performances a more coherent picture can be formed with regards to the roles and functions of technology in performance, thus contributing to the expressive and artistic outcomes of the piece.

4.1.1 Methodology

A qualitative method has been employed in this study through interviews and discussions to examine participants' performing experiences. Six trumpet players volunteered to take part in a series of semi-open interviews and performing tests. All participants were undergraduate students at Birmingham Conservatoire. The subjects were in different academic years, and from both classical and jazz backgrounds. They were from 19 to 22 years of age, and spent between 15 and 25 hours playing their instrument each week. None of them had any prior experience in performing with technology.

Even though two additional subjects were interviewed, they were excluded from the results of the case study as they had prior experience in performing with technology. The call out for the case study did not specify if experienced or unexperienced performers were needed, hoping to attract a substantial sample from both groups. The initial aim was to examine and compare a difference in the performance of the two groups when vibrotactile feedback is introduced. However, due to the lack of experienced subjects, the case study continued to examine the influence of vibrotactile feedback on those without any prior experience. In particular, the case study examined the usability, functionality and performability of a pressure sensor glove through the use of vibrotactile feedback. The glove allows the control of audio processing in real time when pressure is applied on the fingertips where the sensors are attached. Six short melodic exercises demonstrate a variety of compositional strategies able to test and compare the experiences with and without the vibrotactile feedback (figure 4).

Each interview, including the performance tests, lasted approximately one hour and thirty minutes. Participants were compensated with £5 for their time and effort. All interviews were recorded with their permission.

4.1.2 Hardware

The bespoke hardware developed for the case study consists of a sensor glove and a prototyping box enclosure with six inputs and six outputs.[43] The prototype box uses an *Arduino Diecimila* board, an open source prototyping device.[44] The board is capable of receiving up to six analogue input data from sensors and thirteen inputs/outputs from a digital source. Six of those digital outputs are configurable to provide Pulse Width Modulation (PWM) functionality.[45] For this case study, only three inputs and three outputs were used. The PWM function allows the control of small vibrating motors that act as the vibrotactile experience on the performer's body. Connectivity with the laptop is through a USB connection, allowing both power to the board and the motors as well as data transfer from the sensors. The board is housed within a plastic box fitted with female mini-jack connections (figure 5).

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[43] The device later named as *TfTool* is described in *4.2.1 Hardware.*

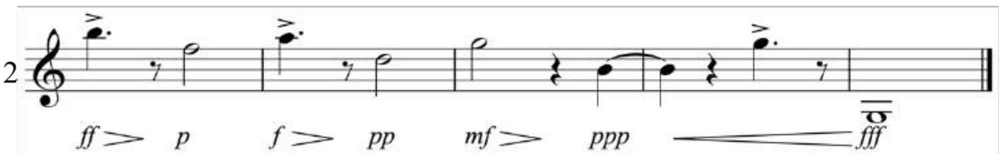
[44] See <http://www.arduino.cc>.

[45] Pulse Width Modulation, or PWM, is a technique for getting analogue results with digital means. Digital control is used to create a square wave, a signal switched between on and off. This on-off pattern can simulate voltages in between full on (5 Volts) and off (0 Volts) by changing the portion of the time the signal spends on versus the time that the signal spends off. The duration of "on time" is called the pulse width. To get varying analogue values the pulse width is changed or modulated. If this on/off pattern is repeated fast enough with a vibrating motor for example, the result is as if the signal is a steady voltage between 0 and 5v controlling the amount of vibrations of the motor. See <http://arduino.cc/en/Tutorial/PWM>.

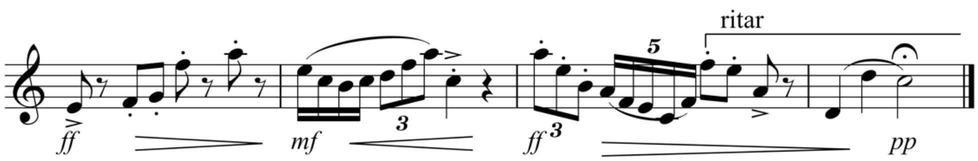
Exercises in Bb

Exercise 1

Exercise 2



Exercise 3



Exercise 4

Exercise 5

Exercise 6

Figure 4 - Exercises performed during the case study.

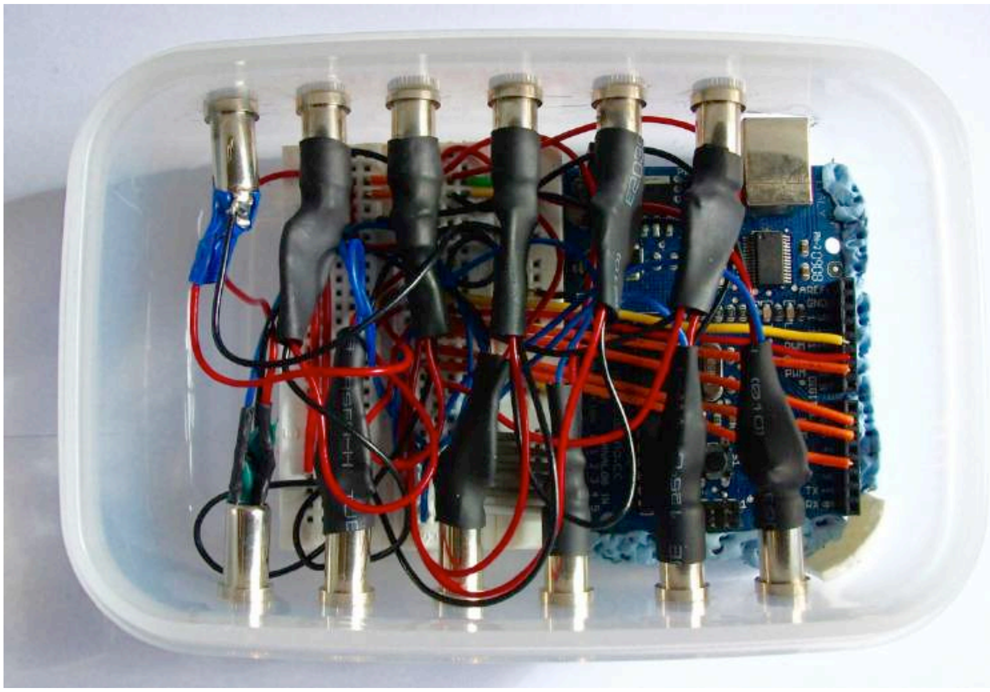


Figure 5 - Enclosure without the lid. There are six inputs and six output connections through the 1/8 female jacks. The Arduino is visible on the right-hand side of the box.

The skin is most sensitive to vibrations at a frequency of around 250 Hz (Mortimer, 2007). The motors used for the case study are 10mm coin vibration motor able to produce vibrating frequency 260 (Hz) resulting into a Typical Normalised Vibration Amplitude of 1.4 G (figure 6).[46]

Figure 6 - Shows the vibrating motor, the rubber enclosure and the 1/8 stereo jack connector. A UK one penny coin is included for size comparison.

[46] Refers to how much vibration amplitude is created when the motor runs at its rated voltage relative to a 100g target mass. It is a simple calculation to compare directly the produced vibration of the motors. Full specification of the motor can be found here:
https://catalog.precisionmicrodrives.com/order-parts/product/310-113-10mm-vibration-motor-3-4mm-type

This type of motor is activated at 1.6V (Typical Start Voltage) with a maximum operating voltage at 3.8V. The sensor glove was created using three Force Sensitive Resistor (FSR) commonly referred to as pressure sensors.[47] The sensors are attached on the glove's fingertips, the index, middle and ring finger. These are the same fingers used by trumpet players to operate the trumpet's valves. Figure 7 shows the FSR sensor (upper left) the glove (bottom left) and the performer using the glove and the placement of the vibrotactile motors (left hand).

Figure 7 - The FSR sensor (upper left). The glove with the sensors attached (bottom left). Performing with the glove and the vibrotactile feedback system (right). The velcro straps allow the placement of the vibrotactile motors.

[47] Pressure sensor in this thesis refers only to FSR sensors rather than any other pressure sensor such as atmospheric pressure sensor.

The placement of the vibrating motors was determined through experimentation with one of the trumpet players who was not included in the final study. The main objectives for the placement of the motors were to ensure comfort, effectiveness and cognition of the vibrations while performing. For instance, when a motor was placed on the shin of the leg, even though vibrotactile sensation was more effective, it was less comfortable than the placement on the hand. Other positions were tested such as waist, neck, chest, arms and other parts of the leg. For the final study, the vibrating motors were placed on the left hand of the performer, the inside of the wrist, the inside of the forearm and the inside of the biceps (figure 8).

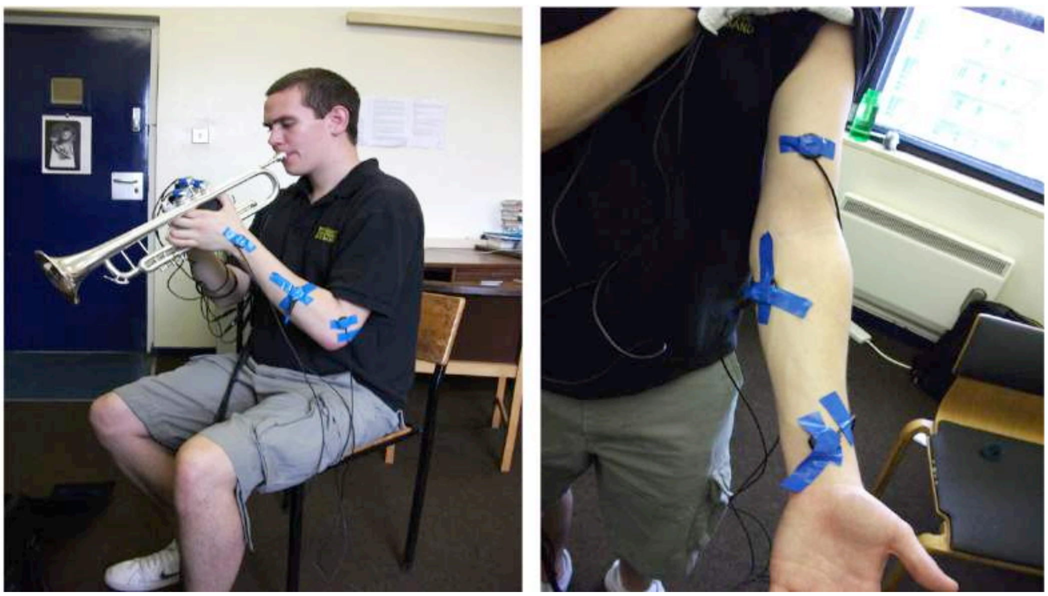


Figure 8 - Different placements of the vibrotactile motors. On the right the placement of the motors used for the case study.

The pressure sensors are activated when the valves of the trumpet are pressed. Depending on the notes and the valve combination needed to produce the required pitch on the trumpet different combination of pressure sensor data can be obtained. For example, note C4 can be played with open valves while the note E4 uses valves 1 (index finger) and 2 (middle finger). When the valves are pressed the pressure sensors register the applied pressure. The system was calibrated for each performer making sure that the pressure sensors are sensitive enough to register values when the valves are used. The data received was then used to control the audio processing and at the same time provide vibrotactile feedback confirmation about the applied pressure. Figure 9 shows the layout of the data flow of the case study.

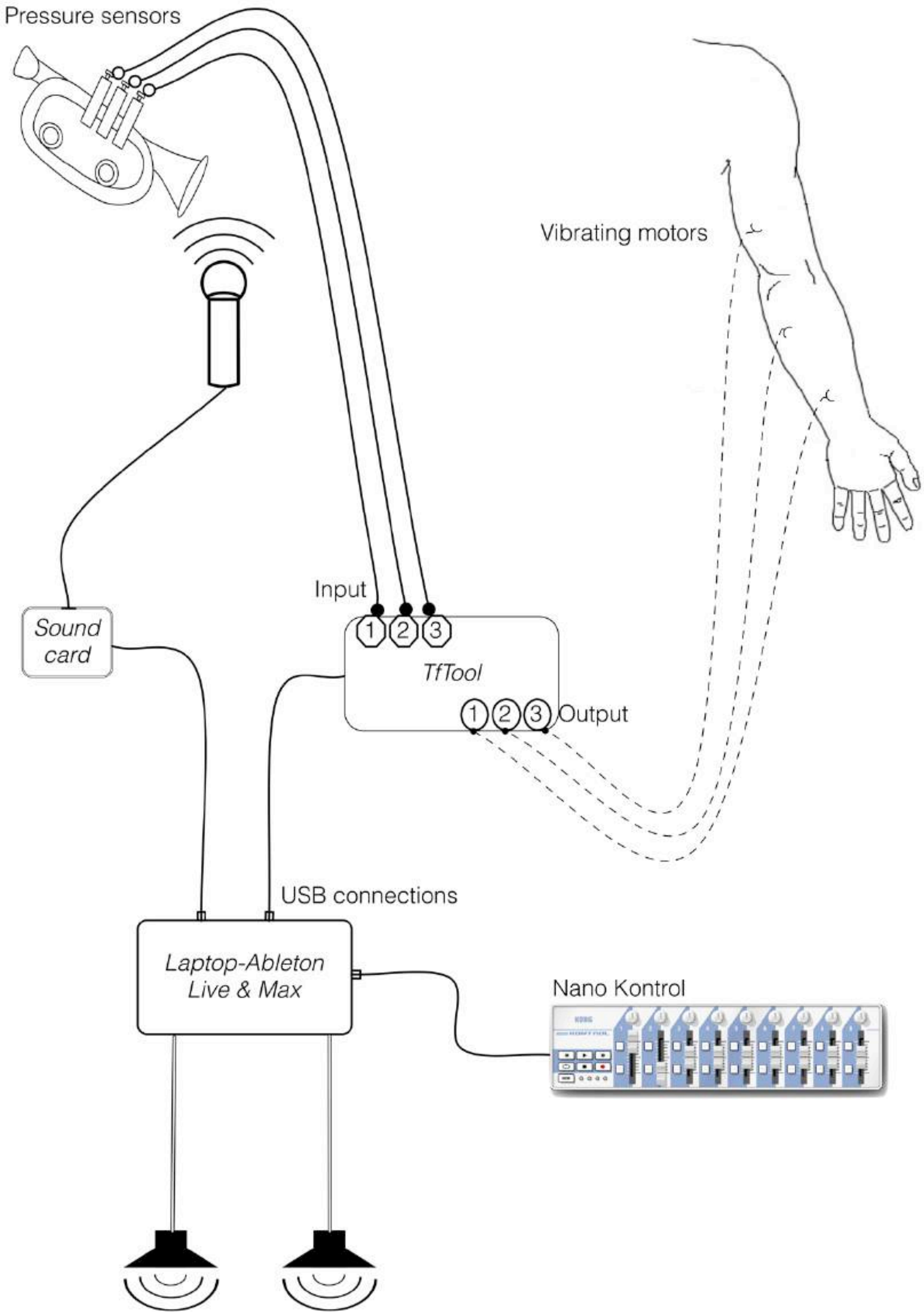


Figure 9 - The layout of the performance tests A and B. Test A uses the Nano Kontrol where Test B uses the sensors and the vibrotactile feedback.

4.1.3 Software

Two different programs were used: Max 5 and Ableton Live. A modified version of the Maxuino v.009 patch is used to control all data to and from the Arduino board.[48] Maxuino is a collaborative open source project developed in the Max environment to provide an easier and user-friendly communication between the software and different Arduino boards. It enables Max to receive data from the analogue sensors through a serial port and use them to control the processing and the motors. Max software provides a bridge between the Arduino board and Ableton Live, which was used for all audio processing. Within Max, data from the sensors are transformed into MIDI messages and sent to Ableton Live. At the time of the study the use of Max4Live software was considered; however, it was more effective to run the two software applications independently, separating the audio processing functions from the control of the sensor data.

4.1.4 Interview Methodology

4.1.4.1 Preliminary Interviews

Before the start of each interview a broad discussion took place with each participant about the aims of the study. Great care was taken not to direct the subjects to favouring any ideas or approaches. The layout of the case study was introduced followed by a description of the interview process and performance exercises that follow. The subjects were interviewed before and after the performance test. General questions were asked regarding the background and practice habits of each participant, including the amount of weekly practice, how long they had played trumpet, the genre of music they usually performed and if they played any other instruments. Following this, questions focused on the participant's understanding of the concept of live electronics and computer music in general. These questions aimed mostly to assess their knowledge of music technology in performance and composition. All the questions were addressed in a semi-open approach with the flexibility to address further any issues that may emerge during the discussion.

[48] See <http://www.maxuino.org/archives/58#more-58>.

4.1.4.2 Performance Test

The performing section of the study was divided into two tests, A and B. The participants split into two groups, *Group One* and *Group Two*. Each group performed the tests A and B in different order. Each test contained the play-through of the same six musical examples (figure 4). *Group One* played first the examples with the test A and then repeated all examples with the test B. *Group Two* performed first test B and then test A. Test A comprised a conventional approach to performing with technology while test B utilised the control of audio processing by the participants alone through the pressure sensors and the corresponding vibrotactile feedback. The standard approach assumes that another person will be responsible for the control audio processing functions during the performance of the piece. For Test A, the Nano Kontrol MIDI device was used to control the effect's audio processing (figure 9). This made it possible to compare the result of adding vibrotactile feedback to both new and previously-learned systems. Each performing test lasted around 25 minutes, and included two play-throughs of each musical exercise.

The short musical examples provided a range of musical and expressive variables, including articulation, note range, phrasing and dynamics. During the tests the tempo was unspecified allowing for free interpretation, something that was explicitly encouraged throughout the process. The examples were influenced by the trumpet fingerings. The finger combination needed to perform a particular note affects the pressure sensors and the way they are activated. In exercise 4, the music required the performer to use only fingers one and two that control the reverb and the frequency shifting effects.[49] In combination with the long notes and the absence of timing the performer was expected to concentrate on how the sound changes and the resulting vibrating feedback received. In addition, exercise 3 examined how the vibrating functions might work in fast musical passages, and tested the amount of awareness when the vibrating feedback was active.

The incoming data from the pressure sensor glove were processed and filtered providing a one-to-one mapping relationship between the sensor input and sonic effect. The audio effects have a linear relationship that reflected the amount of pressure applied through the glove while playing the trumpet. The vibrating motors also make use of a

[49] The three effects used during the tests were, index finger (1) controls the reverb, the middle finger (2) controls the frequency shifts, and the ring finger (3) controls the chorus effect.

direct one-to-one mapping relationship. The received data from the pressure sensor control both the audio processing and the intensity of the attached vibrating motor. This relationship was explained to the participants as ‘the more you press, the more process on the signal and the more it vibrates’. The individual calibration meant that maximum and minimum values received will be retained the same regardless of the difference in the applied force from each performer.

4.1.4.3 Final interviews

The final part of the interviews focused on questions concerning the performers’ understanding of what had happened during the tests. Participants were asked a variety of questions, including: which test (with or without vibrotactile feedback) they would prefer to practice with; the difficulties between the two tests; any difficulties with any particular musical exercise; the usability of the technology and hardware used; and their understanding of the relationships in both tests. The aim of these questions was to examine, from the performers standpoint, how and if vibrotactile feedback made any substantial difference to their performing approach and musical experience. The subjects were asked to evaluate how fast they could adapt, if possible, to this artificially-created haptic relationship. As the interviews were semi-open most of the times the conversation led to additional questions reflecting their personal taste and approach.

4.1.5 Results and Discussion

All six participants strongly agreed that vibrotactile feedback created a more pragmatic and understandable performance relationship between their actions and the ensuing electronics. Apart from the ability to measure the amount of effects processed through vibrations, all participants mentioned one significant difference between the two tests: vibrotactile feedback allowed them to know definitively whether the electronic effects were active or not. This observation is important since none of the performers had any previous experience performing with technology. The sense of uncertainty and insecurity on how the sound is transformed through the live audio processing was apparent during test A. In addition, they mentioned that when they played loud notes, and were not able to hear the processed sound, vibrotactile feedback served as a confirmation and reassurance that the system was working. Four performers became aware of the expressive possibilities while using the sensor glove with the vibrating feedback that was not the case without it. They noticed that while the expression generally comes from the mouth, using the glove and the motors they were forced to think and consider the amount of pressure applied on the valves. One performer commented that '…expression comes from the mouth and you have to think not only how to use the mouth but also the finger pressure to allow expressive changes of the sound'. Another performer observed that '…with a bit of practice (with the vibrating motors) I can learn to manipulate it properly'. Another performer noted that '…you had something coming back, you could feel and you know physically if something was happening or not'. One musician indicated that he could not hear the individual audio effects in test A but in test B he could feel the vibrations and focus more on the sound. Another performer suggested the following during the interview. 'From doing this now, I don't think that I will need additional practice time to get used to the motors. You could feel individually the effects through the vibrating feedback where in the run without the motors I was not able to know what was happening'. Four out of the six performers indicated that, given the option, they would choose to use the vibrotactile feedback in the preparation and performance of such compositions. To them, there was a substantial difference between tests A and B, mainly the awareness and control they had through experiencing vibrotactile feedback. With the remaining two performers, one preferred to focus only on the notated music having someone else to control all aspects of the computer processing. The remaining one had no distinct preference between the two systems.

The performers were questioned about how they perceived the basic understanding of the data flow from the controller, the sensor glove, to the resulting sound. Interestingly the group that took test B first could form a clearer understanding overall, as they could understand test A as 'something incomplete'. In addition, the participants were also asked if they thought that an understanding of the technology involved was necessary and possibly could improve their approach and performance practice. None of the performers were able to fully confirm this suggestion given the short amount of time available. The results of this study suggest that vibrotactile feedback has the ability to provide a framework to understand better the relationships between the performer and the interactive electronics.

After completing the tests, four of the performers requested to explore further the system. At one point, a performer realised that pressing the valves halfway through, the sensors could also be activated. When asked, the performer mentioned that the vibrating feedback made him aware of the sensitivity of the pressure sensors. He was then able to slide between notes, using the half valve technique, creating interesting and unanticipated musical results with the effects. Another performer realised that it was not necessary to press the valves to activate the pressure sensors. Consequently, the performer was able to play with all three effects by pressing on the hard surface of the trumpet. This also meant the performer was only able to play notes within the trumpet's natural harmonic series. In addition, one performer realised that an effect could be activated immediately after a note is played. Using the index finger, where the reverb effect is used, it was possible to play long reverberant notes by holding the first valve (reverb) and then introducing the other two valves (pitch shift and chorus) on the reverb's tail. Overall, the participants reported that the glove was comfortable enough and did not produce any significant problems while performing even in fast passages. In terms of latency, even though it was not measured, it had no negative impact on performers and their performance practice. A notable difference between the two tests is how the vibrotactile feedback and the sense of wearing a glove were able to establish an awareness of the technology which helped into exploring further sound possibilities. One generic observation from all subjects was how vibrotactile feedback could be used for communication within an improvisation session.

4.1.6 Conclusion

Results of this study support the hypothesis that incorporating vibrotactile feedback in technology-oriented performances and compositions can improve the overall control, perception and musicality of the electronics elements of the piece. There is insufficient evidence within this study to provide any statistically significant results regarding the amount of improvement, control and perception in performances. The qualitative results of the interviews gave indications that a vibrotactile feedback system significantly improves the way performers express musicality within the technology. The performers displayed an improved understanding of their actions in relationship with the pressure sensors and resulting sound produced. Consequently, the findings support the theory that vibrotactile feedback can enhance musicians' expressivity and creativity in performances.

Additionally, the use of vibrations suggested new musical possibilities not previously considered by the performers. Although the use of vibrotactile feedback introduces an additional layer of complexity within the system this seems worthwhile. The functionality of the vibrotactile feedback technology can provide a possible solution to a wider problematic use of technology in music performance. Adding vibrotactile feedback in the control path of the musician, the interaction is enriched allowing performers and composers to develop new creative relationships between them.

4.2 Case Study Two - Footpedals

Case Study Two aims to address a specific performance problem, the use of footpedals in interactive electronic performances. Footpedals are one of many approaches by which computers can be controlled by performers. Due to their overall simplicity, cost and compatibility with other MIDI devices and software, footpedals are widely popular. The use and functionality of the footpedal varies according to the decisions made by the programmer/composer. The design and execution of such a performer-computer relationship can prove challenging in a performance situation (McNutt, 2003), (Esler, 2004). Regardless of the level of complexity in any given system, using footpedals can be seen as a form of interaction between the musician and the electronics. Often composers require the on-stage performer to follow notated cues indicating the use of the footpedal to trigger or control specific functions of the computer system. However, it is common practice in such performances to have another musician monitoring the computer triggers to *fix* any missed cues when the performer fails to do so. This situation not only contradicts the idea that the on-stage performers determine all temporal aspects of the composition, but also removes the authority of said performers.

The foremost problem with footpedals comes down to its functionality. There is very limited feedback evidence of what has been articulated by the performer. This leaves the performer with little or no confidence in creating a dynamic system between the controller and the audible result. The flexibility of footpedals allows them to trigger a range of computer functions. It is possible to employ footpedals for the control of anything from audio playback to changing the configuration of speakers in the performance space. Additionally, footpedals may act as switches preparing the computer software to accept another form of input such as microphones, sensors or MIDI data. This approach results in footpedals with no predetermined functionality, making it very difficult for the performer to create a habitual relationship based on the sound feedback channel. The footpedal acts as a chameleon device able to carry out any audio processing, simple or complicated.

Whilst this is encouraging and acceptable, as it provides an arsenal of digital processing functions for composers, at the same time the footpedal is considered problematic from the point of view of the performer. For example, piano pieces such as *Urrealis* by Gorji and *Zellen - Linien* by Tutschku use the footpedal to start recording a section (Gorji, 2005), (Tutschku, 2007). This action does not yield any audible feedback, leaving the performer on stage unaware of whether the computer received this crucial instruction. A common solution by composers is to provide the performer with an additional computer screen that gives visual feedback about the articulated action. From the performer's point of view, this is not an advantage but rather a distraction. The performer already has to change visual focus between the score, the screen and often the conductor and other performers.[50]

The case study examines if by incorporating vibrotactile feedback in the footpedal performer becomes aware of her actions, gains more confidence when performing and is able to engage expressively with the electronics component of the composition. In addition, the results from Case Study One suggested that subjects can adapt and utilise the new relationship between their actions and the resulting vibrotactile feedback thus implying that vibrotactile feedback could be used in existing compositions that use footpedals.

A bespoke device was built to provide vibrotactile feedback for each successive trigger and expressive control for two different types of footpedals, switch and expression pedals. For the expression pedal the vibrations vary in intensity according to the values received from the pedal. Sebastian Berweck, a professional pianist, carried out tests for this case study.

4.2.1 Hardware

Another version of the device called *Tactile-Feedback-Tool* (*TfTool*) was created for the purpose of this case study (Michailidis and Berweck, 2011). The *TfTool* receives the

[50] Case Study Three examine further the pros and cons of the use of vibrotactile feedback in relation to the use of computer screens on stage.

signals from switch and expression pedals, converts them into MIDI data and provides feedback confirmation in the form of vibrations (figure 10).

The device uses the Seeeduino V2.2 (Atmega328P) board, based on the Arduino open source prototyping device.[51] The board is capable of receiving up to eight analogue and fourteen digital inputs. The fourteen digital inputs also serve as outputs, of which six can provide (PWM). Connectivity with a computer is through a mini USB port, allowing programming and powering of the board as well as exchange of data information. Once the code is uploaded to the microcontroller, it stays there until a different code is uploaded. The board is enclosed in a small plastic box to provide easy transportation and protection (figure 10). There are four inputs and four outputs on each side of the box. A 1/4 inch jack is used for all inputs as this was intended for the use with footpedals that have a 1/4 inch jack connection as a standard. The four inputs are configured to use two expression pedals (or other similar analogue sensors) and two switch pedals. The PWM output pins use 1/8 inch jack connection and are capable of simulating voltage control to run the vibrating motors. The same model of motors from Case Study One has been used here.

The sustain or switch pedal closes or opens the circuit giving a signal to the connected software or hardware.[52] The expression pedal uses a potentiometer that acts as a variable resistor. In the same way as other types of analogue sensors, the expression pedal uses the analogue input on the board. This enables the use of continuous controller MIDI values and the resultant vibration. A calibration function exists in the Max software (discussed later) that allows any type of expression pedal to be used. Other analogue sensors can also be used with the *TfTool* device.

[51] The Seeduino board is a clone version of the Arduino using similar function including the Arduino software for uploading the code to the device.
[52] These types of footpedals are often referred as sustain pedals or switch pedals. Sustain pedals because often the same sustain pedal from a digital piano/keyboard is used. Throughout the thesis I will refer to them as switch pedals as it is more appropriate for their functionality.

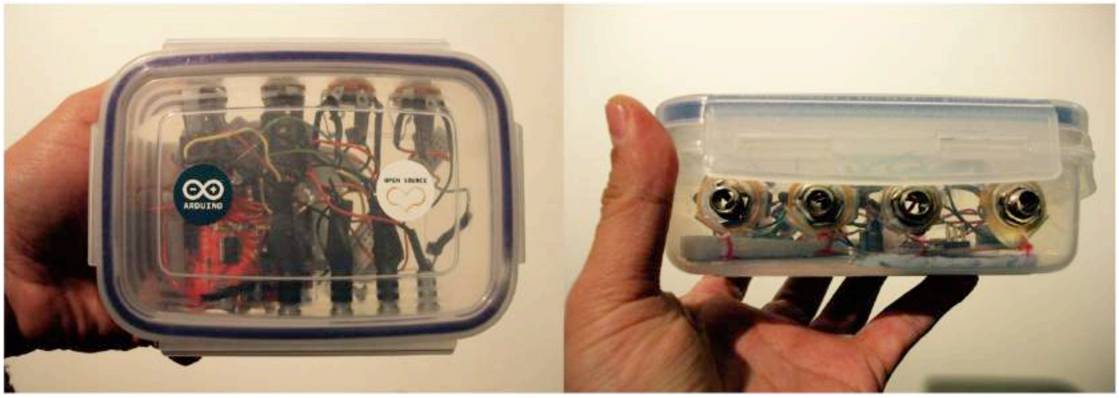


Figure 10 - The *TfTool* device. Right picture shows the input connections for four footpedals, two switches and two expression pedals. Left picture is an overview of the *TfTool.*

4.2.2 Placement of the Vibrating Motors

To allow maximum effectiveness of the vibrotactile feedback, the motors should be placed in optimal positions on the performer's body. Data from Case Study One showed that the placement of the motors depends greatly on the instrument. Tests were carried out with the pianist to assess practicality, effectiveness and discretion during performance. From these trials, the optimal placement for a single vibrating motor was determined to be on the ankle of the left foot of the performer. This is because pianists often uses the right foot for the sustain pedal of the piano. Using two vibrating motors for the switch and the expression pedal, the optimal placement was one on the ankle and the other halfway up the shin on the left leg. This allows for a clear distinction between the two motors. The shinbone is large without too much muscle between the skin and the bone allowing the vibrations to be transmitted and sensed through the length of the bone and joints.[53] A reusable velcro elastic strap is used to attach the motors to the leg.

4.2.3 Test and Results

The *TfTool* device was tested with two compositions often performed by the pianist Sebastian Berweck. First, the composition *Zellen - Linien* by Hans Tutschku, uses a switch pedal to set the computer into a waiting state for the next loud incoming audio signal received through the microphone (Tutschku, 2007). This means that the pianist has

[53] As described earlier in Krueger, Von Békésy demonstrates that vibrations can be sensed not only from the skin of the body but also through deeper receptors in the joints and bones (Krueger, 1982).

no direct feedback information, aural or visual, from the triggering action. During previous rehearsals and performances the performer had to rely on help from another person, tasked with checking and correcting any mis-triggered pedal cues by monitoring the software on the computer screen. The composer confirmed that this is the case with other performers that he worked with thus far.[54] The *TfTool* was easily integrated into the practice routine and allowed the performer to experience the necessary feedback when triggering the footpedal. The vibrotactile feedback became part of the implicit memory used for practicing the piece. The performer, although still not hearing a direct audible result, felt much more comfortable and confident when vibrotactile feedback was present.

The second composition was by Enno Poppe, *Arbeit* for virtual Hammond organ (Poppe, 2007). The performer is required to press the pedal 45 times to change between different sounds. The changes take place in short pauses between the different sections of the piece. Although the performer immediately hears the altered sound when he begins to play, it would then be too late to correct any mis-activations from the pedal. As a solution a computer screen is used close to the performer to confirm successful triggers of the pedal. This is a distraction for the performer who needs to focus on the score and concentrate on the upcoming music. Although a partial setup was used during testing, the vibrating confirmation provided enough confidence for the performer not to look at the computer screen for confirmation. This ultimately led to a more focused interpretation of the composition.

The vibrating motors were found to be comfortable, not requiring any prior experience or practice. The motors are inaudible making them suitable for use in quiet musical passages. *TfTool* can be integrated easily into most existing compositions that require footpedals.

4.2.4 Software Implementation

Max software is used for the implementation of all functions of the *TfTool* making it a generic device easy to implement with any existing composition. Incoming data messages from the pedal inputs are converted into MIDI messages for further control of audio processing within other MIDI compatible devices. The same MIDI message is routed internally within the software to trigger the motors and provide feedback confirmation

[54] Private conversation between Sebastian Berweck and the composer in 2010.

back to the user. This approach of activating the vibrotactile feedback after the MIDI signal means that the vibrations are active only if there is a successful trigger of the audio process. The signal from the pedal can be used for a variety of different functions and controls of the composition. Even though some pedals offer different functions such as the latching mode and polarity switch, these are often ignored since they can be configured within the software patch. This allows the use of any footpedal regardless of their functionality.

All pedals provide the same raw information to the software. This consists of a pulse received by the *TfTool* from the switch pedals or as a continuous stream of data from the expression pedal. The functionality of the vibrotactile feedback needed to reflect the implementation of the functionality of the pedals within the system. As a result five different functions were identified and utilised in an attempt to describe a more generic use of the vibrotactile feedback within the system. Other functions of the composition that do not use footpedals or other sensor technologies could also benefit from the use of the vibrotactile feedback. The five functions are:

a. Active
b. Active Off
c. Duration
d. Upcoming function
e. Expressive

The five proposed functions seek to classify and identify the way vibrating feedback is applied and experienced. The *Active* informs the performer when a function in the system is activated. For example, when the pedal is pressed the performer receives a vibrating confirmation as well as when something is activated within the created system and the performer needs to be aware. The *Active Off* notifies the user that an action is deactivated. Similarly to the *Active* function, this might be enabled through the pedal or within the system. For the *Duration*, the performer is informed about the duration of a particular function such as an audio effect or the length of an audio playback file. The *Upcoming function* alerts the performer about future events within the system and the compositional process. The *Expressive* provides a dynamic feedback on the use and control of functions in the system through the expression pedals, sensors as well as automated functions within the system.

4.2.4.1 Active and Active Off

Active indicates successful triggering of a cue that has been carried out from an external device or internally from the system. In this case study, *Active* informs the performer about successful triggers of the footpedal. It can also be used as a part of the wider system that simply informs the performer about active changes. When used with external devices such as a footpedal, the duration of vibrations depends on how long the pedal is pressed. This is possible as the duration of the motor is configurable. During an intense music passage the instrumentalist might need to hold the pedal longer than usual making sure that the confirmation is received.

Other approaches have been considered to explore the different ways in which vibrations may respond to suggest and represent the *Active* state. Tests have been carried out using the footpedal to experiment with different durations and settings of the vibrating system. The tests included the vibrating duration of 1000ms, 2000ms and 3000ms when the pedal is pressed regardless of how long the user holds down the pedal. Other approaches, more exploratory, were implemented including two vibrating pulses of a 500ms duration with 250ms gap as well as other combinations including three and four vibrating pulses at different timings. Overall, testing different durations created more confusion to the performer than confidence. The most effective approach was to allow the pedal to vibrate for as long as it is pressed. Even though the tests took place in a lab environment rather than in actual performance there is no evidence that different outcomes are expected in a performance scenario.

The role of the *Active Off* function is to indicate that a function has ended. Performers need to know when a software processing function gets disengaged. This could be the deactivation of audio effects, stop an ongoing live recording or terminate any other function in the composition. It can be executed through the performer's action such as a using the switch pedal or through an automated function in the software. The vibrations should be able to reflect the *Active Off* function in a distinctive manner different from the *Active* function. This became a challenge when implemented through vibrations. The proposed solution is to introduce an additional vibrating pulse to indicate the *Off* function. When the pedal is pressed to deactivate something in the system the motor vibrates for the duration it is pressed, similar to the *Active* function. When released, an additional vibrating signal is activated immediately after with a 1500ms fade out duration. Figure 11 shows the *Active* and *Active Off* diagram.

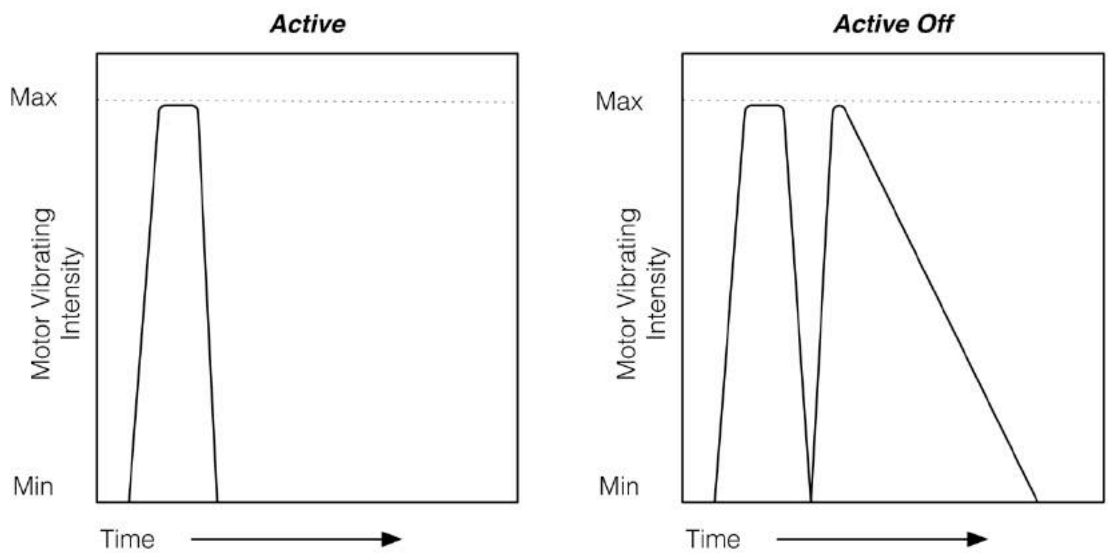


Figure 11 - *Active* and *Active Off* vibrating functions.

This function is particularly useful when performing in a surround environment. For example *Active Off* provides feedback when an audio playback ends regardless of the position of the sound in the surround system.[55]

4.2.4.2 Duration and Upcoming function

The *Duration* function indicates how a particular function is activated for a specific duration. This includes the playback of an audio file or the duration of an audio effect. The vibrations are active for the duration of a function. It can also implement dynamic changes of a function, when possible, through the intensity of the vibration. For example, figure 12 shows a section from the composition *…Big Crunch*. During the audio playback, the performer feels the amplitude of the audio playback through vibrations. In addition, the *Active Off* is also implemented during the end of the audio file as discussed earlier.

[55] Composition *Big Bang…* section 5.2 makes use of *Active* and *Active Off* in this way.

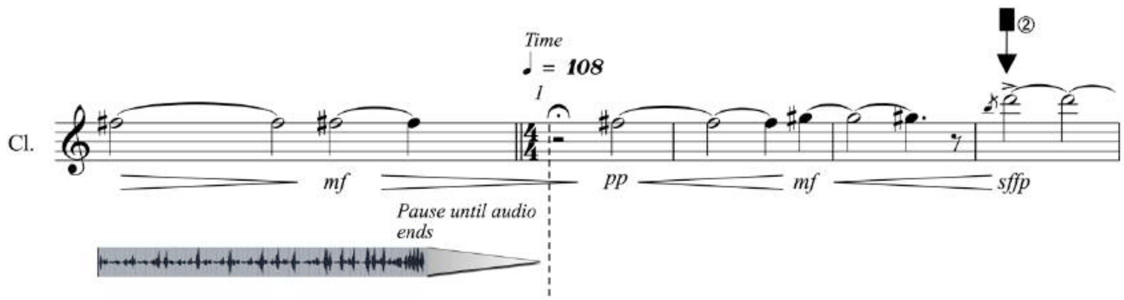


Figure 12 - Shows a section of the composition *...Big Crunch*. The *Duration* and the *Active Off* functions appear in the score.

The *Upcoming* function is effectively a cue system for any upcoming functions in regards to the score and the electronics in particular. The aim is to prepare and make the performer aware of any upcoming changes in tempo, sections, timing and any other functions. In the composition *Barbaróphonos*, the *Upcoming function* is applied in order to inform the instrumentalist about the upcoming changes in the improvisation section. It makes the performer aware of the length of the improvisation without the need for any other external information.

4.2.4.3 Expressive

The *Expressive* function provides information about the state of the expression pedal or a similar sensor input device. The data received from the potentiometer sensor within the expression pedal are of continuous form. This means that there is no sudden jump from one position to the other as it happens with the switch pedal. This produces data in a sequential fashion able to drive the motors. The vibrotactile feedback informs the performer what has been applied to the system. For example, the expression pedal can be used to control the intensity of the reverb in a passage. The vibrations felt can inform the performer about the amount applied to the reverb and thus have a better control. We have discussed earlier that performers are not able to establish a relationship with pedals and other sensor devices because the sonic outcome of their actions bears no constant relation to their actions. With vibrotactile feedback the performer is able to learn and establish new tactile relationships. It can serve as mediator between the performer's actions and the resulting sound. Once this new relationship is established and learned any changes in the audio parameter will not affect the experience of the performer as the vibrotactile sensation will retain the same feedback qualities. In addition, the *Expressive* function can be applied through the playback of an audio file. The amplitude of the audio file can be used for the playback of the vibrations. This does not imply a representation of volume through vibrations but rather a more discreet approach as a means of guidance and communicative feedback from the composition.[56]

4.2.5 Conclusion

This case study examined the use of *Tactile feedback Tool*, a device capable of providing vibrating signals to the performer. The device was used to address a well-known problem in interactive electronics, that of the use of footpedals. To overcome this problem the proposed solution is to apply vibrating feedback channels to inform the performer about the functions of the pedal. Five different vibrotactile applications have been suggested with the use of the pedals: *Active* informs the user when activating a process; *Active Off* informs the user about the deactivation of a process; *Duration* attempts to inform the user about the duration of a process; the *Upcoming function* alerts the user of any upcoming changes in the composition; and *Expressive* is able to provide direct vibrotactile feedback to the user about the applied input. Direct actions of the performer, such as the control of the volume pedal, are translated into vibrating intensity thus informing the user through a closed feedback loop. With the successful integration of software programming and hardware used, *TfTool* can inform the performer about the state of the composition enabling confidence and expressiveness in performance. These five vibrotactile settings can be used in combination and require minimum learning of their intended functionalities in the system. These functions can be integrated into the existing compositions and performance practices. A combination of these functions has been employed in the compositions *Barbaróphonos, Big Bang…* and *…Big Crunch*.

[56] For the interested reader the following papers examine the role of vibrotactile feedback as a musical device reflecting pitch and amplitude (Marshall, 2006), (Birnbaum, 2007), (Giordano, 2011).

4.3 Case Study Three - Cross modality

Case Study Three explores ways in which visual and vibrotactile feedback may remedy the lack of feedback information while performing with electronic controllers and other sensor technologies. The chosen methodology of the study was reflective practice on behalf of an instrumentalist rather than a group of musicians. Having an intimate relationship with the performer, it was possible to study in detail the relationship between the performer and multimodal forms of feedback. This study examined different scenarios that are commonly employed in the practice of performing with technology and in particular within the concept of live electronics. A single musical piece, *Big Bang...* served as working material for this case study, leading the musician through a series of performance settings each involving varying amounts of feedback information.[57] The study investigated the effect and impact of visual and vibrotactile feedback while performing a composition using two footpedals.

Whilst both visual and vibrotactile feedback provided specific and meaningful information, this study demonstrated that visual and vibrotactile modes of transmission could be optimised for different informational content. This suggests that the content experienced by the performer is more important than the specific mode of transmission. In a similar study, Burke *et al.* suggests that the combination of visual-auditory feedback is more effective in single task scenarios under normal workload, while visual-tactile feedback is more effective when performing multiple-tasks with high workload (Burke *et al.,* 2006).

The acoustic musician has to overcome a challenging performance situation when controlling and executing a complex and often unnatural performer-computer relationship. Very often visual feedback through an additional computer screen on stage is commonly employed as a practical solution in order to inform the performer about different functions of the technology. We have already noted how this can present more problems than providing a solution in terms of the concentration of the performer. Another way, suggested through this thesis, is to provide vibrotactile feedback information that enables confirmation for different performing functions of the composition.

[57] For the purposes of this case study the score has been modified in order to examine different performing scenarios.

Technology mediated performance requires a variety of different kinds of interaction depending on the composition. Pieces such as *Voi(Rex)*(2003) and *Extended Apocalypsis* (2011) by Philippe Leroux require the performer to use a handheld switch button that activates predetermined computer functions. In a similar manner to the footpedal issue discussed earlier, the performer lacks important feedback confirmation about her actions. In both pieces the composer supplies the performer with an on-stage display to provide visual confirmation of her actions. In *Voi(Rex)* the on-stage screen is placed at a height within the visual angle of the performer and displays current events and sections of the composition as well as a confirmation for a successful trigger.[58] In *Extended Apocalypsis* the on-stage screen is placed on the floor. Out of the direct visual angle of the performer, it flashes the entire screen for one second when a successful trigger is executed.[59] The compositional approach and the performance setup determine how comfortable and familiar the performing environment will be for the musicians involved. In both cases however, the screen could have been replaced with vibrotactile feedback. Such concerns and approaches are discussed and examined in this case study.

4.3.1 Hardware

The performer uses two types of footpedals: a switch pedal and an expression pedal. The switch pedal changes cues within the piece's program. The expression pedal controls the levels of activation applied to different audio effects. The software Ableton Live is used to run all live audio processing while Max software is used to receive data from the pedals, convert them into MIDI data and control the vibrating feedback received by the instrumentalist.

For the purpose of examining the visual feedback, a 14-inch standard computer display is used to show both changes in numbers according to different cues from the activation received from the switch pedal as well as a dynamic graph of the output of the expression pedal. The screen is positioned in such a way to be visible just above the performer's music stand (figure 13). The use of a smaller, portable wireless display such as a tablet or mobile phone was tested during the construction of this case study;

[58] Email correspondence with Jonathan Green, the electronic musician who performed the piece.
[59] Email correspondence with Peter Plessas, the electronic musician who premiered the piece.

however, at the time there was a significant latency between the wireless tablet device and the laptop, which made the system unpredictable for providing visual feedback.

Figure 13 - On screen visual feedback presented to the performer (left) and the position of the screen in performance (right).

An updated version of the *TfTool* device, discussed earlier in Case Study Two is also employed here. The switch and expression pedals make use of two separate vibrating motors. Signal from the pedals is converted into MIDI through the *TfTool* that then provides feedback through the motors as well as the necessary visual feedback through the screen. The motors are placed midway up the performer's shin, on the left leg for the switch pedal and on the right leg for the expression pedal. The position of the vibrating motors was agreed upon after testing their placement on different parts of the body. This included the ability to be worn during a concert, the musician's performance position, actions, sensitivity and comfort. For a standing performer it was more practical and effective to balance on different legs according to the required use of the pedal. The pedals were calibrated so that the performer senses the vibrations immediately, leaving no gap between any actions and the resulting feedback. Reusable Velcro elastic straps were used, allowing close contact between the vibrating motors and the performer. The diagram in figure 14 shows the equipment and the setup layout for the case study.

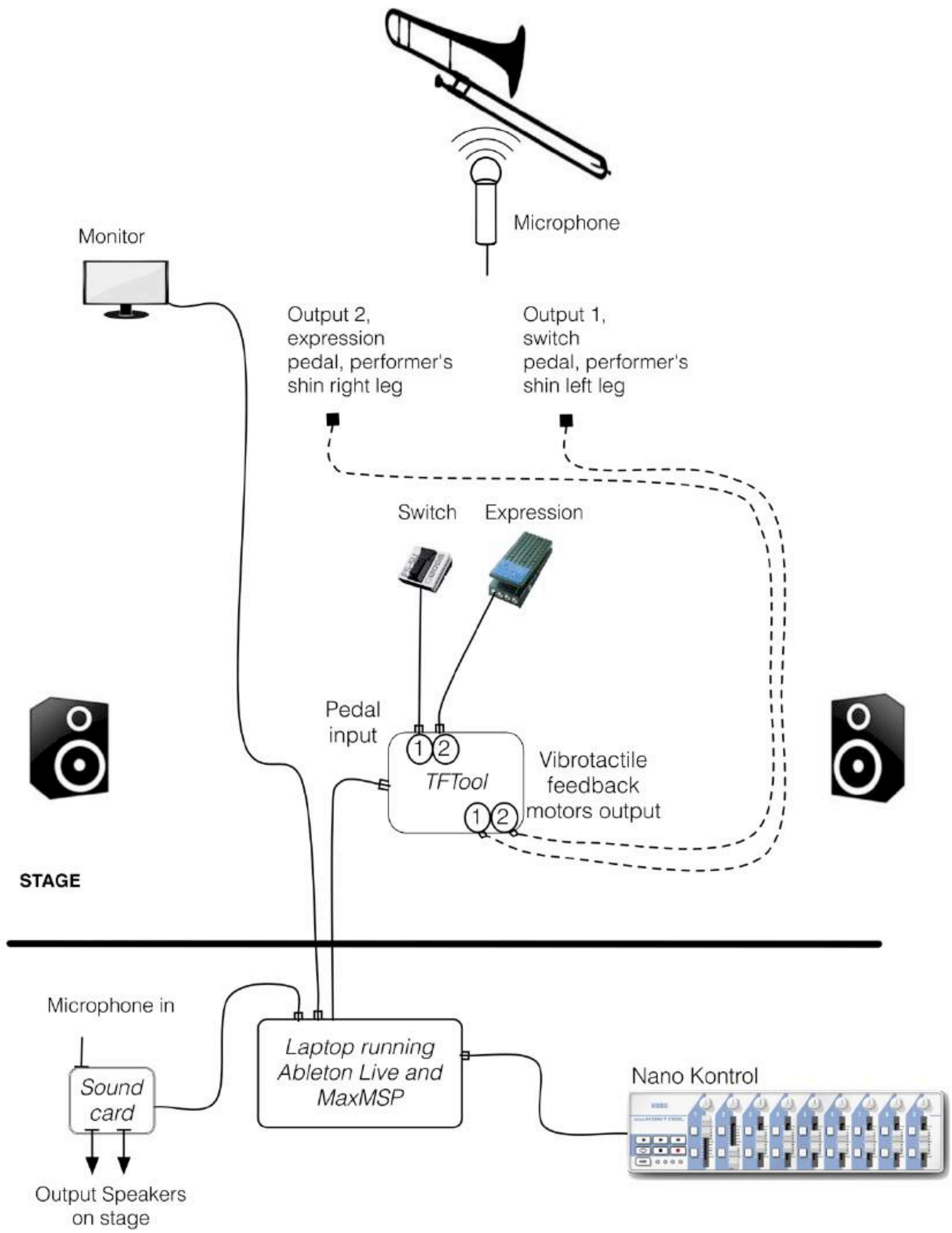


Figure 14 - Layout and equipment used for Case Study Three.

4.3.2 Methodology

The composition *Big Bang…* was used as a framework to examine the integration of two sensory feedback modes visual and vibrotactile feedback. The performer, whilst not experienced with working with processed sound, has a large amount of solo and ensemble experience and training, and performed the piece in its entirety in five different configurations over two sessions. The first session included the performance configurations in the order given below. The second session took place one day afterwards, reversing the order of configurations so as to minimise the effect of familiarity with the piece and preferability.

1. *Duet*: The electronic performer controls the electronics using the *nanoKontrol*. The bass trombonist performs only the notated trombone part.[60]

2. *Solo*: The bass trombonist controls the electronics with the footpedals. There is no additional feedback provided.

3. *Solo*: The bass trombonist controls the electronics with the footpedals. Only visual feedback is provided.

4. *Solo*: The bass trombonist controls the electronics with the footpedals. Both visual and vibrotactile feedback is provided.

5. *Solo*: The bass trombonist controls the live electronics with the footpedals. Only vibrotactile feedback is provided.

These configurations were devised to reflect both the possible combinations of aural, visual and vibrotactile feedback, which may be present considering also the traditional performance practice of live electronics. In the first scenario the electronic components are controlled by the electronics musician while the instrumentalist performs the music resulting in a duet performance. In the remaining scenarios, the on-stage soloist has complete control over the electronic component, albeit with different configurations of

[60] Electronics performer refers to the musician controlling the electronics elements of the composition.

feedback available. After each play-through an open discussion took place with the performer examining how each configuration affected the performance experience. Both sessions were video-recorded and analysed.[61] The following observations developed through discussion with the performer.

4.3.3 Results and Discussion

Both the electronics performer and the instrumentalist perceive the first performance configuration as a duet. They have creative control over the final work and they interact with each other in a manner befitting an ensemble rather than a solo performance. It creates practical and aesthetic implications of conceiving pieces as solos or duets not only for the audiences but also for performers. Should a composition be intended as a solo work, it should be able to be practically executed as a solo, rather than as a duet. This distinction results in significant implications for the development of interpretation as well as the perception of creative ownership of the performance. Feedback from the electronics was not applicable to the instrumentalist since the electronics performer carried out all the audio processing functions.

For the second configuration the instrumentalist controls all aspects of the electronics through the footpedals without visual or haptic feedback. The performer felt insecure and unable to know if a successful trigger was received by the system and triggered the cue. During rehearsals the performer had to stop several times as he was lost in the score after triggering the footpedal cues. This contradicts the habitual relationship that instrumentalists have when performing music, the feedback confirmation about their actions.

The third configuration provides the performer only with visual feedback through the monitor. Within this performance context, visual feedback was deemed most appropriate for presenting semantic information. It was able to directly express semantic information such as the current event or time duration of the piece. This information may be easily understood as it relies on written language or imagery therefore providing a very low learning curve, able to express a range of meaningful information in an efficient manner. From a more practical standpoint, visual feedback can be executed through

[61] For more information about the configurations, see USB flash drive, 2. *Big Bang..,* Case Study 3_Video Excerpts

widely available ‘plug and play’ displays. Notwithstanding these benefits, there are several downsides in the use of visual feedback. Primarily, it requires a change of the performer’s focus. Even though the display was directly above the performer’s music stand in this situation, the performer needed to actively *look at* the display in order to receive any information. There was an inherent separation from the performer and the action that the display was visually representing; a potentially open feedback loop. This may be remedied through the use of electronic scores where actions from the performer may appear directly and on real time on the digital score. Berweck addresses similar issues from the performer’s point of view (Berweck, 2012). The effectiveness of the use of the screen depends largely on the composition. If the composition allows for the attention of the performer to focus on the screen or the performer improvises with the help of the screen then this does not imply any major performing issues. Overall, the performer benefited from the visual feedback in instances where immediate confirmation was needed during the performance. For instance, when using the switch pedal to change a cue the instrumentalist quickly refers to the screen to confirm that he is on the correct cue as indicated in the score.

The fourth and fifth configurations introduce the use of vibrotactile feedback in performance. Vibrotactile feedback provided meaningful information in a different but not necessarily *better* way than visual feedback. Contrary to the use of a display, vibrotactile feedback does not require a change of the performer’s focus. There is a more direct relationship between the performer and the computer. The feedback received by the performer feels inherently more dynamic and personal than that provided by a display. Whilst it functions appropriately as a notification system for triggering cues it is determined to be best suited for the expression of dynamic information. The physical control of the expression pedal was perceived to be very small, particularly given the performer’s lack of experience gauging kinaesthetic properties of his ankle. Vibrotactile feedback effectively magnifies these properties, allowing for real-time dynamic information as to the amount of signal being sent from the expression pedal. Even though it is likely that a performer would be able to improve their abilities to gauge the angle of his ankle through extensive practice, vibrotactile feedback replaces this extended learning process. As opposed to visual feedback, vibrotactile feedback does not require a performer to change focus; however, there are definite limits to the effectiveness of vibrotactile feedback. Most importantly, it presents difficulties in expressing specific semantic information. Whilst a linear relationship exists between the pedals used and the amount of vibration felt the expression of large numbers requires the learning of new associations. This may create a steep learning curve beyond the most basic of associations. Likewise, questions remain as to how to adapt both the placement and delivery of vibrotactile feedback to a wide range of instruments. As a result there is no universal implementation of vibrotactile feedback as it greatly depends on the instrumentation.

The instrumentalist found that configuration four was best and provided a complete feedback experience. The visual feedback was constantly present when needed in terms of the number of the cue and the vibrotactile feedback provided an intimate experience in using the expression pedal.

4.3.4 Conclusion

This case study does not suggest that either visual or vibrotactile feedback is significantly better than the other, nor is such a judgment necessarily the goal of this study. My argument is that it is not the mode through which information is transferred that is important, but rather the kind of information that may be best suited for each mode and instrumentation used. Both visual and vibrotactile feedback may prove to be useful within the wider live electronics concept. However, their benefit depends on the kind of information being transmitted. I will argue that vibrotactile feedback provides more musically expressive feedback than visual.

Composers often rely mostly upon visual feedback when they need to provide non-score related information to the performers. One rationalisation of this is due to the practicality of displays with their 'plug and play' functionality and their commercial availability. As handheld devices such as mobile phones and tablet computers are becoming increasingly fashionable in musical performances, they may provide one avenue by which visual feedback may be developed even further. On the other hand, vibrotactile feedback currently requires often a novel and custom made approach for its development.[62] This may discourage composers and performers from the use of

[62] The following research looks at such novel and custom-made approaches (Marshall and Wanderley, 2006), (Giordano and Wanderley, 2011), (Hayes, 2011), (Marshall and Wanderley, 2011), (Giordano and Wanderley, 2013).

vibrotactile feedback devices, as they are not commercially available. The conclusions of Case Studies One and Two suggest that training and education of new performers with this mode of feedback can result in both practical and aesthetic benefits. McNutt suggests the need for dialogue between performers and composers about the use of technology in performances (McNutt, 2003). Vibrotactile feedback may be a part of such dialogue to increase acoustic instrumentalists' accessibility and understanding of the technology used in interactive electronics performance.

From the composer's point of view it may be worth considering both what kind of information needs to be delivered to musicians during performance and the medium which would suit that information best. Beyond the practical considerations of the modes of feedback explored in this study, it is worth considering some philosophical issues that arise. The first configuration is clearly a duet between the laptop performer and the instrumentalist. While this setup is not necessarily problematic, it does raise the question of whether a piece conceived initially as a solo can be performed as a duet. In addition, the vibrotactile feedback presented during the control of the electronics made the performer feel more responsible for the resulting artistic creation. The way it felt to perform the piece as well as the aesthetic decisions made during the performance were markedly different with the addition of vibrotactile feedback.

This case study provided insights into the practical and aesthetic implications of visual and vibrotactile feedback in interactive electronics performances. More questions are raised with regards to the level of effectiveness of both visual and vibrotactile feedback that extend beyond the scope of this thesis.

4.4 Case Study Four - Performing Electronics

Results from Case Study One, Two, and Three showed that new performing associations may be learned through vibrotactile feedback. Case Study Four attempts to investigate that; if and in what ways vibrotactile feedback can establish a habitual relationship with the performer, and if this may result in increased confidence suggesting an expressive and creative use of the technology involved.

The assumption in this case study is that through time, over different performing, compositional and rehearsal techniques, the performer can establish and develop an expressive and performative approach to interactive electronics through vibrotactile feedback. To do so, the performer needs to be monitored systematically while accessing and evaluating the performance experience. The composition *Barbaróphonos* provides the framework for this case study and examines the role of vibrotactile feedback over time.

4.4.1 Background

Having gained experience of performing and composing with technology over the past number of years, I have noticed an emerging pattern in the relationship between performers and technology.[63] My attention hones in on two interrelated issues that greatly affect and influence the performer's ability to present what we might refer to as *successful* technology-driven music performance: firstly, the often limited documentation and supporting material for the electronics section and second, the lack of quality rehearsals with the specific performance setup. Other non-musical factors such as performance venue, cost, rehearsal times and hardware issues also contribute to uncertainty and frustration from the performer's view (Berweck, 2012). A fully featured rehearsal will only take place just before the concert.[64] This is similar to learning different sections of a piano concerto, only being able to perform in its entirety complete a few hours before the concert. When technology is involved, all hardware and software elements are part of the composition even though they are not presented in the score.

In 2003, McNutt argued that it is important for the performer to practice with the equipment used in the concert and performers should be able to understand the technology and the effect that it has on the processing of the sound (McNutt, 2003). Today, this issue is still apparent to the performer and impacts deeply on how professional performers are trained in this field (Bullock *et al.*, 2013). For most instrumentalists the technology is not adequate to their expectations, resulting in

[63] During my studies at Birmingham Conservatoire I have organised and curated numerous computer music concerts and I have performed my music in festivals and conferences. I have acted as the electronics performer looking after the technology in numerous performances by composers such as Kaija Saariaho, Philippe Hurel, Pierre Boulez, Jonathan Harvey, Hilda Paredes and worked with internationally renowned performers in this field such as Garth Knox, Barbara Lüneburg and Xenia Pestova.

[64] A rehearsal a few hours before the concert is becoming a standard practice. Due to mainly logistics and the expenses involved the performer very rarely gets a chance to rehearse with the same equipment that will be used in the concert. As a result the rehearsal time allocated is used to adjust and fix problems rather than allowing the performer to develop and expressive relationship with the technology.

widening the gap rather than bringing them together. There are many reasons why technology might look unappealing to a newcomer. The limited and unfamiliar feedback experience from the use of the electronics, the lack of instructive information and the overall understanding about the resulting sound contributes substantially towards a problematic experienced.

This case study is based on the collaboration with a trumpet player. The performer required a new interactive electronics piece as part of his final year project. The collaboration was a great opportunity to examine further the aims and concerns discussed above, as well as giving me the opportunity to research further different approaches and long term implications of vibrotactile feedback. The trumpet player, Ben Murray, was an experienced classically trained performer participating in orchestras and various concerts and at the time of the collaboration he was unfamiliar with any form of technology-driven performances. His lack of experience was favourable to the research since the outcome of monitoring any influences of vibrotactile feedback would be without prejudice.[65]

What is noticeable in this collaboration in contrast to what is often expected for such technology-driven concerts, were the regular rehearsals. The same hardware and software technology was used in both rehearsals and concert. As we were both based at Birmingham Conservatoire, it was possible to setup the equipment permanently in a rehearsal room giving the opportunity for the performer to have regular rehearsals with the electronics with no setup time. The performer learned to operate the software and hardware, including the use of vibrotactile feedback, without any additional support. As a result, it was possible to have regular rehearsals that resulted in the formation of a vibrotactile habit. The habit formed a communicative link between the performer and the technology ensuring confidence and expressiveness during the performance. In addition, regular discussions took place concerning the role and use of the technology involved from the composer's standpoint and how the technology was experienced through the performer's eyes.

[65] The collaboration started 5 September 2011 with meetings and rehearsals becoming more frequently towards the concert day 19 April 2012.

4.4.2 Creative Process

This collaboration examines further the impact of a long-term use and application of vibrotactile feedback. It was not until the end of the collaboration that I was able to reflect on how the taken approaches and methods had any effect on the performer and the composition.

For the purpose of this case study I identified four stages in an attempt to demonstrate the creative process of the composition. The aim being to describe the working process through identifiable stages that blended together in an artistic and creative way. This provided an inside view on how technology relates to creativity and development and on the performer's understanding. The processes identified here are unique for this composition and the case study and they do not necessarily suggest a definitive guide for composing interactive electronics pieces. The four stages can be described as:

- *Space and technology;*
- *Software and interaction;*
- *Score and sound;*
- *Fine-tune.*

The first stage, the *Space and technology* included decisions regarding the technology involved in the piece, including other non-musical elements such as the role of the acoustic space of the concert hall. *Software and interaction* addressed how and in what ways the use of software relates to the technology and interactivity and how they are manifested in the composition. The third section *score and sound* looks at the score as an artefact and how the crafted sounds related to both the hardware and software. Finally, the *fine-tuning* process provided a framework for small changes and hardware fixes to take place during rehearsal. These four interconnected stages related to the way the performer understood the role of the technology in the composition, suggesting an emerging expressiveness during performance through the formation of habit. Vibrotactile feedback made it possible for such links to take place and made the performer aware of how his actions transformed the sound processing of the interactive electronics.

4.4.2.1 Space and technology

In terms of hardware, several different sensor technologies were tested, including Inertial Measurement Unit (IMU), bend, proximity and light sensors. None of the sensors was considered suitable to be used for the concert to deliver the required performance standard. The main concern was that the technology would overcome the performativity of the trumpet player and result in another gimmick performance.

Even though there was a deliberate attempt to avoid the use of footpedals, it was however, the ideal *solution* for this concert, taking into account the instrumentation and the performer's ability to perform with the technology. Through two different types of footpedals, expression and switch, the performer was able to control all aspects of the electronics. In addition, it was possible to utilise the knowledge and experience gained from Case Study Two. After testing different pedals, the *Line 6 FBV Express MKII* pedal was chosen for the composition.[66] This multi pedal device has four configurable switches and one expression pedal. The device connects directly to the laptop through a USB cable and is able to provide direct use of MIDI data without any additional programming. In order to use the footpedals with vibrotactile feedback, a modification was carried out on the initial software patch making use of the incoming MIDI signal directly from the pedal.

Even though four sustain pedals and one expression pedal were used the vibrotactile feedback is provided only by two motors, one for all switch pedals and one for the expression pedal. The performer senses and associates the physical function of the pedals based on their functionality. Accordingly, the resulting audio process is disconnected from how the vibrotactile feedback is felt. We discussed earlier how the performer is not able to form audible habit associations between the footpedal and the sound since the outcome can constantly change throughout the composition. If we discard how the audio is treated, we can create new associations based on physical action, notably the vibrations. The final position of the motors was on the shin of the right leg for the expression pedal and on the shin of the left for all switch pedals. Since the instrumentalist was performing in a standing position it was possible to shift his body balance on different legs depending on the required trigger. The overall approach was successful in terms of the way vibrotactile feedback felt, and how the performer

[66] See < http://uk.line6.com/footcontrollers/fbvexpressmkii.html>

experienced it. The performer mentioned that he was also able to mentally correlate the use of left and right leg by looking at the device; left side (switch pedals) received vibrations on the left leg and right side (expression pedal) received vibrations on the right leg.

4.4.2.2 Software and Interaction

Ableton Live and Max software were used for the creation of the composition discussed in this case study. Both allow a flexible approach to the control of the motors and the manipulation of audio processing.[67] Through rehearsals, experimentation and discussions with the performer it was possible to form a basic understanding about his level of competence in performing with the pedals and the overall technology. During this creative time with the performer, ideas were formed with regard to the level of interactivity that the performer could cope with during the performance. The level of competence was not measured under a specific test but rather through trial and error derived from various compositional approaches. The abstract framework, concerning the performer's ability with the electronics, influenced the whole composition as well as the way interactive elements are employed. Similarly, acoustic composers often try in advance performer's performance abilities, especially for extended techniques, to make sure that the written score is playable. As a result of these workshops, the final piece was not technically demanding for the acoustic part but rather technically demanding in terms of how the electronics were to be performed. Four performance elements discussed in Case Study Two are included and implemented in the score.

- *Active*
- *Active Off*
- *Upcoming function*
- *Expressive*

[67] During the time of the collaboration, I was involved in an ongoing research project for the Integra Curriculum Pilot program, part of the education strand of the Integra Project at Birmingham Conservatoire (Bullock *et al*., 2011), (Rudi and Bullock, 2011). My collaboration with the trumpet player, presented in this case study, was also an opportunity to explore and document the role of the *Integra Live* software in the process of developing and learning a new piece from the performer's view. Thus, the initial aim was to use the *Integra Live* software for this case study. However, due to limitations of the software at that time, there were concerns about the ability to provide the vibrotactile feedback.

What is interesting here is the way vibrotactile feedback helped in understanding the role of the software and the technology involved. Even though the performer was not considered technically savvy, vibrotactile feedback provided a direct link and response to his actions. This was enough to establish confidence when performing the electronics. The performer found the vibrotactile feedback very helpful and was able to connect immediately with the functions carried out by the software. In particular he mentioned, 'This seemed to help especially when registering whether I had pressed a switch or not'[68]. After a number of rehearsals, as a test, the vibrotactile feedback was deactivated from the pedals without the performer knowing. The performer stopped the rehearsal asking if there was something wrong with the motors. The habitual relationship that had been formed when pressing the pedal and the vibrating feedback, made him aware of it. When asked if he could have performed the piece without the vibrotactile feedback he mentioned that he most likely could not. In particular, he mentioned that the motor associated with the expression pedal was very helpful and gave him better control.

4.4.2.3 Score and Sound

The piece was titled *Barbaróphonos,* meaning the person with barbaric voice. The trumpet as an instrument, has very expressive qualities resembling the expressiveness of the human voice, and influenced this composition. Since the performer was inexperienced in performing interactive electronics the title *Barbaróphonos* was a good analogy. Through rehearsals and tryouts the performer showed an interest in improvisation through audio processing. As a result, the composition includes an improvisation section which is considered as being the performer's own barbaric voice. To implement the overall idea of the piece the performer uses three microphones, each representing a different voice. The aim was to engage the performer and the audience into a musical conversation where each microphone has a different voice character. As a result, the score reflects how the technology is implemented as well as how the performer is able to implement the electronics.

[68] Quote by the performer, Ben Murray from his Final Year Project report, Birmingham Conservatoire, Birmingham City University. 2012(Unpublished).

4.4.2.4 Fine-tune

This section of the process was the most important for the performer and for this case study. The aim was to allow enough time for the performer to become familiar with the technology used in the composition and examine how expressiveness could be influenced by the technology. In addition, this fine-tuning relationship between the performer and the technology gave time to revise any issues with the software and the hardware.

Two and a half months before the concert, the piece was completed, including all elements of the electronics. At this point, through discussion, rehearsals and experimentation the performer had a general understanding of the technology involved in the piece including vibrating motors, the *TfTool*, microphones, speakers and software. Figure 15 shows a diagram of the workflow of the piece as presented to the performer. It includes how the audio is routed as well as the way footpedals and vibrotactile feedback are used. The permanent setup in a practice room allowed the performer to have regular rehearsals without the need of the composer or any other technical personnel. The initial setup was done together with the performer explaining all hardware and software connections and relationships. The permanent setup included a step-by-step written guide to run the piece including fixes for possible problems. The performer was able to rehearse the whole piece, go into sections and control the electronics without any additional support from the composer.

During discussions the performer gained confidence and experience in functions and approaches concerning the technology. In addition to the rehearsals carried out by the performer alone, there were weekly rehearsals with the composer to adjust and fix any hardware, software issues including changes in the score. Since vibrotactile feedback was introduced from the very beginning of this collaboration and used throughout rehearsals, the performer saw the electronics and the vibrotactile feedback as a part of the same technology rather than something separate.

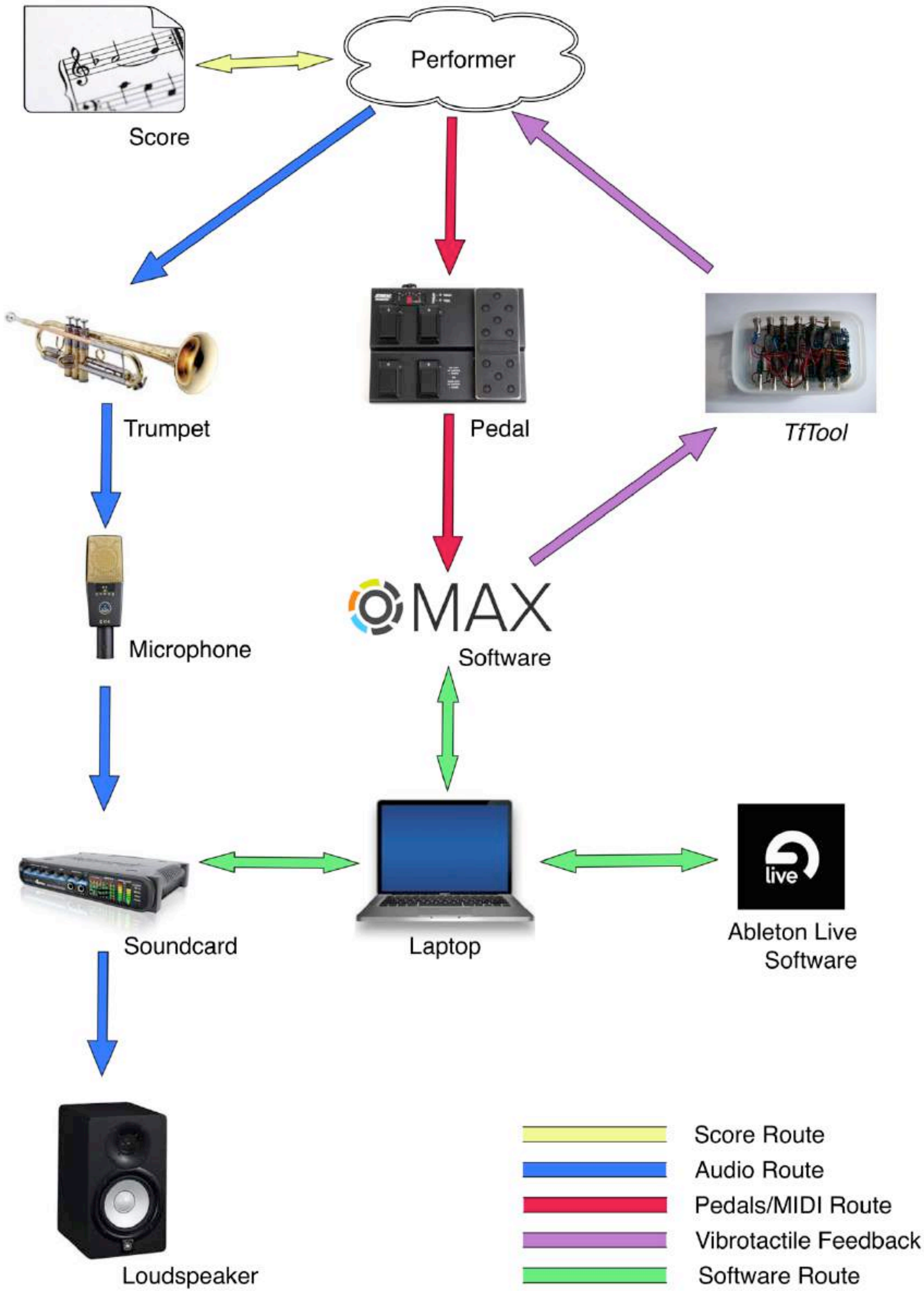


Figure 15 - Layout of the composition *Barbaróphonos* presented to the performer.

4.4.3 Conclusion and Discussion

The whole process from the conception and performance of this composition was aimed towards understanding the role of the electronics and the technology involved, as well as the effect of a long-term use of vibrotactile feedback in performance. The case study examined these questions through the creative process of the composition and feedback from the performer.

The approach taken in this collaboration places the performer within the compositional process and allows him to experience, from a practical and theoretical point of view, the role of technology. The performer is a part of the created technology, which is seen as the instrument, thus making him a *hybrid performer* (discussed in Chapter Two). As a result, this approach allows the performer to establish a confident and trusting relationship with the technology allowing expressive nuances to form and develop. Understanding the limitations and functions of the technology included in the composition frees the performer to become more expressive.

Vibrotactile feedback has a significant role in building such trust with the technology. The feedback from the technology is immediate and most importantly physical yielding an intimate relationship between humans and machine. In addition, the ability to carry out rehearsals on his own boosts the confidence of the performer. When asked, the performer mentioned that in performance he felt more aware and less distant from the technology. It is accepted that other factors can also influence the ways technology might be understood in a composition. The technological complexity of the piece and the level of knowledge and experience by the performer are equally important.

Vibrotactile feedback can establish a new habitual relationship in a relatively short amount of time. Towards the end of the collaboration the performer mentioned that it would feel *unnatural* if the vibrotactile feedback were not active when pressing or controlling a footpedal. It is necessary to acknowledge that the habitual relationship might have been established faster since there were no *bad habits* to consider and *fix*. The performer was an amateur interactive electronics performer unfamiliar with any music technology practice. Vibrotactile feedback provides a basic amount of information, making it easier to establish a habitual relationship. As discussed in Case Study Three the feedback information through vibrations cannot include complex information, which benefits the speed in which habit can be established.

The case study provides insight about the use of vibrotactile feedback and how the familiarisation and knowledge of the technology suggests confidence and expressiveness in performance. The link between the performer and the technology strengthens the performer's confidence in performance. Vibrotactile feedback enables the performer to experience the technological device as a musical instrument rather as a object. Based on the amount of time spent rehearsing this composition, I argue that the performer experience the technology in a responsive and musical way able to form an abstract representation of the technology.

CHAPTER Five

Compositions

Chapter Five demonstrates the use of vibrotactile feedback through four original musical works. Firstly, the composition *Barbaróphonos* for trumpet and interactive electronics, is influenced by Case Study One and includes four of the techniques and approaches presented in Case Study Two. The next composition *Big Bang…* for bass trombone and interactive electronics has influences from Case Study Three and Case Study Two. The third composition *…Big Crunch* for clarinet and interactive electronics, applies the findings from Case Study Two. The fourth and final composition, *Live Mechanics* for piano and interactive electronics, has no direct influences from the case studies but rather demonstrates how vibrotactile feedback can be used as a sound source in the creative process of the composition.

5.1 Barbaróphonos

Ben Murray, a final year student at Birmingham Conservatoire, commissioned the composition for his final year project. The composition was premiered in the Adrian Boult Hall, Birmingham Conservatoire on 19 April 2012. The word *barbarophonos* first appeared in texts attributed to Homer, where he needed to describe those who spoke a non-Greek language or those of incomprehensible speech. The origin of the word comes from the Greek word *βάρβαρος*, '*barbaros*', meaning uncivilised and the word *φώνος*, '*phonos*', meaning voice. The literal translation refers to a person with barbaric voice.

The aim of the piece is to establish a sense of an on-going conversation between three voices through the changing and introducing of different musical styles and sections. The performer takes the role of three different sound characters through the use of three different microphones. As the performer moves between the microphones there is an element of theatricality during performance. Each microphone has its own *voice* and welcomes the performer to discover his musical voice.

A significant part of the composition is the improvisational section beginning at rehearsal mark E, which appears in the middle of the piece. This section encourages the performer to input his personal artistic voice to manifest the *barbaric* concept of the composition. The approach taken depends greatly on the artistic interpretation and decisions by the instrumentalist. The improvisational section also has the option of including an electronics performer for the control of the audio processing parameters.[69]

What follows is a discussion of the electronics in the piece and the music. Vibrotactile feedback is implemented in different ways throughout the piece that connects, express and informs the actions of the performer and the electronics involved.

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[69] During rehearsal and workshops the performer, being classically trained, was overwhelmed with the improvisation section making it very difficult to control the electronics and at the same time think about the improvisation.

5.1.1 The Electronics

Each microphone uses different input channels in Ableton Live. This allows the use of different sets of audio effects and processing techniques that create the individual characters. Each microphone is represented in the score by letters. Letter *L* shows the left microphone, *M* shows the middle microphone and *R* the right microphone. When a letter appears in the score the performer turns and face that particular microphone. With different sets of live audio processes the performer changes the sound by moving to different microphones. There are instances when the performer is required to switch microphone while holding notes. This technique gives a seamless integration of different sound from the two channels (figure 16).

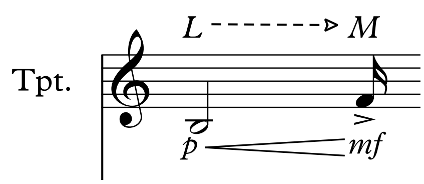

Figure 16 - Moving from the *Left* microphone to the *Middle* microphone while holding a note.

Microphones on stage are placed accordingly to recreate a stereo sounding image for the audience while the performer moves from left to right. Figure 17 below shows the layout of the setup for the composition.

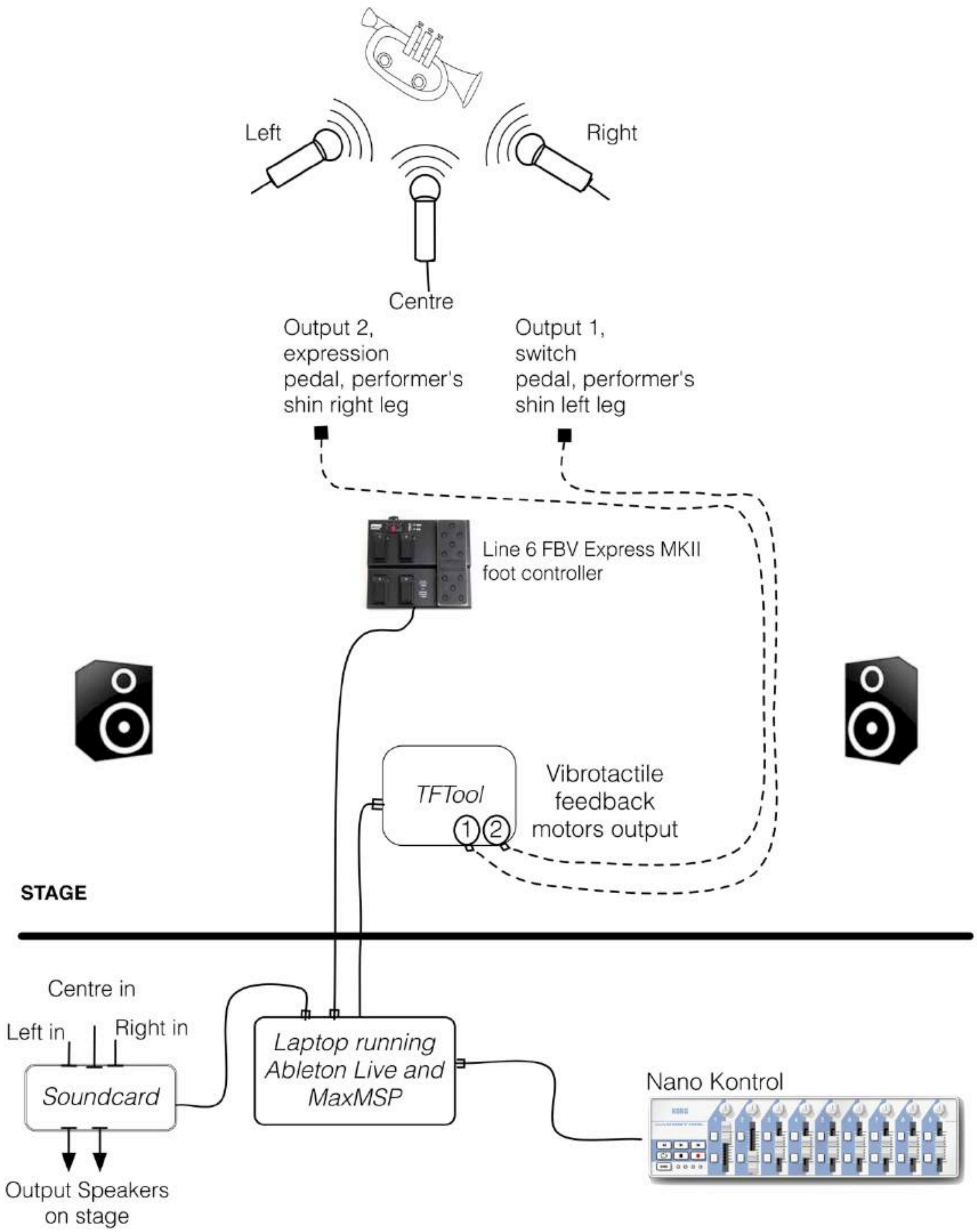

Figure 17 - Layout of the composition *Barbaróphonos*.

The performer controls and interacts with the electronics of the composition through the use of an expression pedal and four switch pedals using the *Line 6 FBV Express MKII* foot controller.[70] A simple icon based notation system was created to provide the necessary information to control the pedals.[71] Triggers received from the switch pedals control a variety of parameters in Ableton Live such as audio playback, turning on/off audio effects as well as navigating into different sections. The expression pedal being a continuous control signal affects the amount of audio processes of the composition. The pedal device (*Line 6 FBV Express MKII)* sends MIDI messages directly without the need to convert them. As a result the *TfTool* device was used only to provide the vibrotactile feedback to the performer from the information received from the pedals. Figure 18 below shows the notated icons of the pedals in the score.

To show how the expression pedal is controlled the standard notation of a hairpin was used. In bar 102, figure 18, the expression pedal icon, followed by the hairpin suggests the amount of action taken from fully closed to fully open position. The length of the hairpin indicates the duration of effect of the expression pedal. In the excerpt below, the switch pedal activates the functionality of the expression pedal, which then gradually controls the expression for a bar. In bar 103 the expression stays *open* and in the next bar the expression pedal goes back to the close position. The number next to the switch pedal icon registers the number of cues that the switch pedal activates in the system.

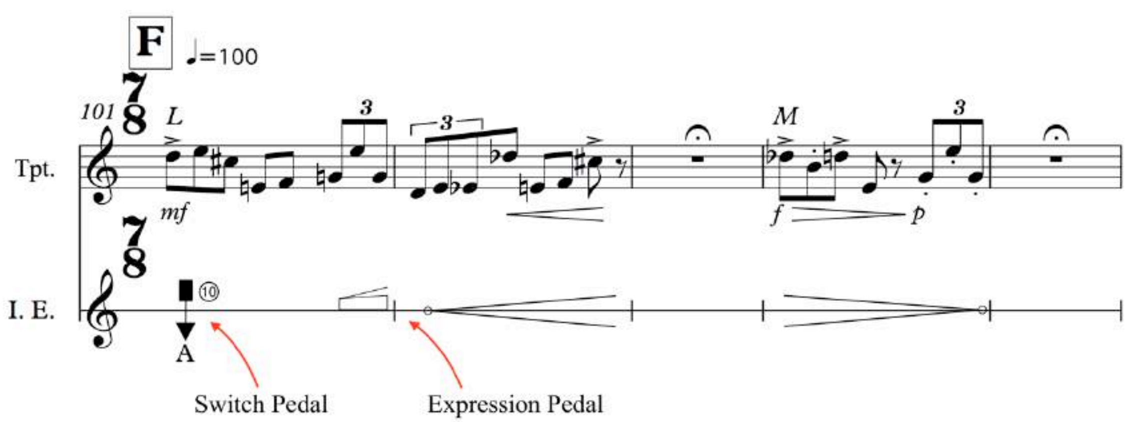

Figure 18 - *Barbaróphonos* bars 101-105.

[70] The functionality of the pedals can be configured within the software.
[71] Similar approach is taken in all compositions.

The way vibrotactile feedback is applied throughout the composition can be further examined through the four functions suggested in Case Study Two.[72] The *Active* function provides feedback for every successful trigger of the pedal. *Active Off* informs the instrumentalist when the playback of an audio file has finished. Figure 19 below, bar 63, the instrumentalist feels the *Active Off* function suggested by the end of the audio playback. In bar 64, the *Active* function provides feedback when the switch pedal is pressed which changes the functionality of the expression pedal in the next bar.

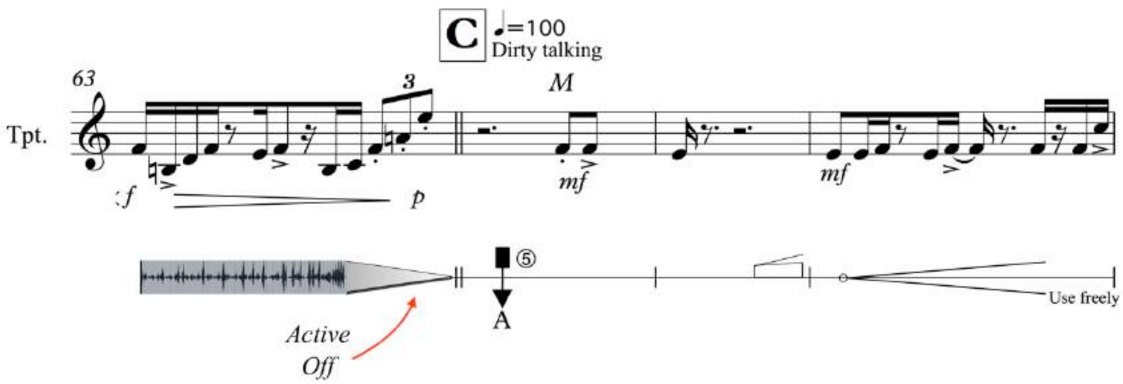

Figure 19 - *Barbaróphonos* bars 63-66, *Active Off* function to inform the performer about the end of the audio playback.

The *Expression* function provides feedback about the control of the expression pedal. The *Upcoming function* prepares the performer about future events. During the improvisation section rehearsal mark E, the instrumentalist senses important time notifications through vibrations. The improvisation starts by pressing the switch pedal in bar 90. That action activates an internal clock that is set to vibrate at 2:30 minutes for three consecutive pulses, at 4:00 minutes for two pulses and at 4:30 for one pulse. All pulses are activated on both legs and have duration of one second and rest for one second at maximum density (figure 20). The instrumentalist registers the vibrating pulses as notifications to move on the next section.

The improvisation is based upon a particular set of instructions and requires the use of switches and the expression pedal. The improvisation section can be overwhelming for the (non-improvising) performer, as they have to think about the improvisation and

[72] Discussed earlier in 4.4.2 *Creative Process*

control the pedals. To simplify this section, another performer can be employed to take responsibility for the control of the electronics. The electronics performer controls a particular set of faders and buttons on a MIDI controller functioning in the same way as the footpedals on stage. The stage performer feels the actions carried out by the electronic performer retaining the connection with the electronics. When a fader for example, increases the amount of reverb the stage performer feels the intensity of that as vibrations on his body.[73]

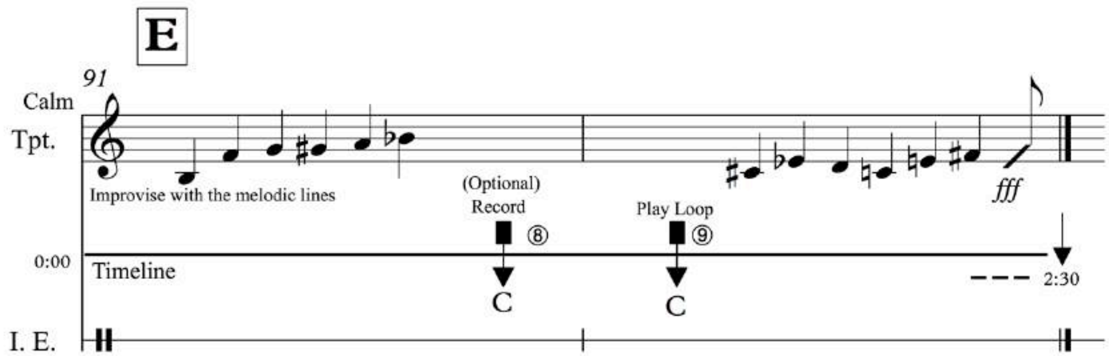

Figure 20 - Beginning of improvisation section E. Upcoming function activates three pulses indicated by the three dashes close to the end of the duration of 2:30.

Vibrotactile feedback played a major role in the way the composition was performed. In the words of the performer:

> I did not improve my technique in the conventional sense but the physicality of controlling the electronics with the vibrating feedback has improved my technique in another way. I do feel that I did improve my performance presentation skills because the nature of the piece required it. The piece was not technically demanding (in terms of the notated score) and allowed me to focus more on the performing aspect rather than worrying about the notes.

Without vibrotactile feedback, the performer would have been disconnected from the electronics elements and that would have limited his ability to engage with the composition in an artistic way.

[73] The audio processing effects can be examined within the Ableton live software patch available on the USB flash drive.

5.1.2 The Music

There are three sections in the composition. The first section, bars 1-90, introduces the role of the three microphones and the different voices including the harmonic and melodic content of the composition. It starts with a free tempo without bars, which leads up to rehearsal mark A where a tempo is introduced. This encourages the performer to freely present the three voices and demonstrate the role of microphones to the audience.

Rehearsal mark A acts as a transitional phase between the free tempo and the regular beat. From bars 36-63 the instrumentalist plays on the right microphone all the way through, and introduces the playback of a pre-recorded audio file with the footpedal at bar 48. The audio file was recorded during one of the rehearsals of that particular section and is treated in the studio. Unable to exactly match the tempo and phrasing of the playback, the performer creates an interesting sound environment that blends the two sound sources together. In addition, the playback comes on only in the left loudspeaker and creates a stereo image between the real and the digital. From bar 79 until 90 the section changes in character towards a more *authoritative* mood with fast passages and more accidentals and articulations.

Section two, from bars 91-100 is the climax of the piece. It indicates three different melodic sections and provides the performer with a creative platform for the development of his musical style and voice. The duration is indicated not through the bars of the score but through a time line shown in figure 20 above. This section is subdivided into three parts each representing different moods *Calm*, *Authoritative* and *Barbaric.* The score suggests the melodic lines that the improvisation should be based on and the given melody that the performer has to prepare in advance. As described earlier, the performer has the option of using footpedals to control the live audio processing or employ an electronics performer to do so. During the *Barbaric* subsection, the performer is expected and encouraged to move away from melodic lines and introduce extended techniques and other performance techniques to create his barbaric voice.

The final section starts from bars 101 until the end of the piece and can be further divided into two sections. The first subsection from bars 101-124, gives the performer the opportunity to *recover* from the improvisational section just before. The performer shifts between microphones resembling a conversation between three people. The long pauses provide an opportunity for the performer to recompose himself, and also serve as pauses similar to those found in a real conversation. Furthermore, in bars 125-147 the section develops a rhythmic and melodic pattern preparing the audiences for the end of the piece.[74] The section is open to any articulations suggested by the performer that give the opportunity to have a personal influence on the composition. From bar 129 onwards the performer interprets freely the use of the expression pedal and they are free to apply any articulations on the notes. The expression pedal controls the *dry/wet* functions of a set of audio effect. The free articulation in the music and the felt vibrations from the expression pedal are aimed towards an alternative way of experiencing and expressing the music. The combination of the two, the use of pedal and the free implementation of the articulations, allow the performer to have a creative and expressive control over the music.

5.2 Big Bang…

The composition *Big Bang…* for bass trombone and interactive electronics is an attempt towards a creative and musical interpretation of the theory of the Big Bang about the creation of the universe.[75] The aim of the composition was to reach a point of *singularity* during the performance in a process similar to the Big Bang. The chosen instrument, bass trombone, seeks to address the Big Bang theory in an abstract and comic way. With this idea in mind, the piece requires flexibility and *room for expansion* to address the vastness of the universe and the Big Bang. As a result, the electronics are treated in a way that are *flexible* and adjustable to provide the following performance practices:

- Playback of pre-recorded audio files on cue.
- Manipulating live audio through different audio effects at specific times and durations.
- Record during performance for future playback.
- Control of volume.

[74] During rehearsals, the performer included the rhythmic patterns of this section in his preparation of the improvisation section in an attempt to have a sense of continuity between the two.
[75] Not to be confused with the TV series.

Within this five-minute piece, there are seven cues that control these parameters. The vibrotactile feedback provides the necessary feedback confirmation to the instrumentalist. The performer uses two pedals for the control of the electronic elements, a switch and an expression pedal. They are used both separately and in combination with each other; the switch pedal activates an audio process and the expression pedal provides control over this process. The first performance took place on the 16 January 2012 at the Recital Hall, Birmingham Conservatoire.

5.2.1 The Electronics

The composition uses a similar software approach as in the piece *Barbaróphonos.*[76] The Ableton Live software handles all live audio processing while the Max software converts the footpedal's actions into MIDI data through the *TfTool.* In addition, the *TfTool* controls the audio processing and the motors. A microphone on stage captures sounds performed by the instrumentalist. Four of the functions described in *4.2.4 Software Implementation* are applied in the composition. These are *Active, Active Off, Duration* and *Expression.* Not all functions are addressed to the same extent. For example, the *Duration* function appears only in bars 46-47 and vibrates for 10 seconds, the duration of the audio file (figure 21). The function appears as fade-in/fade-out function due to its short duration. The performer senses the duration of the audio file as the vibrations increase and decrease in intensity. As a result performers are able to adjust their performance to match the audio playback.

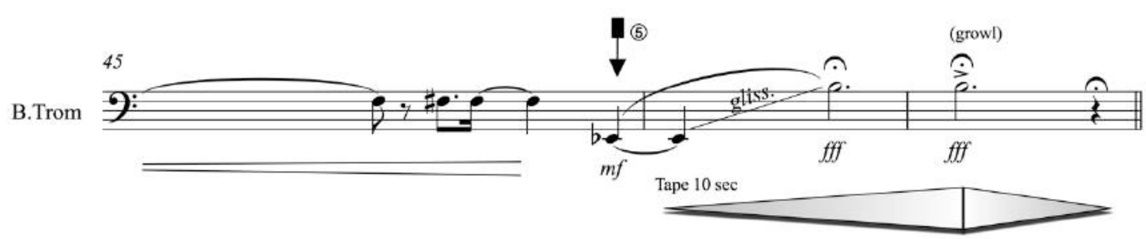

Figure 21 - *Active* function, end of bar 45 and the *Duration* function at bars 46-47.

One of the limitations of using the expression pedal is the insufficient kinaesthetic information obtained through the foot movement. It is very difficult to control the pedal

[76] Elements of the composition *Big Bang…* are discussed also in Case Study Three.

through a notated score from the foot movement alone. For example, in figure 22 the expression pedal controls the amount of processing effect applied to the live audio without immediate results. The audible feedback is settled which makes it difficult to relate the values of the pedal.[77]

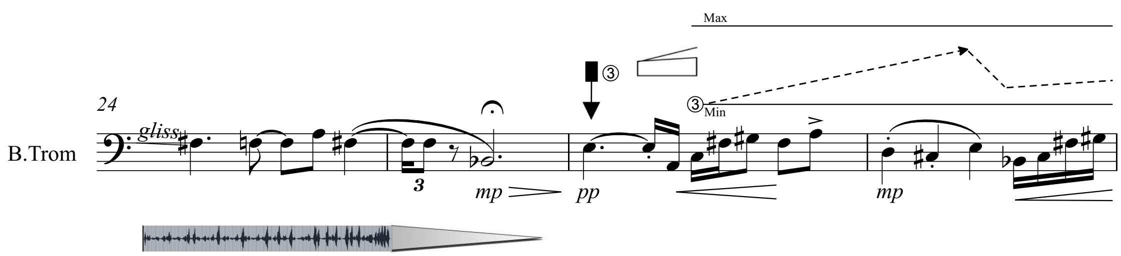

Figure 22 - The *Active* function of the sustain pedal and the *Expressive* function at bar 26.

Vibrotactile feedback provides a constant relationship through the intensity of vibrations and the way they correspond to the movement of the expression pedal. The performer connects the scored notation with the felt vibrations and thus is able to have a more accurate and expressive performance. As a result, this establishes a habitual relationship between the action taken through the visualisation of the score and the felt vibrations, rather than establishing a habit between the action taken and the sound performed. The instrumentalist retains the same physical experience regardless of the sounding result.

Active and *Active Off* functions produce different results in terms of feedback experience. It was necessary to address such differences within the score. Even though notational conventions are outside of the scope of the thesis, it was necessary to come up with a notation that specified the different ways of providing vibrotactile feedback. In addition, it was important to reflect of such a difference of information about the electronics in the score. A simple solution was to have an *empty* pedal cue that indicates the *Active off* function and a *full* pedal cue the *Active* function.

[77] Indicated by the dotted line within the suggested maximum and minimum margin of the two lines. The expression pedal here controls the amount of reverb and the dry/wet mix for a harmonizer.

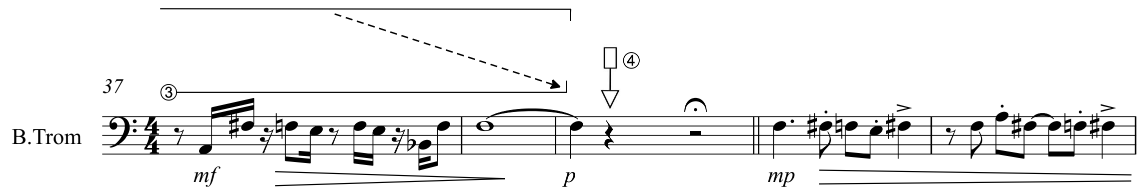

Figure 23 - The *empty* switch pedal icon in bar 39 indicates the *Active Off* function.

The role of vibrotactile feedback in this particular piece has been mainly informative and I am arguing for the necessity of such informative feedback in interactive electronics. Being able to sense how the electronics function improves the experience of the performers significantly and builds a trustful communication between the two. The performer ought to step away from a one-way interaction with technology and rather cultivate creative outcomes from a truly interactive relationship. The ability to experience and sense the technology, even at such a basic level allows performers to connect in a musically meaningful and creative way. The performance setup is shown in figure 24.

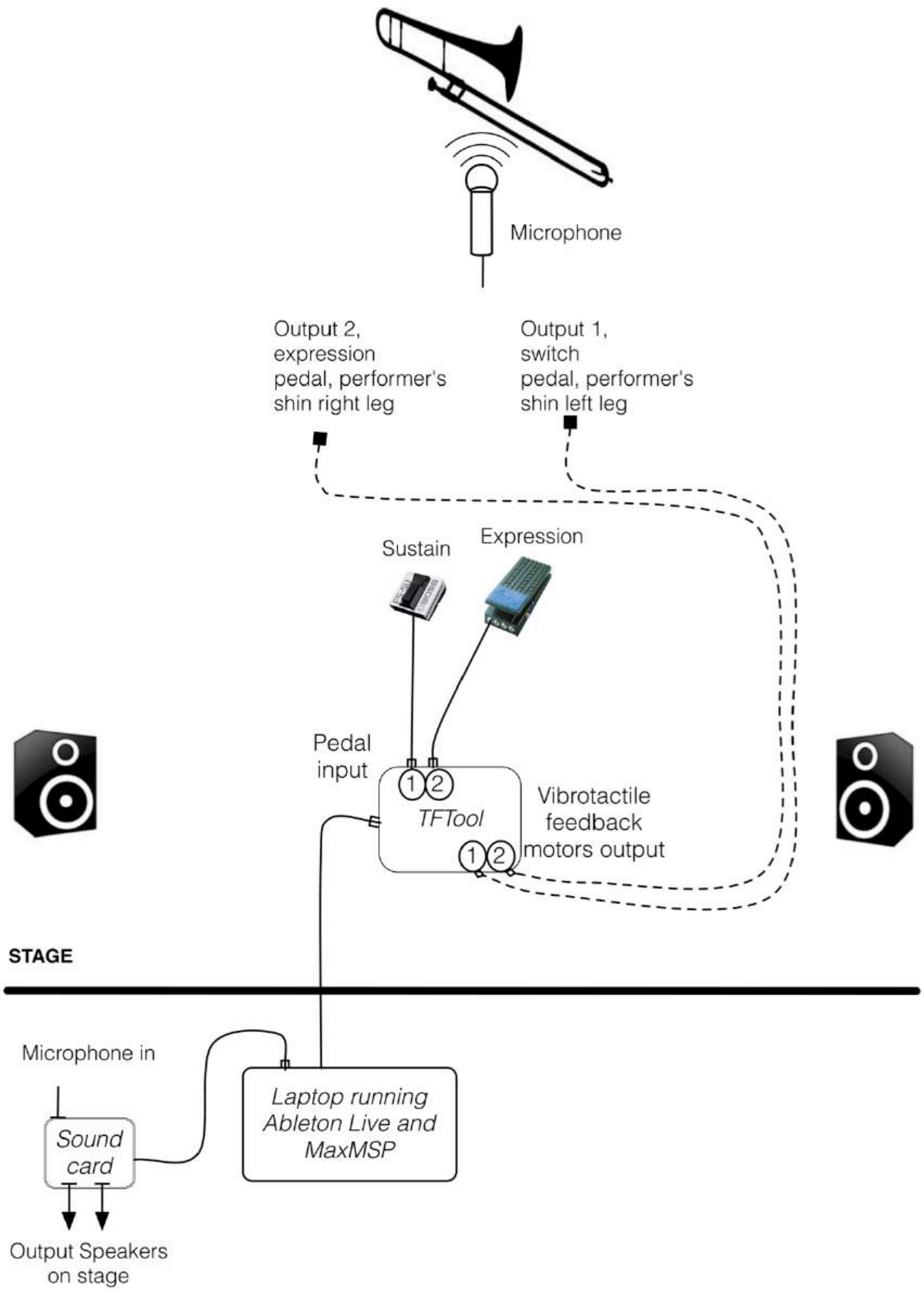

Figure 24 - Layout of the composition *Big Bang...*.

5.2.2 The Music

The composition has three sections. Section A (bars 1-45), section B (bars 46-47) and the final section C (bars 48-73). The piece starts with a simple melodic theme. The delay effect from the electronics is activated before the performer plays any notes. This approach gives a sense of an on-going process that the audience just happens upon. There are no bars, time signature or tempo and this encourages the performer to focus more on how the delay effect responds acoustically in space. Following the introduction up to bar 10, different melodic lines are developed along with new audio effects and pre-recorded audio material. In a similar manner to the composition *Barbaróphonos* the pre-recorded material was taken from the same passages in the score during rehearsals.

Section B, figure 21 above, shows the climax of the piece. A combination of different techniques such as audio playback, glissando and growl techniques implies an abstract representation of the title of the piece Big Bang.

Section C attempts to reproduce musically what happened after the Big Bang. It starts at bar 48 by triggering the sixth cue on the footpedal, which enables a live recording. The repetitive energetic section with the fast tempo and semiquaver notes continues up to bar 59. The seventh cue on the footpedal stops and loops the recorded section. The expression pedal controls the volume of that looped material which is open to the performer's interpretation.

5.3 ...Big Crunch

The composition *...Big Crunch* for clarinet and interactive electronics is a palindromic approach to the composition *Big Bang…*. The idea of the piece is the opposite to that of *Big Bang* detailing how the universe will eventually come to an end. The expanding universe started by the Big Bang will eventually stop and start to collapse into itself pulling everything to a singularity, the Big Crunch.

The piece makes use of a surround environment with quadraphonic loudspeakers placed around the audience. The aim is to capture the imaginable spiral movement as the Big Crunch forms and takes place. The piece employs similar compositional techniques and approaches as the composition *Big Bang* and was premiered on the 29 September

2011 at the Integra Festival 2011, Royal Danish Academy of Music in Copenhagen, Denmark.

5.3.1 The Electronics

The electronics were developed with the Integra Live software. Live audio from the clarinetist is captured through a microphone via a soundcard, which is then processed live through the software. The processed sound is performed via a quadraphonic loudspeaker system. Aside from a variety of different live audio processing techniques, the piece also utilises the playback of pre-recorded audio files triggered via a switch footpedal. Information from the pedal is received through the *TfTool,* which communicates with the Max software and converts the received information into MIDI messages for the control of the Integra Live software. In addition *TfTool* provides the vibrotactile feedback back to the performer. There are seven triggers in total activated by the pedal. All triggers utilise the *Active* function. The *Active Off* function is implemented through the software only when the playback of an audio file comes to an end and informs the performer about this action.

The software makes use of a function called *scenes*. *Scenes* provide ways to organise and control the live audio processes of the software.[78] The duration and how they function are configurable, giving the user the ability to *perform* the live processing during the performance. Effectively, the role of a *scene* is to control the cursor that affects the audio processing. When the cursor overlaps with a *block* it activates that *block* and the audio processes included in that *block* (figure 25). The audio processing takes place only inside a *block.* If the cursor is not overlapping with a *block* then that *block* is deactivated and there is no sound. With the use of the footpedal the performer goes through different *scenes* controlling the cursors and thus changes the different audio processes.

The state of *Scene 2* (figure 25) is on *play* mode. This means that when activated, via the footpedal, the cursor will *jump* to *scene 2* and it will play the *scene* for the specified duration. What is interesting here is how the cursor in *Scene 2* overlaps between three different *blocks* from three different tracks with the possibility to run three different audio processes simultaneously. It allows a creative approach on how live audio is

[78] *Scenes* in *Integra Live* have three different states, pause, play and loop. This affects the way the cursor is played to enable the audio processing of different functions within the *block*.

processed and integrated in the composition. Excluding track one (which contains only the controls for the playback of all audio files), track two and three take turns between different sets of audio process. In each *block* there is configurable fade-in/fade-out for the volume of the sound processing. When a *scene* is selected through the footpedal, the fade-in and fade-out of *scene* allow a seamless integration of the audio effects. For instance, the fade-out of the volume in track two, *block* one are effortlessly shifted to the effects in track three, *block* two. Figure 25 below shows the main window of Integra Live. In the red square, *Scene 2* is highlighted. The duration of each *scene* is shown in seconds by the timeline above.

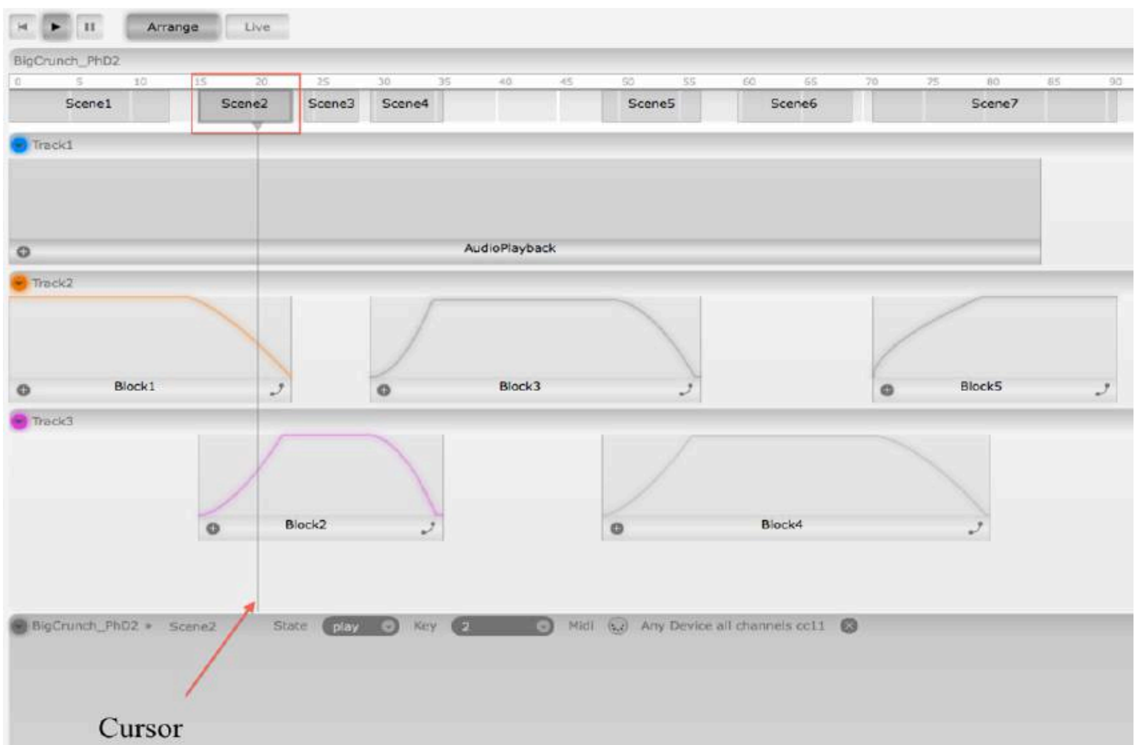

Figure 25 - *Integra Live* software shows the *scenes* and the cursor. Note how *blocks* one and two are active (highlighted) because of the cursor overlaps the two blocks.

The *QuadAutoPanner* module, inside Track 1, *AudioPlayback* block is used for the playback of the audio files. *Modules* in the software refer the audio effects and other processing functions. All *modules* are modular. The *QuadAutoPanner* enables an automated circular panning that control the speed and direction of the sound. The module becomes active when the file project is loaded. As a result it is impossible to know without looking at the screen what the current position of the audio file will be in in the surround system when the audio playback is triggered. In addition, the score requires the performer to wait for the audio playback to stop before they move to the next bar (figure 26). With loudspeakers away from the stage and in the heat of the performance the performer is not confident in relying only on audio feedback to acknowledge that the playback has finished. Through the *Active Off* function, the vibrations inform the performer when the playback has finished, regardless of the position of the sound through the surround system.

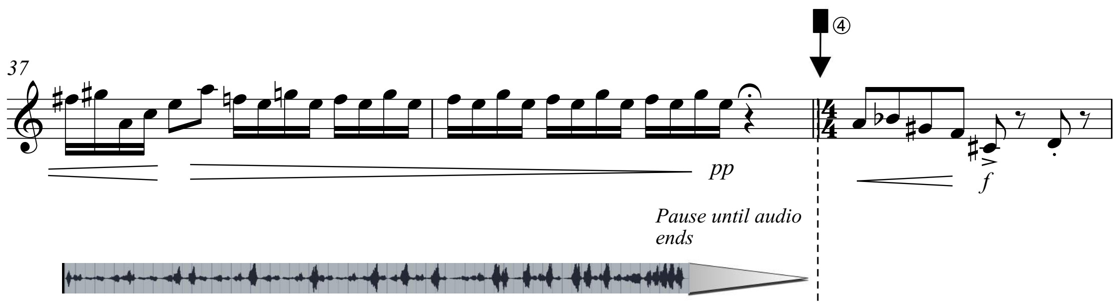

Figure 26 - Bars 38-39, the *Active Off* function applied at the end of the audio playback

Both the *Active* and *Active Off* functions significantly support the performer’s overall performance, understanding and confidence. The performer senses the feedback confirmation for every footpedal trigger. It creates a *musical relationship* between the technology and the performer. The system is no longer passive but active and responds to the actions carried out by the performer. When asked, the performer mentioned that the integration of the vibrotactile feedback was seamless, easily adapted and at the same time reassuring when using the technology. The performer noticed difference in confidence and expressiveness when using the vibrotactile feedback. Figure 27 shows the layout of the composition.

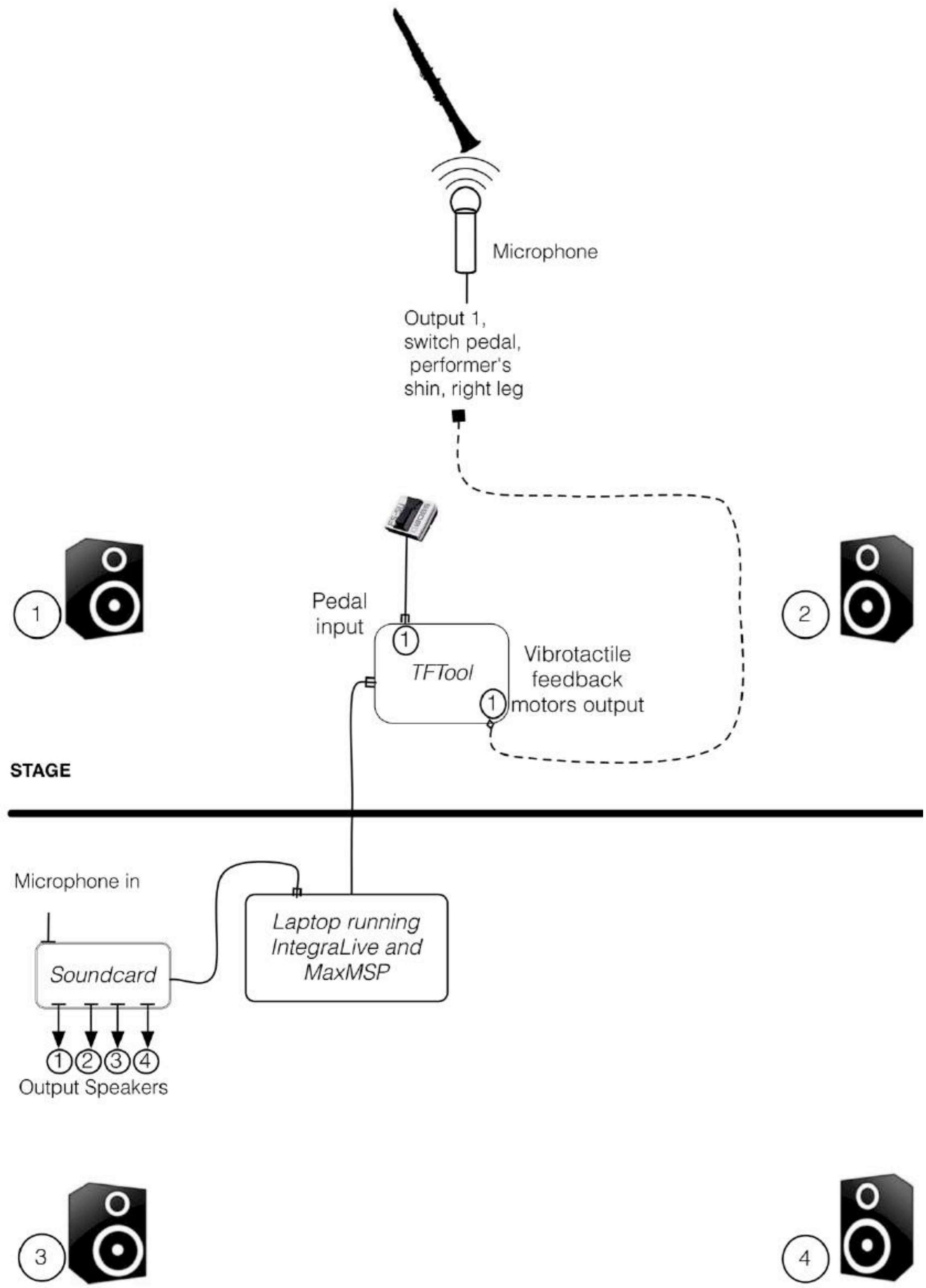

Figure 27 - Layout of the setup for the *…Big Crunch.*

5.3.2 The Music

The composition is developed over five sections A-E. Section A, introduces the surround system to the audience. Sound from the clarinet is diffused live through the *QuadAutoPanner* module. Figure 28 shows the controls of the *QuadAutoPanner*.[79] In the score the F sharp note is repeated throughout Section A and through the automated panning of the surround systems the F sharp appears and moves in different positions in space.

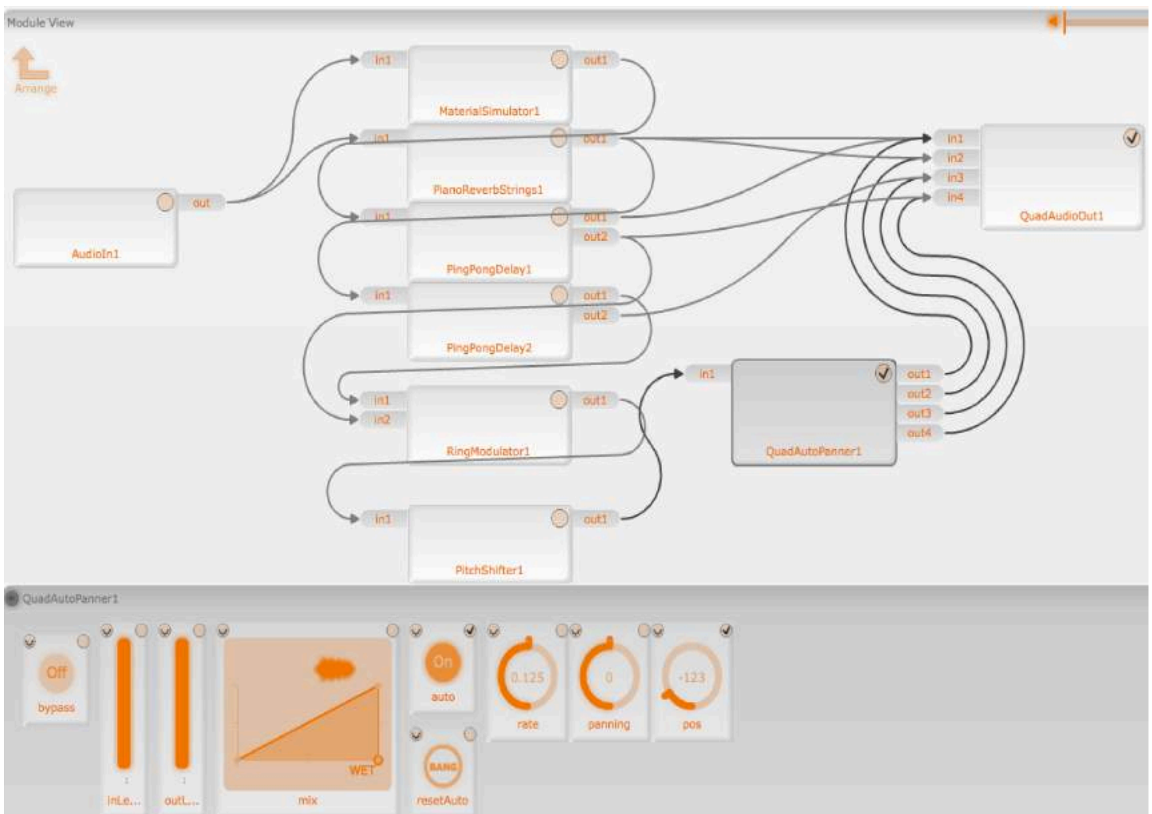

Figure 28 - Inside *Block* 1 of the *Integra Live* software. The lower section shows the controls of the highlighted *QuadAutoPanner* module.

Section B starts at bar 1 and continues up to bar 23. The section gradually moves away from the central note F sharp through forming different rhythmic and melodic lines.

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[79] The *rate* dial controls the speed and direction of the panner. The ratio provided is based on a complete circle of the sound around the four speakers over one-second. The rate 0.125 means that it takes eight-seconds for a complete circle. Positive values have clockwise motion and negative values anti-clockwise motion.

Section C (bars 24−38), starts with the trigger of the second audio file from the footpedal. Similarly to the other compositions, the performer plays along with the playback. Interestingly the two sound sources, playback and live, uses two different QuadAutoPanner modules, one moving clockwise and the other anti-clockwise both at different rates of speed. Section D (bars 39−67), is the climax of the piece. The singularity point where everything collapses occurs at bar 62 with the triple forte on the note G sharp. At bar 59, the performer triggers the third audio file adding another layer of sound complexity. The final section E, arrives at bars 68-85. This small section aims to reflect on the echo from the climax of the piece.

Throughout the piece, particular notes are repeated creating a reference point where musical ideas are developed further. This addresses the concept of the piece in terms of repetition and how gradually everything is compressed into a singularity. Figure 29 below shows how melodic lines are developed around those notes.

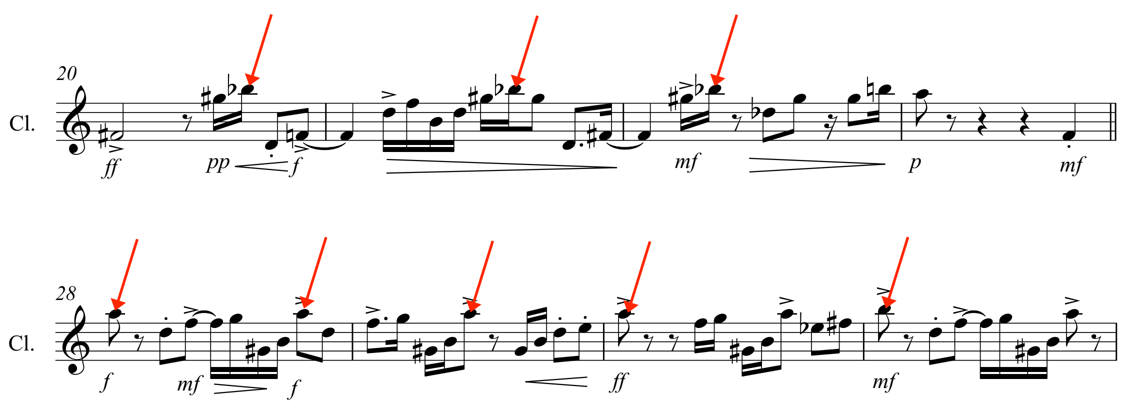

Figure 29 - Bars 20−23 (top line) and 29–31 (bottom line) …*Big Crunch.*

5.4 Live Mechanics

Live Mechanics for piano and interactive electronics uses vibrotactile feedback in a very different way from the compositions demonstrated earlier. The vibrotactile feedback has a direct and creative interpretation with the sound rather than focusing on ways to inform performers about the functions and controls concerning the electronics. Vibrating motors are used to resonate the strings of the piano and create the sounds mechanically. This brings back the energy from the performer's actions through the sensors on the glove to the instrument. The created sounds come from the vibrating motors that the performer controls.

Through various experiments and tests carried out with vibrating motors their characteristic feature became apparent, particularly the ability to bounce when vibrating due to the high-speed rotation. This is mainly noticeable when attached on a resonating material. There is no traditional notation employed, rather written guidelines about the layout of different audio processes and functions. The performer improvises through the learned system and as a result, there are many different performance versions without one necessarily being truthful to the score.

5.4.1 The Electronics and the Music

The keyboard of the piano is not used to perform any notes. To emphasise this, the performer closes the lid of the keyboard when on stage. The electronics do not provide any vibrotactile feedback back to the performer's body but rather extend the performer's embodiment with the instrument. The motors are placed loose on the strings inside the piano to enable movement when vibrating and produce a distinctive string-like sound (figure 30). The audible results resemble many miniature hammers hitting the strings. The sustain pedal of the piano allows for the overall control of the resonating strings.

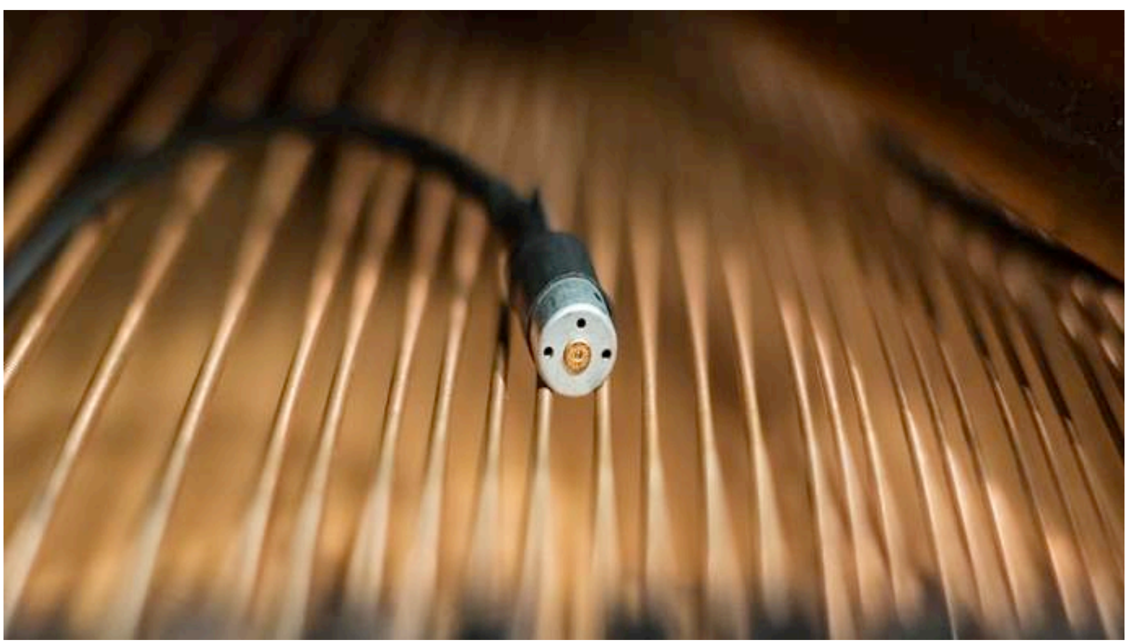

Figure 30 - One of the five motors placed loose on the piano strings.

The density of vibrations is controlled through a bespoke pressure sensor glove worn on the right hand of the performer. The incoming data from the sensors control the vibrating functions of the motors in a linear, one-to-one, mapping relationship.[80] The more pressure applied to the sensors the more the motors get excited and vibrate the strings. *Live Mechanics* makes use only of the *Expressive* function discussed earlier in section 4.2.4. The pressure sensors function in a similar manner to the expression pedal, being able to control the amount of the applied vibrations. The glove uses the right hand side of the piano, facing the piano, to apply the pressure (figure 31). The audiences are able to view the gestures as the *creation* of the sound and form their own understanding of the music.

Figure 31 - Performing the composition with the bespoke pressure sensor glove at Frontiers Festival 2015, Recital Hall, Birmingham Conservatoire.

[80] The linear relationship implies that, after calibration, the pressure applied to the sensors is proportional to the amount of vibrations by the motors.

The glove consists of five pressure sensors attached to the right hand's fingertips, that corresponding to the five vibrating motors. Each motor has a different specification, including shape, material, rotation speed, and matching G force, which results in different sounding outcomes.[81] In addition, the loose motors tend to move when vibrating and thus producing melodic lines often similar to a chromatic scale. The movement of the motors is unpredictable and the performer is unable to control the direction. Figure 32, shows the layout of the setup between hardware and software.

The glove connects directly to the inputs of the *TfTool* device, which facilitates the process of capturing the data from the pressure sensors as well as controlling the motors.[82] The Max software receives the data from the sensors and controls the motors. When the motors are activated, the produced sound is captured through a microphone, which is then processed through Ableton Live. The standing position of the performer allows them to control the sustain pedal of the piano and the resonating sound of the strings. The performer has in their arsenal a wide range of audio processing possibilities that are predefined and strategically mapped.

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[81] More information about measuring the vibrating amplitude in G force can be found here: <http://www.precisionmicrodrives.com/tech-blog/2013/02/25/why-is-vibration-amplitude-in-g>.
[82] Another version of the *TfTool* is used able to receive data from five sensors and control five motors.

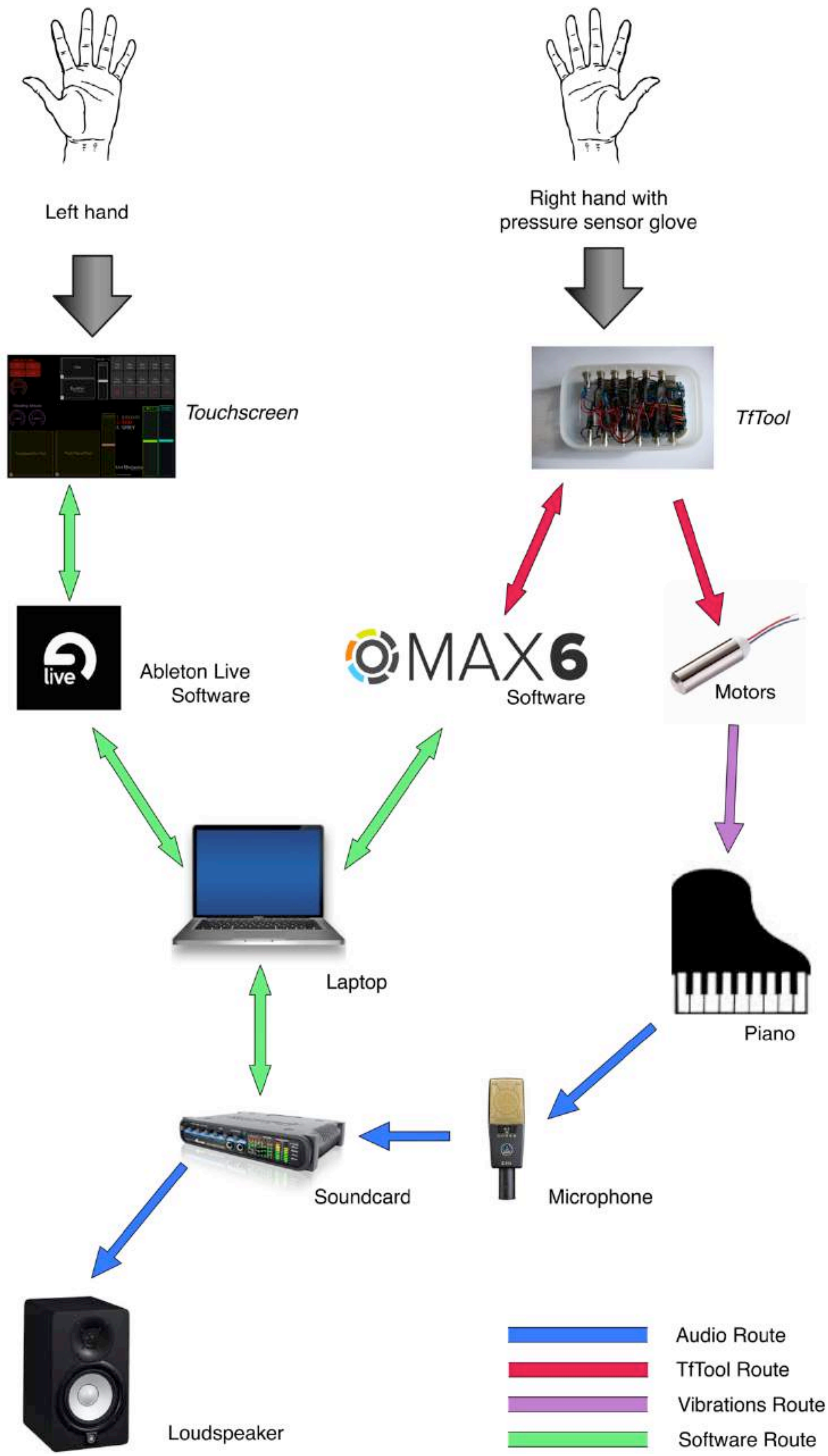

Figure 32 - Schematic of the data and audio flow for *Live Mechanics*.

The left hand of the performer controls a touchscreen tablet device (iPad) through the *OSCtouch* application.[83] Figure 33 shows the controls for the audio processing and the sections of the composition. The tablet communicates with the laptop wireless through a private network and provides *Open Sound Control* (OSC) messages. The messages are transformed and scaled into MIDI messages throughout the OSCulator software and allow the Ableton Live software to make use of the received information. The tablet is placed inside the piano and is not in direct view of the audience.

There are three main sections the *Brown*, the *Red,* and the *Grey*. These sections control different audio processes in Ableton Live. The *Brown* section includes two x-y planes. These two x-y planes provide four different controls associated with the *Grain Delay* effect found in track two in Ableton Live software. The *Red* section allows the performer to record any duration and is automatically looped and played back when stopped. When initiated, the duration of the first loop serves as a buffer window that records and overlaps any incoming audio after that until the performer presses the *stop* and *clear* buttons. The *feedback* dial controls how much audio from the last recording should be included with the new looped recording. For example, if the feedback is at 100%, the old material will be looped at full volume along with new sounds from the microphone. This approach enables the formation of a climax by overlapping and adding sounds and textures to the original material. When the feedback is at 0% the looped material will not be included in the following loop since the feedback percentage for the volume was at 0%.

The *Grey* section allows the control of ten pre-recorded audio files, which are looped when activated. The two rows are effectively the play buttons where the third row is the stop button. Each of the five columns corresponds to one of the pressure sensors on the glove. When activated, each sensor acts as a volume fader, where the pressure determines the amplitude of each audio file. This enables the volume control of those files as well as controlling the amount of vibrations applied on the strings. The fader on the left is the master volume for the whole *Grey* section. The x-y plane *(Pan)* on the top,

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[83] More information about the application can be found here: <http://hexler.net/software/touchosc>.

controls the panning for the outgoing audio, while the bottom x-y plane *(Dry-Wet),* controls the amount reverb and flanger effect of those audio files.

The *Vibrating Motors* section in purple does not control any audio processing. It affects how the motors behave. The two knobs act as fade-in and fadeout ramp functions for all the motors and determine the duration (up to 2000ms) that it takes for the motors to reach a certain value provided by the glove. When a knob is at 0ms the motors reach the ascending or descending value immediately. When set at 1000ms (the knob turned half way) the motors will reach that value gradually, within 1000ms. This allows the motors to become smoother when pressure is applied and less aggressive and mechanical. When depressing, the sensors return to 0. With the adjustment of the fade-out function the motors leave a resonating vibrating trail.

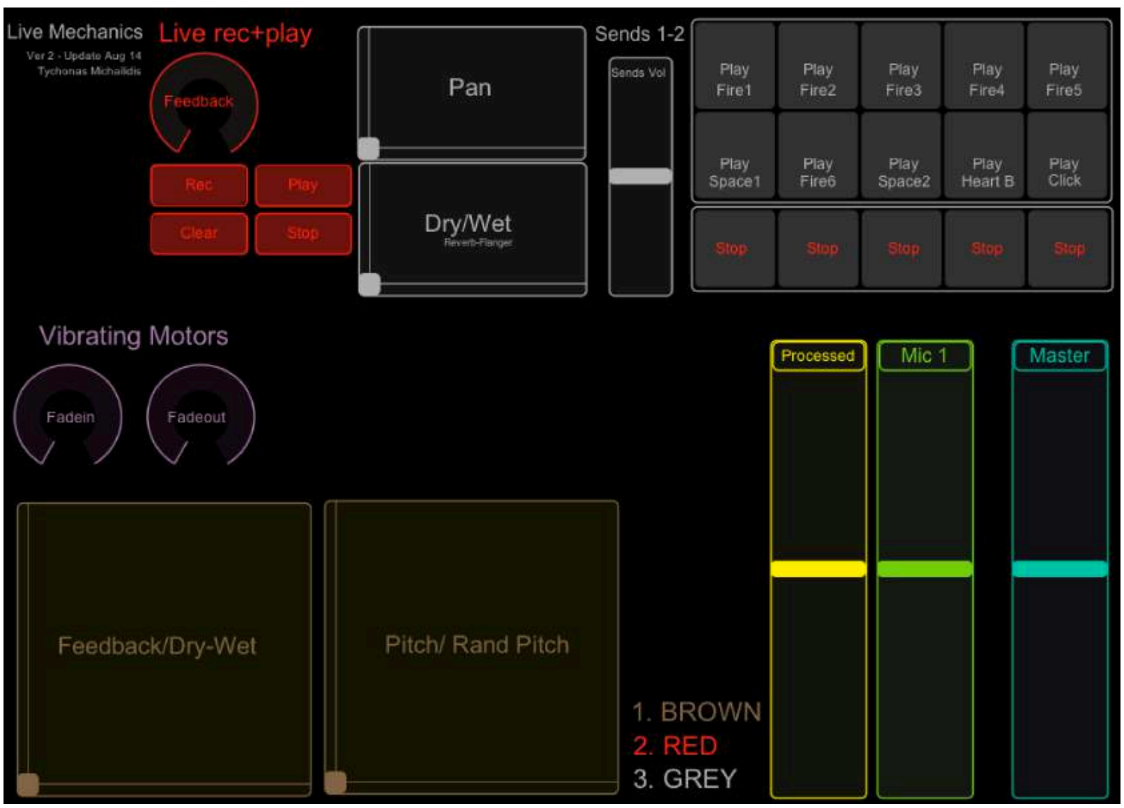

Figure 33 - The touchscreen control functions.

There is a need for two-hand coordination to perform this piece. The right hand creates the sound whilst the left hand *crafts* the sound. Another significant aspect of this performance is the theatricality of gestures evident from the hand wearing the glove. Applying pressure to the sensors on the glove does not require any hand gestures or movement; however, the right hand movements are exaggerated, and with the coordination of the touchscreen control on the left hand, the audience experiences the *digital effort* that is implied in the piece. The audience is more likely to accept the gestures from the right hand as responsible for the creation and control of the sound without noticing the functions carried out by the left hand.

Even though there is no notated score, the performer must go through the electronics and rehearse the sections and the processes of creating and manipulating the sound. The performer is encouraged to create her version of the performance. Whilst the composition uses the piano as the sounding instrument, the performer is not required to be a pianist to perform the piece skillfully. The vibrating motors and the relationship between the mechanical production of sounds, allows the performer to develop an embodiment relationship with the instrument and provides expressive performance nuances through the technology.

CHAPTER Six

Conclusions

Chapter Six summarises the role of vibrotactile feedback in music performances and compositions. Different elements, realisations and conclusions are discussed as well as the limitation and further research opportunities through vibrotactile feedback.

6.1 Summary of dissertation

In this thesis I examined the role, use and application of vibrotactile feedback in interactive electronic performances. While vibrotactile feedback has been applied and used in music making in the past, no such work has demonstrated the ways in which vibrotactile feedback may be used to enable performers to express the technology they are using within the compositional process. The methodology in this dissertation was necessary in order to identify, examine and demonstrate the role of vibrotactile feedback in context. The vibrotactile experience is unique to the individual and thus can only be examined through the close monitoring of the performer's experience. The case studies and compositions presented in this thesis propose a deeper understanding of the role and application of such feedback.

The only way to demonstrate its underlying theory and make assumptions on applications and creative reasoning is through practical demonstrations of the use of vibrotactile feedback in technology-mediated performances. Through the use of electronic prototyping devices and motors different systems were created that enable the control and function of the vibrations artificially. The assumption here is that we cannot examine the musicality of a musician without the instrument. As audiences, we digest the functionality of the instrument as being a part of the expressive reality of the musicality of the musician. Even though the addition of motors at first may seem foreign to the music making process, it provides a framework that allows performers to comprehend the technology as a part of their own expressivity and creativity.

The findings and results gained from the four case studies and the four compositions presented here have demonstrated the different applications and usage of vibrotactile feedback. These suggest not a universal understanding of how vibrotactile feedback affects the performer, but rather an understanding as to why vibrotactile feedback influences the performer's experience and how such influences can become a creative and expressive part of the compositional and performance process. Vibrotactile feedback is a tool and its success depends greatly on its use within the context of a wider interconnected system. It cannot assume creativity or claim the delivery of better music performances or compositions. It does, however, shorten the gap between performers and the technology, and enables new ways to experience the technology in an immersive and personal way. It is important to examine and consider vibrotactile feedback within a performance environment, as its affordances can change depending on the approach taken by the composer. We need to acknowledge that different instruments, due to physical constraints, might not benefit to the same extent. Vibrotactile feedback is a creative and communicative tool that brings performers and composers closer to technology; it has the potential to transmit meaningful information and to create and establish interactive performance links.

This thesis presented a comprehensive overview of vibrotactile feedback within the context of performance technology. As noted in Chapter One, my concern was to provide a complete view of the use and role of vibrotactile feedback by identifying problems and concerns about the functions and roles of technology in music performance. These issues are acknowledged and filtered through my own personal experience as a composer and performer. Chapter Two focused on how interaction in performance is defined and impacted upon performers, composers and audiences. In order to describe these interactive elements in technology-driven performance, the term *Interactive Electronics* is proposed. The term aims to address and put forward interactivity as a creative aspect between the performer and the technology. The interaction between the performer and the technology should be prominent and transparent to the audience. The proposed genre also moves away from what might be described as traditional *Live Electronics,* where technology and performer are often seen as two separate entities. *Interactive Electronics* instead, is a necessity in music making that may free us from habitual performance techniques. In *Interactive Electronics* the role of feedback is an essential part of its realisation, able to provide the much needed bidirectional relationship between the performer and technology. I have examined how active feedback information becomes an integral part of the interaction process in performances, demonstrating how vibrotactile feedback returns musicality and expressiveness to technology-driven performances.

Chapter Three focused on philosophical concerns of interaction as well as phenomenology and perception of the body, including theories concerning affordances and the formation of habit. It then addressed how a tool might become an instrument through the incorporation of vibrotactile feedback and how habit is involved in interaction. The chapter argues that the performance concepts of *digital* and *physical effort* should be made clear to the audience in order to encourage them to form their own ideas regarding the generated sound. It is demonstrated that vibrotactile feedback can enhance physical effort and permit expressive nuance.

Moreover I have discussed how latency alters our perception and cognition and breaks down existing habitual relationships. When the familiar task of instrument performance is interrupted by use of technology, additional feedback information can be used to improve the disparity between the performer and instrument.

Chapter Four presented four cases studies in which the functions and applications of vibrotactile feedback in technology-mediated performances were demonstrated. The case studies examine the use of vibrotactile feedback from different perspectives, and result in a set of compositional approaches. The case studies also examine how vibrotactile feedback influences the performer's musicality and expressivity as well as the implication when used for long period. Over time, vibrotactile feedback establishes a habitual relationship between the performer and technology such that performance without vibrotactile feedback felt *unnatural*.

In Chapter Five vibrotactile feedback is applied within four compositions. Practical constraints and limitations are considered, such as the positions of the motors on the performer's body and the overall effectiveness of the vibrating feedback on the instrumentalist.

6.2 Thesis contributions

Vibrotactile feedback is a tool with creative and communicative characteristics that allows the musician to become expressive through the technology. It affords an intimate experience for the user, something that is often neglected in technology-mediated performances. This thesis provides three main contributions related to vibrotactile feedback within musical performances.

The first contribution of this work is the way in which vibrotactile feedback may be applied in compositions and performances as demonstrated in Case Study Two. The five different approaches of using vibrotactile feedback within the compositional process are *Active, Active Off*, *Duration, Upcoming function* and *Expressive*. While the use of all approaches is not required for each composition, a combination of the approaches may be used to enhance the intentions of the composition or performance.

The second contribution of this thesis was to identify how vibrotactile feedback allows expressiveness to emerge in compositions and performances. Even though evidence from the case studies and the compositions are subjectively limited to individual performers, there is strong evidence that the performer is able to form assumptions about the functionality of the technology through vibrations, which may suggest an expressive awareness towards musical performances and compositions. The closed feedback loop relationship allows performers to make the necessary expressive adjustments during performances.

The third contribution of this thesis is a description of how of vibrotactile feedback can create a habitual relationship between the performer and technology. Through vibrations, as demonstrated in Case Study Four and in the composition *Barbaróphonos*, the performer establishes a habitual relationship in response to the functionality of the technology. The closed feedback loop between the performer and technology is generated through physical vibrations of the device. The performer is then able to make associations with the device through this physical interaction and not the resultant sound.

6.3 Future research

At the time of writing, many electronic devices have become available that utilise vibrotactile feedback as a form of communication. Notably, the Apple iWatch provides vibrotactile feedback to inform the user of various functional states. There is a learning curve associated with interaction, in which the user learns the meaning of the feedback. A similar interaction can be seen in the observations of the performer in *Barbaróphonos* in which the performer was required to learn and understand the received vibrating feedback associated with his actions.

One of the main limitations of the received vibrations is the ability to transmit complex information. The information is examined through the application of a single motor as discussed in *4.2.4 Software implementation*. Even though two motors were used in *Barbaróphonos,* their interaction was not examined. Therefore, the use of multiple motors and their ability to provide more complex information to the user should be explored further. Such complex information could include spatial awareness during performance. For example, the placement of two motors on the body could imply directionality through subtle alterations in the timing between the two. Incorporation of additional motors could generate further complex information such as depth and intensity.

Another area of future research would be to explore the use of vibrotactile feedback within other areas in the performing arts. Dance performances, for example, benefit from vibrotactile feedback when dancers interact within a virtual environment (Polydorou, *et al.* 2015). Through a wireless system the dancer can receive vibrating feedback for different functions, including cues from the virtual space, direction, density and expression. The ability to communicate wirelessly removes the constraint of being physically tethered to technology. The use of vibrating feedback can also be applied in networked performances. Performers, dancers, musicians and other artists can communicate through vibrations while being in different physical or virtual spaces.

Further research could also be focused on creating a notation classification system for vibrotactile feedback and to explore how such feedback may allow us to understand the technology. Such a haptic notation system will provide a common ground for performers using technology.

The use and application of vibrotactile feedback may add another level of intricacy to an already complex performance setting. The ability to use vibrotactile feedback will become imperative in future technology-mediated performances not only because of the communicative nature, but also more pertinently due to the creative possibilities afforded by interaction. In this thesis, I have systematically identified the issues related to interactive electronics as a performance practice and demonstrated the benefits to performers taking this approach through practical examples. The use of vibrotactile feedback in technology-driven performances and compositions provides a different communicative pathway that makes performers aware of expressive qualities while using technology. The outcome of these practical examples and compositions allows me to conclude that vibrotactile feedback can be used to enhance musicality and creativity in music performances.

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Appendix A

Bullock, J., Coccioli, L., Dooley, J., & Michailidis, T. (2013) Live Electronics in Practice: Approaches to training professional performers. *Organised Sound*, Vol 18(2), pp. 170–177.

Live Electronics in Practice: Approaches to training professional performers

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Teaching live electronic music techniques to instrumental performers presents some interesting challenges. Whilst most higher music education institutions provide opportunities for composers to explore computer-based techniques for live audio processing, it is rare for performers to receive any formal training in live electronic music as part of their study. The first experience of live electronics for many performers is during final preparation for a concert. If a performer is to give a convincing musical interpretation 'with' and not simply 'into' the electronics, significant insight and preparation are required. At Birmingham Conservatoire we explored two distinct methods for teaching live electronics to performers between 2010 and 2012: training workshops aimed at groups of professional performers, and a curriculum pilot project aimed at augmenting undergraduate instrumental lessons. In this paper we present the details of these training methods followed by the qualitative results of specific case studies and a post-training survey. We discuss the survey results in the context of tacit knowledge gained through delivery of these programmes, and finally suggest recommendations and possibilities for future research.

1. INTRODUCTION

Emmerson and Smalley (2001: 59–60) define live electronic music as follows:

> In live electronic music the technology is used to generate, transform or trigger sounds (or a combination of these) in the act of performance; this may include generating sound with voices and traditional instruments, electroacoustic instruments, or other devices and controls linked to computer-based systems.

In this article we will restrict ourselves to the subset of this involving one or more performers of acoustic instruments, whose sound is processed electronically during performance, and who may additionally initiate controller-based input to the processing system. Given this definition, the possibilities for what may constitute a live electronics setup are vast, ranging from a single microphone with amplification to a large ensemble where every player has an individual microphone, going into a network of computers running complex real-time algorithms incorporating a multitude of performer-driven audio and control processing.

However, even the most basic setups can pose problems for performers. In the simple case of an amplification-only system, a performer may need to consider their own position and continuously adjust the proximity and angle of their instrument to the microphone. This kind of 'microphone technique' is common amongst popular music and jazz performers who are familiar with amplification (Hughes 2012), but may be non-obvious for a classically trained musician. Also, on a basic level, the performer will need to adjust to their awareness of their amplified sound – something that may at first be disconcerting, especially in a large auditorium where some latency may be introduced by the positioning of the speakers and the length of the audio cables. Giving a convincing musical performance with such a system where the performer feels 'in control' and can work expressively and homogeneously with the electronics requires practice and experience.

According to McNutt (2003), technology in performance has a 'disruptive' effect, which is proportional to the performer's lack of familiarity with the electronic system being used. This relationship is shown diagrammatically in Figure 1. McNutt also notes that 'practising with the equipment is therefore every bit as important as practising with the score' (McNutt 2003: 299). One of the key hypotheses of this article is that the most common scenario in professional performance is that shown in the top left of Figure 1. Here the performer has a low level of familiarity with a highly complex system, creating a situation where performer and technology are 'divergent', and hence having a disruptive effect on the musical experience.

Despite this predicament, formal training for instrumental performers in live electronics is rare. The use of technology has been integrated in the training and personal development of composers for over thirty years, whereas the training of professional performers in the use of new technologies has only been explored in a few select institutions worldwide. Even then, it has only been with the small number of professional performers most interested in developing their work in this direction. Likewise, attempts to design hardware and software modelled on the practical needs and expectations of instrumental performers have been rare. For example, a recent

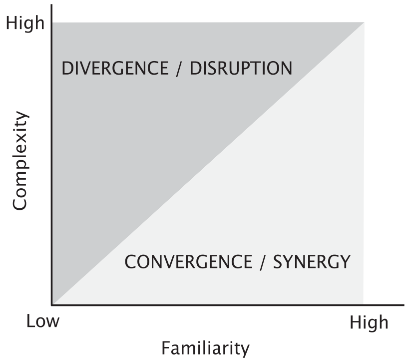

Figure 1. The effect of system complexity and performer familiarity on musical experience

software-based system designed for computer-music pedagogy by a world-leading research centre aspires only to meet the needs of 'composers, new media artists, computer scientists, and engineers' (Zbyszynski, Wright and Campion 2007: 57). In the associated paper, words with the root 'compos-' (compose, composition, composer, etc.) appear seven times; 'performer', 'performance', 'perform', 'instrument' and 'instrumental' have no mentions at all.

The most commonly used software in live electronic music, Cycling 74's Max/MSP is even further from taking a performer-centric approach, advertising itself as a means to 'create interactive and unique software'.[1] Thus, Max/MSP is not designed for live electronic music, but rather as a more general-purpose programming environment for audio, video and interactivity. Learning a programming language is a non-trivial task requiring a hierarchy of skills (Jenkins 2002), many of which fall outside the domain of traditional musical performance. This presents a significant challenge for performers, most of whom have busy practice and concert schedules, and little 'mental space' for learning the multiple skills required for programming. A common solution is to provide performers with a ready-made Max/MSP patch or stand-alone application. However, this means that for every new piece performers must familiarise themselves with a different graphical user interface (GUI) and a different interaction model with its own bespoke workflow. Such GUIs, typically designed by composers, are of variable quality and often incomplete, esoteric, confusing and undocumented. This inevitably disempowers performers by forcing them to rely on composers and/or technical assistants who act as intermediaries to the technology. In practical terms this means the changes and adjustments inevitably required in rehearsals tend not to be made by performers, and responsibility for aspects of the musical result are ultimately delegated to someone else.

1.1. A practical problem

We therefore identify two main issues with live electronics pedagogy:

1. Training in live electronics for instrumental performers is not readily available.
2. There is a lack of performer-centred software to support learning and professional practice of live electronic music.

This leads to the following questions:

- How can we most effectively teach live electronics to instrumental performers?
- What should we teach to performers – what should the methods, objectives and outcomes be?
- Is a single approach possible, or a diversity of approaches required?
- What are the best software and hardware setups for teaching instrumental performers?

In order to explore these questions, we have conducted a series of practice-based studies over a period of two years. In the following sections we outline two approaches to live electronics training, and the teaching methods employed.

2. TWO DISTINCT METHODS FOR LIVE ELECTRONICS TEACHING

Although conceived as separate methods and delivered in different contexts there is inevitably some overlap in the approaches used and this will be highlighted through the study survey. Both methods: 'performer training workshops' ('workshops' herein) and 'curriculum pilot' ('pilot' herein) took place as part of the Integra project, supported by the Culture 2007–2013 programme of the European Union (Rudi and Bullock 2011). The aim of the Integra project was to bring together new music ensembles, research centres and higher music education institutions from eight European countries and Canada, to promote the wider dissemination of live electronic music. Integra aimed to provide composers, performers, teachers and students with the software tools to interact with technology in a more user-friendly and musically meaningful way (Bullock, Beattie and Turner 2011). The activities of the Integra project ran along four main strands:

1. Artistic: a series of commissions of new works, concerts and two international festivals (Birmingham 2008, Copenhagen 2011).
2. Scientific: the development of Integra Live, a new software application for composing, performing, teaching and preserving live electronic music.

[1] http://cycling74.com/whatismax.

3. Heritage: the migration of seminal live electronic music works that use obsolete technology to the Integra Live software, so that they can be performed again.
4. Education: a pilot to teach live electronic music technologies in conservatoires, training sessions for performers, public workshops and outreach initiatives.

Both of the methods outlined below formed part of the 'Education' strand of the Integra project.

2.1. Method 1: workshops

The Integra workshops were delivered to performers from five professional new music ensembles: Ensemble Ars Nova, Athelas Sinfonietta, Ensemble Court-Circuit, BIT20 Ensemble and Grup Instrumental de València. Each ensemble was paired with a corresponding Integra partner research centre,[2] responsible for delivering the training sessions. The aim was to provide the performers with core competencies in live electronics to enhance their own practice and also to further the promotion of new technologies in performance across Europe. A primary outcome was therefore not only to pass on knowledge, but also to instil confidence both in ability and the software being used.

The workshops were delivered in two phases. Phase one provided an opportunity for five performers from each Integra ensemble to travel to an Integra research centre for two days and gain small group and one-to-one instruction in the use of technology in performance. In phase two, the five original performers along with live electronics specialists from the associated research centre delivered a two-day interactive demonstration, open to all members of the ensemble. The aim of this second workshop was to consolidate the learning of the original five performers, and to inspire and engage the other ensemble members.

2.2. Method 2: pilot

The pilot aspect of this study was also delivered as part of the Integra project. The aim was to design and deliver a programme of study for the teaching of live music technologies for performers at higher education level in three institutions across Europe: Birmingham Conservatoire, Institut für Elektronische Musik und Akustik (IEM) at the Universität für Musik und darstellende Kunst Graz in Austria and the Malmö Academy of Music in Sweden. Initially designed by Gerhard Eckel, Peter Plessas, Kent Olofsson and one of the authors, the pilot was experimental in nature, with a view to eliciting qualitative findings about the most effective ways to establish a tradition of live electronics study and performance practice within the context of higher music education. Like the workshops, the pilot was delivered in two phases. In the three mentioned academic institutions, four instrumental teachers were chosen or self-nominated to be trained in the use of live music technologies. These teachers were then trained over four one-to-one sessions with live electronics specialists using the newly developed Integra Live software as a learning tool. The teachers, in partnership with the live electronics specialists then devised an appropriate programme of study to be delivered to instrumental students.

In phase two, small groups of students were recruited to receive four training sessions with their teachers (supported by the Integra technical team) across a year of study. The precise nature of these sessions was tailored towards the individual interests and aptitudes of the instrumental teachers and students concerned, in a manner intended to be analogous with one-to-one instrumental teaching. The pilot sessions delivered at Birmingham Conservatoire hence varied greatly. Below we describe three of the contrasting approaches taken.

2.2.1. Example 1: pianist

The first example illustrates a musical approach following the traditional performer-as-enactor paradigm, where the role of the performer is to 'realise' through performance the intentions of a composer as specified through a score.

The study focuses on an exploration of Roger Smalley's *Monody* for piano and ring modulator, with the aim of adding the piece to the student's repertoire. The piece has simple live electronic requirements and provides an ideal way to introduce an inexperienced musician to live electronic music. The piece asks for the piano to be ring modulated by a sine wave. A MIDI keyboard controls the pitch of the sine wave. A conservatoire piano tutor and one of the authors worked with a student performer, in a number of sessions spread over a period of nine months. During these sessions it was demonstrated how to connect each part of the system together and what each part's function was. The piece was performed a number of times during the pilot. After several sessions the student was able to setup the system without assistance when she needed to practice.

2.2.2. Example 2: percussionist

The second example illustrates a musical approach following the performer–improviser paradigm; the role of the performer here is more exploratory than in

[2]The five research centres were Birmingham Conservatoire, IEM (Graz), Malmö Academy of Music, Muzyka Centrum (Krakow) and NOTAM (Oslo).

Example 1, with the performer having autonomy over the electronics used. In this study no specific piece was practised, but rather the student developed a 'structured improvisation' over the course of the sessions with their instrumental tutor. The sessions were experimental in nature, beginning initially with the student playing different percussion instruments through a range of Integra Live modules. As the sessions progressed, the student was able to build small networks of modules and save them as Integra Live 'blocks' so that each session built upon the work of the previous one. Finally, simple real-time controllers (such as foot switches and pedals) were incorporated into the sessions and basic performance instruments were developed, such as an 'extended marimba', where 'sustain' could be added artificially via the control of a foot switch.

2.2.3. *Example 3: trumpeter*

Like Example 1, our third example follows the performer-as-enactor paradigm, but in this case a new piece was composed in collaboration with an undergraduate trumpet student, and was incorporated into the performer's end of year major project. This enabled the performer to gain an insight into not only live electronics performance but also the process of developing a new work. The process took less than six months from experimentation and composition to rehearsal and final performance of the piece in concert. Of the three examples given, this was the most technically complex, requiring three microphones, a footswitch and expression pedal and vibrotactile feedback motors attached to the performer's body. The piece used Ableton Live and Max/MSP with pre-recorded material as well as interactive live sound processing.

3. RESULTS

In the following section we present the findings gathered from the pedagogical methods described above. These will be presented in the form of results from a post-training survey, and qualitative findings gathered through interviews and observation.

3.1. Qualitative findings arising from the curriculum pilot examples

The qualitative findings of the research relate specifically to the 'pilot' teaching method outlined in section 2.2, specifically examples 1–3. These findings resulted from direct observation of teaching sessions as well as post-pilot interviews with participants.

It was observed by the authors that more time was needed in the pilot in order to train instrumental teachers prior to the teachers working with their students. This was corroborated by reports from Integra researchers in other countries, and was particularly evident when it came to using the Integra Live software. Though Integra Live claims to offer the user an easy way to compose and perform with live electronics, many of the instrumental teachers did not learn the software as quickly as anticipated. The reasons for this were observed to be lack of familiarity with the primary metaphors used by the software such as 'timeline', 'scene', 'block', 'envelope' and 'module' as well as a lack of a priori knowledge of 'standard' audio processing such as 'delay', 'reverb', 'filter', 'synthesiser' and their respective parameters. However, once the basic structure and operations of the GUI had been learned, teachers were able to experiment with the software without necessarily understanding the underlying operations.

There was also insufficient time across the pilots to cover a range of basic-level audio tasks such as microphone techniques, audio interfaces, mixing desks and diffusion. In some of the pilots, the students were nonetheless still able to operate the electronics on their own by learning a given setup sequence, without necessarily understanding the function of individual components. This was observed to be the case, for example, in the 'pianist' example described in section 2.2.1.

In the 'trumpeter' example (section 2.2.3) the performer was provided with significant additional time to familiarise himself with live electronics techniques, since the standard one-to-one sessions were supplemented by many sessions working with the composer on the development of the musical work. It is also an exception in that it did not use Integra Live, but rather Cycling '74/Ableton's Max for Live software. The regularity and quality of rehearsals and 'tryout' sessions in this pilot was observed as providing the performer with a high level of confidence and control over the electronics. A mock-up system was set up in a practice room to allow the performer to practise regularly and familiarise himself with the electronics. The mock-up system was put together so that the performer alone, through written guidance, would be able to rehearse the piece with the electronics, go into sections, and control the piece without assistance. The ability of the performer to regularly rehearse with the full concert setup had an impact not only on the actual performance but also on his learning outcomes. In relation to this, the performer made the following comments:

> I did develop my music technology skill in terms of equipment set up and knowing the basic function of each component. I learnt most of this during the Easter holidays when I was setting up the equipment regularly to rehearse. As a result I also learnt the basic operations of the Ableton Live and Max/MSP software.

The approach in this pilot was directed towards the effectiveness of tangible outcomes such as a concert performance, and how these might have an impact in the overall pedagogy of live electronics. In this regard the performer noted:

> I did not improve my technique in the conventional sense but the physicality of controlling the electronics has improved my technique in another way. I do feel that I did improve my performance presentation skills because the nature of the piece required it. The fact that the piece was not technically demanding allowed me to focus more on the performing aspect rather than worrying about the notes.

The performer also stated the following:

> I have been extremely fortunate to have had the opportunity to perform a piece with live electronics and execute a successful Major Project. The journey was a steep learning curve but I have acquired skills in this genre of music that I can transfer to similar projects in the future. My initial interest in performing with live electronics has grown a lot since the very start of this process and I would gladly accept further collaboration in this field of music.

3.2. Project survey

In addition to the qualitative methods used, a post-training survey was provided to participants in both of pedagogical methods explored in the study: workshops and pilot. The purpose of the survey was to elicit feedback about the impact of the training across both approaches in order to identify potential patterns in responses to the training received. Participants were asked which of the two training methods they had undertaken, so where relevant, we are able to identify trends relating to specific methods.

3.2.1. Survey results

Fifteen people completed the survey; six of these were from the 'pilot' study and the remaining nine from the 'workshop' study. The majority of participants considered themselves 'advanced' musicians, had 15 (or more) years' experience and were aged 21–39, with 66% of those being below the age of 29. Most of the participants over the age of 29 tended to be from Integra music ensembles, and were taught with the 'workshop' teaching method (section 2.1).

Of the participants, 80% defined themselves as classical musicians, 53% electronic musicians, with many of them working across other musical genres (Figure 2); 43% identified themselves as being students, whilst the remaining participants considered themselves professional musicians working as performers, teachers and academics; 47% of participants were female and 53% male.

The groups' levels of experience with music technology *before* the training mostly ranged from 'no experience' or 'novice' (60%) to 'competent' (20%), with only 20% considering themselves 'proficient' or 'expert' (Figure 3). The experience consisted mainly of using microphones, mixing desks, loudspeakers and MIDI keyboards/controllers with regard to hardware, whilst Sibelius and Cubase were pieces of software that the majority of the group was familiar with. Levels of experience prior to the training were higher in the 'workshop' study than the 'pilot', with average confidence levels of 'competent' and 'novice' respectively.

The responses showed that the training had a positive impact on the participants' confidence with music technology. Prior to the training, 41% of the sample had 'some confidence' using music technology, with 25% having 'no confidence' at all; the remainder of the sample felt 'confident' or higher. After training, the general level of perceived confidence using music

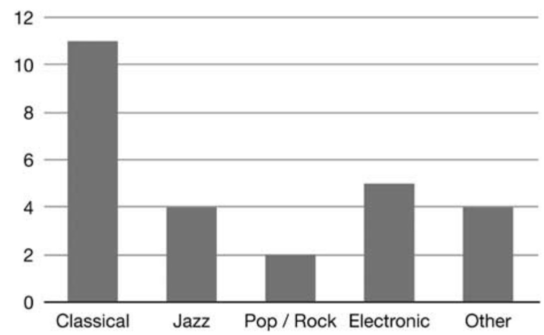

Figure 2. Participant genre descriptors for musical practice

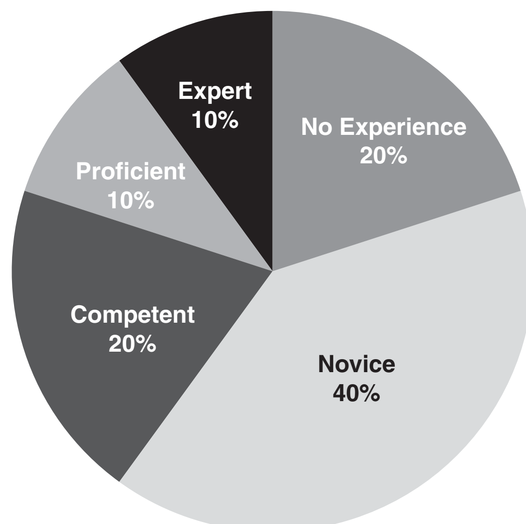

Figure 3. Participant ratings of music technology experience level before the training

Table 1. Comparison of average confidence levels before and after training

Measure	Pilot	Workshops
Average experience before:	Novice	Competent
Average confidence before:	Some confidence	Confident
Average confidence after:	Confident	Very confident

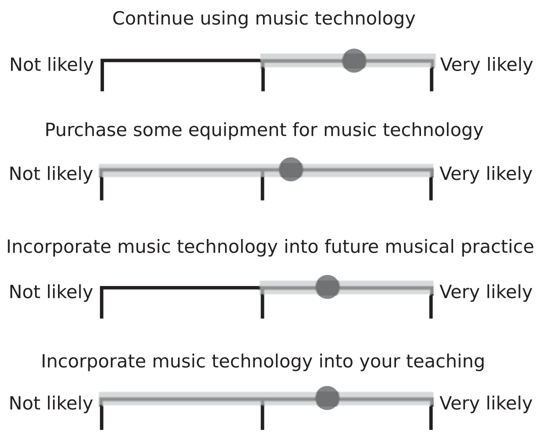

Figure 4. Likelihood ratings for music technology actions as a result of the training

technology was raised: 50% of the group had 'some confidence', with the remaining 50% identifying as being 'confident' or better. Average confidence levels across both study groups went up proportionally. The relative changes in confidence in relation to initial experience are shown in Table 1.

The impact of the training on the use of technology showed that participants were likely to continue using the technology demonstrated and to incorporate technology into their future musical practice (Figure 4); purchasing equipment and incorporating technology into participants' teaching where relevant was also likely. Those most likely to incorporate technology into future practice and teaching were taught using the 'workshop' method, with 50% giving a response of 'very likely' for both of these questions compared to 50% giving a response of 'quite likely' for the 'pilot' method.

Participants were asked to rank which aspects of the training they had learned the most from: 46% of participants ranked 'actual performance' most highly, with 31% ranking 'workshopped examples' most highly; 15% ranked 'spoken training (lecture/presentation)' most highly. The overall ranking based on rank averages was (highest first):

- actual performance
- preparing for live concert
- workshopped examples
- spoken training (lecture/presentation).

4. DISCUSSION

From the survey results some general trends can be observed. The authors' personal experiences reflect these trends and have helped to develop our own approaches to music technology pedagogy. The most pertinent discovery is that performers favour practical approaches that work towards a specific outcome such as a concert or informal performance. This was also reflected in the qualitative findings arising from the pilot. Setting up equipment, using software and repeating these tasks in different environments makes the learning process more meaningful and productive: learning should be relevant to musicians' musical practice. For this reason, score notation software, MIDI keyboards/controllers, microphones and speakers were all aspects of technology that most musicians were familiar with.

Those who participated in the 'workshop' teaching method came from the Integra project professional ensembles. These participants were on average 10 years older than the 'pilot' participants, with higher music technology experience levels, and higher initial and final confidence levels. This suggests that learning music technology, as with learning an instrument, takes time and dedication, potentially entailing years, rather than months, of study. Like an instrumentalist, who must learn their instrument through hours of practice and performance experience, the discipline of live electronics may need to be approached in a similar manner. This is supported by qualitative data from 'open' fields within the survey. In response to the questions 'Are there any other improvements you'd like to see in this training?' and 'Do you have any other comments about the training?' answers included:

> 'More time to try out the technology.'
>
> 'More practical approach with more emphasis on the theatrical implications of using technology on stage. That is a very important part of performing (in my opinion) with technology that is not really explored yet.'
>
> 'It would be interesting if it were a bit longer.'
>
> 'More time needed.'

Our research did not show any transformational changes in musicians' relationships with technology, suggesting that skills and knowledge are acquired gradually and accumulate over time. Long-term, gradual exposure to music technology is key to transforming musicians' perceptions of it. However,

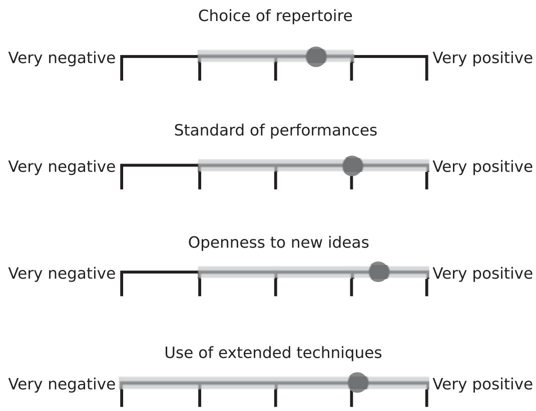

Figure 5. Likelihood ratings for effects of training on aspects of musicianship

the results did indicate a transformational impact on the general musicianship of some of the performers. This is illustrated in Figure 5, which shows the averages, minima and maxima for related Lickert-scale reponses. Over 80% of participants said the training had a 'positive' or 'very positive' effect on their standard of performances, openness to new ideas, and use of extended techniques. The survey results also show a significant increase in stated likelihood for performers to use and incorporate technology into professional practice following the training.

In terms of the two distinct pedagogical methods explored in our study, no single method consistently showed 'better' results than the other. However, given methods did show patterns of greater effectiveness in certain areas. For example, the one-to-one sessions used in the 'pilot' method resulted in an at least half of participants indicating 'positive' or 'very positive' effect across 'choice of repertoire', 'standard of performances', 'openness to new ideas' and 'use of extended techniques'. By contrast the 'workshop' method resulted in an average of one-third indicating 'positive' or 'very positive' effect in these areas. In terms of 'impact on use of technology', participants attending the workshops were more likely on average to 'continue using music technology', 'purchase some music technology equipment' and incorporate technology into future musical practice or teaching. Participants who attended the pilot consistently rated the quality of training as being higher, with a higher average score for 'quality of tutors', 'equipment provided', 'length of session', 'quality of given information' and 'overall'.

The higher average scores for the curriculum pilot in the 'effect on musicianship' are thus correlated to the above average curriculum pilot scores for 'quality of training'. This is perhaps unsurprising, since the pilot had a far higher teacher–student ratio – in most cases this was one-to-one or two-to-one. The higher average scores for the workshop participants' 'continue to use technology' answers could be explained by factors such as the higher age of the workshop group, higher disposable income due to being in employment, and the practical requirements of working in professional artistic practice.

5. CONCLUSION

We outlined in our introduction the significant challenges that instrumental performers face when confronted with the performance of live electronics repertoire, and we offset this against an international shortage of live electronics training for performers at higher education level. We then presented two distinct pedagogical methods for teaching live electronics to instrumental performers: workshops given to professional ensembles and a pilot based on individual instruction. We described how these methods were implemented in practice, and presented results from a post-study survey in the context of tacit knowledge and personal experiences of the authors. Our results show a consistent incremental improvement in perceived confidence with technology, with *all* survey participants being 'quite likely' or 'very likely' to continue using music technology. This may seem intuitively obvious: training musicians in music technology improves their confidence and engagement with technology. However, what is perhaps more pertinent is the effect of training on 'musicianship', with the majority of participants identifying either a 'positive effect' or 'very positive effect' on 'choice of repertoire', 'standard of performances', 'openness to new ideas' and 'use of extended techniques'. It could therefore be concluded that it may be beneficial to incorporate music technology instruction into programmes of study for performers at higher education, regardless of their intention to incorporate technology into their wider practice. That is, the addition of music technology instruction to performance curricula may be advantageous solely for its potential benefits on general musicianship.

A common thread across the study has been that a high-level software environment was used as the primary teaching tool. Without including a control group, it is difficult to draw firm conclusions about the significance of this. However, a previous study states the following in relation to the use of Max/MSP, the lingua franca of live electronic music:

> The typical learning process of a student composing computer-based music involves encountering many of the same programming problems and inventing the same solutions as their predecessors. While solving basic problems in programming, signal processing, or music has a definite pedagogical value, much of this activity is counterproductive and often impedes serious musical or aesthetic investigation. (Zbyszynski, Wright and Campion 2007: 57)

This observation chimes with our own experiences, and we did find some evidence within our survey data that reflects this, with one student writing as a final comment: 'The training was so simple in comparison with Max/MSP.' Removing the requirement to learn a programming language as part of the process enabled the training to focus entirely on practical application and musical engagement. This meant the training had effects that reached beyond improving musicians' music technology skills, resulting in a greater awareness of their instrument, performance practice, extended techniques and new repertoire possibilities.

We observed that participants primarily favoured pedagogical approaches involving a 'hands on', practice-led delivery style. As with conventional music study, live electronic music training can be provided through a combination of one-to-one lessons and group sessions delivered as practical workshops. The results of our third pilot example (trumpeter), also highlights the importance of the environment in the context of performer training. We propose that higher music education institutions should establish dedicated live electronics practice rooms for instrumentalists, where they can practise live electronics repertoire independently. Future work could include a longer-term study, implementing these proposals, and tracking progress over a number of years. This could be more effective if it involved a statistically significant number of students across a small consortium of partner organisations.

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Communication through haptic interaction in digital performance

Introduction

This chapter aims to contribute towards the theory and techniques of creating an immersive stage environment for choreographic performances and installations. A number of digital performances are known to employ audio-visual material with the intention of creating relationships between the real-time projected material and the performers. However, such approaches often cause problems in performances. Dancers are expected to form a relationship with other dancers on stage and also with projected imagery. Due to the nature of the performance space and the performer-audience relationship, the dancers cannot experience visual elements in the same way as the audience. The performers tend to be in the midst of the action while the audience is situated in the optimal position to experience the composition of the performers, the projected visuals, the audio and the scenography of the space. Whilst dancers are able to interact 'live' on stage with ever-changing visual and audible aspects of the performance, their sense of interaction with the technology or other performers may be diminished due to a lack of feedback gained from visual or acoustic cues. The performers may not be in line of sight or audio might not be adequate during the heat of the performance. This chapter proposes ways to overcome this problem, by offering different input stimulations, through haptics, that enhance the relationship between performers, or between performers and technology, adding an additional layer of spatial and emotional awareness.

The chapter begins with an introduction to relationships between aural and tactile feedback and a discussion of gesture in haptic interaction. It continues by constructing a theoretical approach to technologically mediated embodied performances with reference to the choreographic installation *Ukiyo Moveable Worlds* and the participatory installation *Whisper[s]*. The former example concentrates on the interactional qualities between one performer and an artificial intelligence system, while the latter utilizes networked technologies, sensors and motors to initiate technologically mediated relationships between participants. In the following section we explain how current technologies can be utilized to create a reactive space involving haptic technologies. Finally, we draw the various components of our research together by proposing an analytical framework for thinking about different scenarios and modes in which these technologies can be used.

Aural and tactile feedback relationship

The relationship between tactile and aural feedback is often difficult to illustrate. This is because both feedback modalities are a by-product of the same action-reaction mechanism, making it difficult to separate them. Action refers to the energy or energies that have been applied and transferred from one agent to the other. As a result of the applied energy, the 'reaction' produces audible and tactile results. Such audio-tactile reaction is perceived as feedback, allowing the initiator to make adjustments. For instance, this could include tapping the fingers on the table or hitting a bell with a hammer. Both actions provide aural and tactile feedback gained from a single action. The 'volume' of feedback received, aural and tactile, depends greatly on the applied energy[1]. The more powerful the hit, the louder it will sound

[1] Other factors such as material, shape and temperature between two agents should also be considered.

and the more the hammer and bell will vibrate. What is important here is that both feedback modalities are supplementary to each other, and it is impossible to separate them from activities in everyday life. Apart from the physical laws that govern the universe, a fundamental aspect of this multimodal integration (cf. Calvert and Thesen, 2004) is due to the formation of habit over the years regarding the relationship between aural and tactile (Mäki-Patola, 2005). Consider again the example of hitting a bell with a hammer. It will be 'unnatural' to experience the received aural feedback three seconds after hitting the bell. Our perceptual understanding of audio-tactile relationships is closely related to the habit formation of latency that exists between the two. We have established a habit relationship of coupling the aural and tactile feedback in a particular way. In instrumental performance, the introduction of latency in the audio-tactile feedback relationship changes learned kinaesthetic-acoustic mappings and disrupts the inner prediction of the instrument's responsiveness. That is, the behaviour of the instrument changes unexpectedly for the performer and needs to be relearned (Mäki-Patola, 2005).

Looking at the available technologies and how we interact with them, such audio-tactile feedback relationships are often *designed* and introduced artificially into products. The majority of handheld touchscreen devices provide audible feedback in relation to user interaction in order to simulate acoustic feedback that occurs naturally in physical interaction with 'real world' objects. The incorporation of such feedback modalities can be a key factor in differentiating a successful product. For example, when using the onscreen keyboard on a touchscreen device, there is insufficient auditory and tactile feedback through contact with the physical device. An auditory cue indicates whether a key has successfully been 'pressed' as found with the traditional typewriter or with computer keyboards. The addition of auditory feedback to the user therefore serves as to enhance and confirm the actions of the user.

In performing arts, and in particular in instrumental music performances, for example, the aural-tactile relationship forms the basis of learning and performing an instrument. The instrument reacts to the energy that it receives from the performer by producing both, aural and haptic feedback. Through instrumental practice, the performer is able to learn and internalize these responses. Interestingly, a threshold exists on the amount of latency with which the performer can cope when separating the aural from the tactile feedback. Exceeding such a threshold exposes the performer to a problematic performing environment. A study by Dahl and Bresin (2001) shows that 40-55ms could be the 'break-point' where the performer notices latency and needs to adjust to other strategies for sensory input information in order to continue playing. The study shows that different musical training can produce different thresholds for such reliance on aural and tactile coordination. The familiarity with different performance settings, such as an orchestra or a jazz ensemble, suggests there are variable levels of confidence for the performer in terms of the relationship between tactile and aural feedback (Dahl and Bresin, 2001). Orchestral performers were able to play in-tempo with larger delays present between physical input and resultant sound due to the necessity of an orchestral timing where long distances between performers often require them to adjust their tempo.

Sawchuk et al. showed a variable break-point of latency depending on the instrument used and piece performed (Sawchuk, 2003). For instance they noticed that the performer could tolerate latency at 25 ms when playing a synthesized accordion, but latency could be tolerated up to 100ms when using a synthesized piano. Furthermore, they observed that performers felt more confident in a large performing hall where the reverberation of the hall is greater, rather than in small halls with tighter reverb.

The importance of such audio-tactile relationship becomes apparent in particular when examining digital controllers and their use in live electronics performance. The majority of digital controllers available to performers do not provide sufficient tactile feedback (if any at all) to enable expressive nuances in the performance to be felt. For example, it is difficult for performers to know the angle of an expression pedal without visual cues because its range of movement is small (around 30°) and insufficient kinaesthetic information can be obtained through foot movement within this range to determine accurately the relative position of the pedal. Furthermore the movement of a digital controller may be mapped non-linearly to the controlled output (audio or visual) and it is generally very difficult to infer the nature of this mapping through the physical state of the controller. It is therefore necessary to provide additional haptic cues through vibrotactile feedback, supplementing the information that the performer gains from other sensory modalities. A study conducted by Michailidis and Bullock (2011) examined whether incorporating haptic feedback in music performances can improve the overall control, perception and musicality of live electronics by instrumental performers. The results suggested that adding vibrotactile feedback to a sensor-based controller can significantly improve a performer's understanding of relationships between the controller and resulting sound produced. Additionally, the use of haptics suggested new musical possibilities not previously considered by the performers when using the controller without the vibrotactile feedback.

Gesturo-haptic Interaction

The most common uses of haptic feedback involve direct (often linear) mapping between input values (e.g. from physical controllers such as foot pedals or sensors) and output values controlling the magnitude of the vibrotactile vibration. That is, the specific volume of vibrations felt on the body has meaning *in itself*. For example, data received from a gyroscope sensor measuring the angle of rotation could be used to control in a linear fashion the amount of vibration received. However, an alternative, somewhat more advanced approach is to allow *multiple* values over time, in multiple dimensions to carry meaning. Rotman (2002) describes this approach as 'gesturo-haptic'. Movement data can be captured through combinations of motion capture technologies (gyroscopes, accelerometers, range and depth-sensing cameras) and stored on physical media as time series. This data can later be 'played back' through mapped vibrotactile feedback devices, effecting a re-embodiment of the disembodied movement. A simple example would be using an accelerometer to measure the movement of a hand back and forth. This data could be later re-played through a combination of two vibrotactile motors on the front and back of the hand, one motor 'pushing' back, the other 'pushing' forwards.

Movement in itself doesn't equate to gesture. A gesture has a beginning and end point and is often (though not always) intended to express meaning or communicate information (Cadoz and Wanderley, 2000). In the context of digital arts performance, gesture is certainly multi-faceted, serving a range of functions from abstract and expressive gesture in dance to 'functional' gesture in composed sensor-based control-processing relationships in interactive music. Once a gesture is captured, it becomes dislocated from its original embodied form. That is, once the gesture is stored numerically, it is deprived of its original meaning (if any) and becomes only a representation of movement. As Rotman writes:

> '…haptic gestures do not communicate as such; they are not signs in Saussure's or Pierce's sense though they may become so retrospectively in that they come to signify (if that is the term) their own happening; their meaning is the fact and consequence of their having occurred.' (Rotman, 2002, p.102)

There is thus an opportunity for the digital artist, in the process of mediation between movement capture and haptic gesture, to manipulate creatively the gestural time series in order to bring about a particular haptic sensation for the performer or to synthesize entirely artificial haptic gestures, which may have significance only within the digital virtual space of the work in question. This process becomes particularly interesting in the case of having two or more performers, with one performer originating the motion (which is captured), and the other receiving the captured haptic gesture. A system like this could be used bi-directionally, to simulate the 'throw and catch' of a virtual ball, for example. However, any such correspondence between received haptic gesture and meaning (I am receiving a ball) would need to be learned, or at least inferred within the given context. As Rotman warns:

> '…the gesturo-haptic is a medium with features opposed to the alphabetic: by enacting and executing its "messages" it is evidently governed by a participatory rather than functional logic, having to do primarily with action, deeds not words and inscriptions, with *faire* rather than *dire*, with performative and interactive states before constative and descriptive statements.' (Rotman, 2002, p.103)

Technological Embodiment

In his paper *After Choreography*, Birringer (2008) emphasizes that real-time digital performances mostly involve some sort of projectional activity. Performances follow traditional scenographic structures, in general, where the audience is situated in the optimal position to receive primarily audio/visual stimulations. At the same time there is a shift in emphasis away from the physical body towards the inter-relationship of the digital elements *with* the physical bodies. Birringer states:

'... this marks the enactment of movement that has less to do with steps, phrases or placements of the limbs than with gestural or postural articulations of motion "mapped" onto image, sound and light movement.' (Birringer, 2008, p.119).

One example of such a technique can involve a real-time video feed which is being filtered through software and then projected back to an onstage screen. This technique involves having a dedicated camera, aimed and oriented at a very specific part of the set. This results in a camera which is setup for a specific task, most likely for a short period of time and will probably not be utilized for the rest of the performance. If that projection image provides visual feedback to the performer, then the static position of the camera means that the performer must be within the range-view of the camera and must also notice the projected image. From the performer's perspective this can be an overwhelming situation in the context of an already-complicated performance, and presents an unnecessary cognitive burden.

Maurice Merleau-Ponty views the phenomenal body as our primary access to reality and further subdivides it into two notions: the body schema and body image (Merleau-Ponty, 2002). In his book *Bodies in Code*, Hansen distinguishes between the two:

> 'The body image characterizes and is generated from a primary visual apprehension of the body as an external object, the body schema from what, with autopoietic theory, we have called the operational perspective of the embodied organism.' Hansen (2006, p.39).

In other words the body image refers to how the body is *represented* whereas the body schema refers to the *organism*, which is caused by movement and subsequently causes it.

It is clear that when a performer is offered visual stimuli from a video loop the visualized body image drives the body schema. As described by Polydorou:

> 'In the first generation interactive media works, where a performer or a member of the audience interacts with a direct one-to-one relation with the projected image, the visualized body image drives the body schema. The system will only respond interactively after it is being offered an analog signal, usually in the form of movement from the interactor. All subsequent movement,

even though originating from the body schema, is a result from the immediate visual or audio stimulation derived from the body image (Fig.1).' (Polydorou, 2011, p.58).

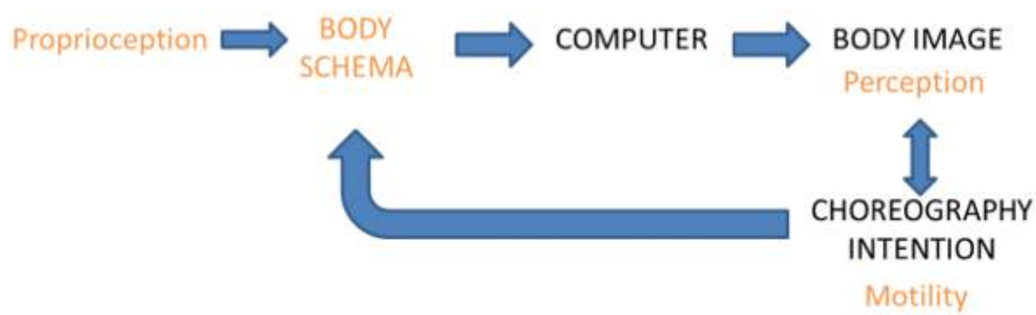

Figure 1. 1st Generation Interactivity - Interacting with body image (Polydorou, 2011)

Talking about 1st generation interactivity, Birringer mentions that this 'layering of indirect and remote manipulation of the kinaesthetic and the kinaesonic can be highly complex, especially if the kinaesthetic qualities of the projected images contradict the human body motion observable in the phenomenal body' (Birringer, 2008, p.119). Birringer continues to warn that these digital articulations created by the body but 'at a distance from the body' can induce new associations between sensations and sense perceptions that cannot be assumed to belong in the 'intuitive' vocabulary of a dancer's physical thinking and kinaesthetic experience (Birringer, 2008).

In order to avoid this situation, the technological stimulation, which aids the choreographic intention, must not be sourced by purely looking at the body image but rather by an all rounded perception which originates from the performance space itself. Polydorou describes such a scenario in his thesis:

> 'At the start of an interactive dance, a connection is established between the performer and the space, through the interfacing technology. We have the visualized space, the computer which is hosting the rules imposed by the designer and the performing body which becomes the mediator of the two. The dancer perceives the space shifting and along with the motility derived from the choreography/intention as well as the dancer's proprioception, the body schema becomes an embodied potential. As we can see from Figure 2, the body schema is transferred through the embodied agent directly to the computer. As the body schema is digitized, the space architect needs to interpret the data in ways which make the space transform and not only become an extension of the dancer but also possibly a dance partner with its own initiative which equals that of the dancer (Fig.2).' (Polydorou, 2011, p.60).

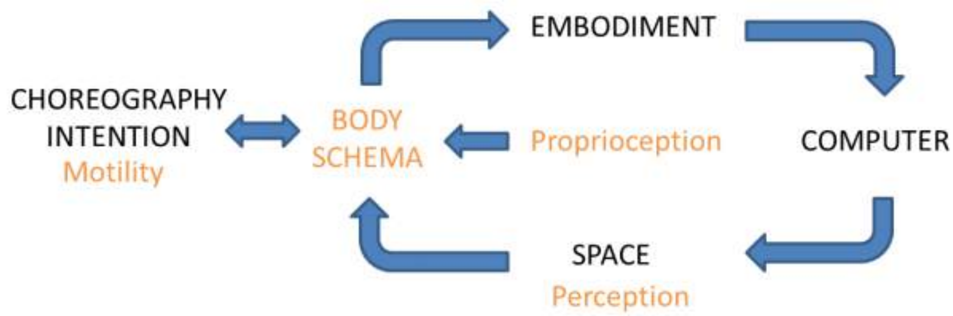

Figure 2. 2nd Generation Interactivity - Interacting with body schema (Polydorou, 2011)

Polydorou continues by comparing the 1st Generation Interactivity (Fig.1) where the live video feedback loop is prominent with the 2nd Generation Interactivity (Fig. 2) where the visual representation of the body image is absent and focused primarily on abstract audio/visual cues that are generated as a consequence of the dancer's movement. He explains that:

> 'The interactive audio-visual feedback is more subtle, taking more time to develop, and it does not directly relate to the body image. It is perceived more subtly, therefore it is being "absorbed" by the body schema at a slower rate, allowing the dance to get *influenced* by not *directed* by it.' (Polydorou, 2011, p.58)

Hansen, refers to this phenomenon as a disconnection of the fundamentally visual body image, resulting in the viewer (or performer) technically being enabled to utilize the excess of the body schema over the body image to increase her agency as an embodied being (Hansen, 2006, p.20).

For the section *Creation Scene* in *Ukiyo Moveable Worlds*, performed in 2010 and directed by Birringer (2009/2010), Polydorou creates a system in which the performer and machine would work together to shape and evolve a real time generative 3D world[2]. The *Creation Scene*, being a scene in a choreographic installation, aims to immerse both performers and audiences in a dream-like fragmented world that stimulates the perceptions and emotions of the viewers by offering them an ethereal journey through a world generated right in front of them.

[2] Part of the performance can be found here https://www.youtube.com/watch?v=mnCtnH1NdY0

Figure 3. Isobe performing in Sadler's Wells (2012).

During the *Creation Scene*, the performer becomes immersed into her own virtual space, working along with the system, and aims to shape the Hiroshige inspired landscape, turning the dark industrial space into a peaceful green landscape with falling leaves or an icy eerie and mysterious forest with volcano rocks and walking trees. Matching the concept of *Ukiyo Moveable Worlds* and the mixed realities, the creation scene exists and takes place in two realms at the same time. The dancer is performing her choreography around a weather balloon, while an evolving world is being projected on to it. By using an inflatable weather balloon, suspended above human height in the air, the image is engulfing the sphere, adding extra texture and dimension to the image, while the dancer softly moves around it acknowledging its existence. As the dancer is wired with sensors, an interface controlling the virtual realm, the actions performed by her acquire a double meaning. Not only are they viewed by the audience as performing acts (the touch of a hanging leaf) but also they have an effect on the evolution of the virtual space. Starting from a flat concrete surface, the space is slowly transformed into a beautiful landscape, with mountains, grass, trees and lakes and populated by the eerie walking tree and mysterious black figures.

'The place' Polydorou describes, 'like an extension of her wishes flows onto her dress and then the dress extends all around her, creating a fortress of solitude. She can invoke trees, she can make the grass grow, she can call for the sun or she can call for rain' (Polydorou 2011, p.80). As the three dimensional world passes through the different evolutionary stages, the dancer and artificial intelligence system work together to shape the malleable environment as according to their impulses at any specific moment in time. Birringer described *Isobe* as a performer with 'acute sense of bodily self-awareness and alertness, that listens through all her sensory channels, perceives through her entire body, with movements that feel animal-like, suspended somewhere between the rhythmic and the arrhythmic as she navigated real and virtual spaces' (Birringer and Danjoux 2013, p.234). The world is beautifully rendered on a suspended weather balloon, right in the middle of Isobe's 'magic circle' of interaction.

Upon reflection, the communicative limitations of the *Ukiyo* project are apparent. Even though there was an artificial intelligence system developed, which was working both independently and in collaboration with the dancer, the communication infrastructure was heavily one-sided. Through the performer's technological embodiment (sensors and a camera vision system) the system could identify where the performer was located in the space, identify her gestures and movements, and react accordingly. However, there was no way for the system to communicate back to the performer. For example, that the tree she planted was fully-grown or that it had suddenly started to rain. The only way for the performer to obtain this information was to turn towards the projected image and view the result. In doing so the camera, which was programmed in advance, would capture that movement from the dancer and trigger another section of the world which was not intended. This not only caused loss of agency and reduced sense of belonging in the digital space but most importantly it forced the dancer to re-think the kinaesthetic experience.

The Unhealthy Divide

Before investigating the on-stage links between multiple performers, it is beneficial to examine another performance/installation stemming from a phenomenological perspective. In her book *Closer*, Kozel (2007) claims that phenomenology can help to bridge the unhealthy divide between solitary and shared experiences. By working alongside Thecla Schiphorst, Kozel aimed to analyze the 'conditioned reactions and physiological behaviours of performers and audience members'. In their installation *Whisper[s]: wearable body architectures* they aimed to represent the participants as "common and shared signals in multiple networked system" (Schiphorst and Kozel, 2002). According to Kozel, the design of their system encouraged the audience member to attend to his or her physiological data or affective corporeal state and to send it to another as a 'poetic amalgamation of sound, visualisations and haptics'. The two goals of the project were to 'amplify the poetic capability of our mobile devices and their convergence with our bodies, both in what they convey and how they are worn' (Kozel, 2007, p.238). By identifying a number of characteristics that they believe are the glue of human exchange – invisible layers of emotion, physicality, vitality, imagination, gesture and attention – Kozel and Schiphorst created different configurations of sensors, actuators and networking protocols in order to access and transmit this data.

The *Whisper[s]* project had three slightly different iterations, all of them in a participatory installation format inviting members of the public to wander around the space while wearing garments embedded with small wireless computers. In the first iteration, participants could access their own breath and heart data through simple gestures and transfer those, in the form of real time visualizations, on video 'pools' which were spread around the installation space. In the second, more playful iteration, both men and women were asked to put on skirts embedded with small fans and vibrators. Wanting to move away from a primarily ocular-centric feedback system, Kozel and Schiphorst embedded garter belts that sensed muscle contractions of one person which were then used to trigger the fans and the vibrators in the skirts of another. Kozel explains in *Closer*: 'We wanted to escape the visual in order to enhance the kinaesthetic and tactile, to draw people into different qualities of awareness that did not privilege vision' (Kozel, 2007, p.314).

While reflecting on the procedure and the reactions of the participants, Kozel identified three distinct and very interesting relationships. It is important to note that *Whisper[s]* aimed to investigate the participation of a public audience with very little past experience in using networked haptic and responsive technologies. It was therefore expected that most participants would spend a big portion of their initial exposure to the system in a mode of self-reflection and experimentation. The first relationship, revealed as soon as the participants put on the garments, was between oneself and one's own visualized physiological data. When this relationship became apparent, participants shifted their attention and intention to an exploratory mode, which slowly revealed the possibilities of being embodied through technological mediation in a digital networked space. The second relationship that was revealed was between self and others. Kozel (2007, p.316) explains that some people were fundamentally uncomfortable with the procedure and they choose to remain engaged with exploring their own data. Perhaps the most interesting relationship was the last one, self-to-system, where participants realized they were part of a holistic system, one that purely spawned into existence just because they entered the space. Furthermore, the space became a composition of a community of bodies with un-manifested potentialities that invited experimentation and self-reflection.

As this chapter concentrates on performers, there are some fundamental differences that need to be taken into consideration. As is evident in both *Ukiyo Moveable Worlds* and *Whisper[s]*, there is an urgent need to shift away from a purely visual feedback. In addition, Kozel states about her project: 'The decision to focus on tactile and haptic outputs was born of an awareness that the visualisation of body data out of the first version of *Whisper[s]* somehow limited the gestural and imaginative interaction' (Kozel, 2007, p.314). The one-to-one mapped interactions (Figure 1.) greatly impacted the kinesthetic and proprioceptive intelligence, as intention needed to be directed in controlling instruments. According to Birringer (2008):

> In such environmental practice there can be no set piece (choreographic), nor can one speak of improvisation, since the interactive potentials are shaped by particular aesthetic and mathematical principles requiring that performers adopt specific physical techniques to play the instruments of the medium and learn new proprioceptive and sensory process (p.119).

It is therefore imperative that technologies do not limit kinaesthetic processes but rather become part of, and offer stimulations to, the mechanism that inspires and creates the intention of the dancer.

Polydorou identified three techniques that drove the intention of the dancer in *Ukiyo Moveable Worlds*. Firstly, it was the sense of being part of a narrative. Secondly, it was a sense of agency both in the long term (form the island) and short term (change the color of the sky, plant, trees, etc). Thirdly and perhaps more importantly for this case, it was the reassurance of spatial belonging through technological embodiment with the virtual space (Polydorou, 2011, p.85). Kozel described the participants entering her networked space as hesitant, careful, always listening and aware, like they were "discovering the self anew, entering into a gestural dance with one's body in order to access things that were intimately familiar but strange at the same time" (Kozel, 2007, p.291).

Performers on the other hand need to be confident, without any doubts regarding whether the technology will work or not. In the case where the technology becomes an 'instrument' for the dancer, such an instrument should be in a position to provide direct and sufficient feedback to establish confidence by providing confirmation about the performer's actions. Such an approach will form a technological 'habit' that would potentially allow the experience of the 'instrument' to become an extension of the body. Merleau-Ponty, in *Phenomenology of Perception*, discussed how we learn to use tools in our everyday life (Merleau-Ponty, 2002). He introduced the importance of habit and skills and how they impact on a perceptual level on the body schema when it comes to manipulate objects. Through the process of acquiring skills the body schema changes, thus altering further the potentialities of carrying out an action. At a further extent, through this process, unfamiliar objects become familiar tools that are incorporated and act as an augmentation of the phenomenal body. This depends on the way that motor skills are involved in developing a body schema and how feedback enables the development of that motor skill (Merleau-Ponty, 2002).

The senses address the body schema in to determine external properties of the environment and the objects such as 'near' or 'far away', 'large' or 'small', 'heavy' or 'light', 'high' or 'low' and so on. Interestingly, the elements that allow one's body to distinguish the variation of external objects and the environment have evolving and interchangeable properties. In music performances, for example, such distinction is prominent to the instrumentalist where the performer's body schema evolves through years of practicing and performing. The way an instrumentalist experiences such external influences, such as how the instrument is registered on the body schema, depends greatly on haptic and tactile feedback. The body schema cannot be evolved through visual and aural feedback alone. An instrumentalist cannot develop any performative aspects without physically experiencing the instrument. Similarly the relationship between dancers and the technology should provide some physical experience possible to enable an expressive link between the two. Even though the performer controls and manipulated the properties of the system the absence of haptic feedback creates a gap that limits the development of a new body schema. Hansen, who expanded the ideas of Merleau-Ponty into the domain of new media, argues that technologies can change or enhance our sensory experiences, consequently affecting our view of embodiment. By envisioning a world with a fluid interpenetration of the virtual and the physical realm, he prioritizes touch, the perception of spatial depth and motor activity claiming that the body can synthesize and compliment our other senses resulting in a holistic experience. Moving towards indirect interfaces (including optical, ultrasonic sensors or machine vision) creators of such performance systems generally prioritize the development of software techniques over physical interaction techniques, and performer's sensual and cognitive needs are often not addressed.

The Technology

Our aim is to provide and suggest a tool with which dancers and choreographers can further develop and explore the implications of vibrotactile feedback. We propose the use of vibrotactile feedback as a means to provide a creative multi-directional communicative channel between digital technologies and the dancers. In addition, the vibrotactile feedback, through the technology, can be utilized as a creative communicating link between dancers themselves. At this stage, due to the wider implications and approaches possible with vibrotactile feedback we avoid suggesting any dogmatic 'solutions'. We propose the use of vibrotactile feedback through two the examples provided in this chapter. Firstly we studied the performer-technology relationship and secondly the performer-performer relationship through the technology. The performer can benefit from the introduction of the vibrotactile feedback as a means of communication whilst immersed in a technology-oriented environment. The technology and the overall system can provide, through vibrotactile feedback, meaningful information to the performer about current states and functions otherwise limited to visual feedback. The placement of the motors on the body has not been fully investigated creatively in a performance setting and can be a topic for further research.

In terms of hardware, we defined our needs based on the following three criteria:

1. The device should be wearable and light in order to have minimum impact on the performer
2. The device must be wireless to allow free movement of the performer on stage
3. The device should be able to provide Pulse Width Modulation (PWM) in order to drive the motors

Since the technology is not absolute our approach is focused on how the technology can best suited for the criteria above[3].

[3] Even though many devices met our criteria to differing extents we decided to use X-IO Technologies' x-IMU (www.x-io.co.uk). The device is capable of providing up to 4 PWM outputs and can be connected to a laptop wirelessly via Bluetooth. The vibrating motor (www.precisionmicrodrives.com) is attached securely on top of the device with a plastic tape. The device weights a bit over 50 grams including the motor, the battery and the plastic housing as shown below. It is easily attached around different parts of the body with a Velcro strap. In addition to providing vibrotactile feedback via PWM, the x-IMU contains a gyroscope, accelerometer and magnetometer, which can be used to gain positional and movement information.

Conceptual Framework

Based on our research and artistic practice incorporating vibrotactile feedback into music and dance with digital technology, we have devised an analytical framework for haptic interaction in interactive performance. The framework consists of three primary interaction types, which we term 'modes' and two secondary interaction types, which we term 'scenarios'. We illustrate the framework below through practical use-case examples.

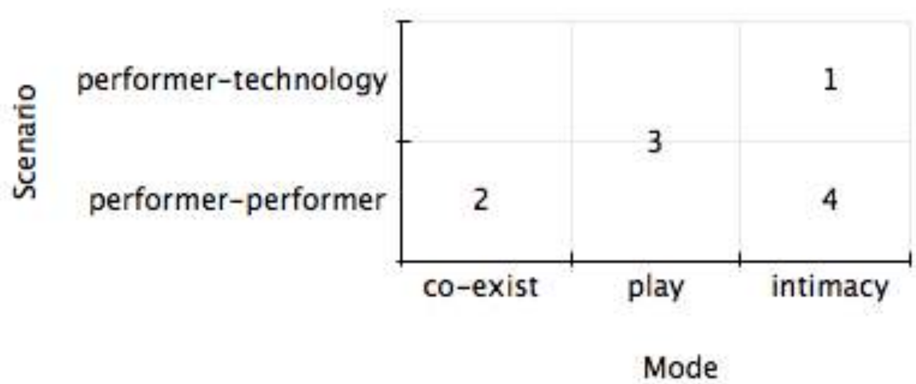

Figure 4. Haptic interaction grid showing 4 states distributed across combinations of mode and scenario

Performer-Technology

The Performer-Technology mode concerns interaction between the human performer and the technology 'system' (including all control processing, sound generation, visual and haptic elements) within a digital and physical space. For example, we have used Microsoft Kinect to digitally capture movement of the human body and use this data to provide a virtual skeletal image in space that will represent the performer in a virtual world. For the purposes of this example we placed the performer in a virtual 3D dome.

The data is managed through a bespoke software IMU2OSC created by one of the authors (http://birminghamconservatoire.github.io/IMU2OSC/) that bridges the functionality of the device with OSC to allow flexibility and diversity in its use. The IMU2OSC software is able to provide data to and from the x-IMU. In addition, it allows network capabilities where a host computer is used as a bridge between many computers expanding further the creative possibilities.

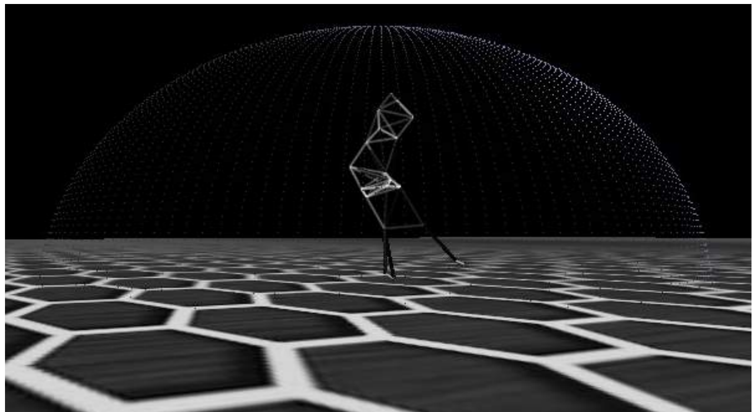

Figure 5. The performer performers within a virtual space and 'feels' the boundaries of the dome through vibrotactile feedback

When the skeletal image of the performer comes into contact with the boundaries of the virtual dome, a vibrotactile signal informs the performer about his/her actions (Figure 5.). Even though such a relationship seems straightforward and relatively simple, it is nonetheless powerful as it provides informative feedback and thus confidence about the performer's actions as well as provides awareness about the performer's physical presence within the virtual world. In another example, the boundaries of the dome can change and interact with the performer depending on the type of movement and gestures initiated by the performer. The IMU capabilities of the x-IMU (described above) can additionally provide information about the acceleration and position of the performer that can be further enhanced in the creative relationship between the performer and the technology. The shape of the dome may be a result of the movement and gesture of the performer during the performance.

Performer-Performer

The Performer-Performer mode concerns the interaction between two (or more) performers mediated by a haptic communication channel. For example, two performers are able to interact through vibrotactile feedback and, in a similar setting to the performer-technology relationship, data captured from gestures and other actions carried out by one performer are transformed into vibrations communicated to the second performer. In this mode it is possible to experience different levels of density of the vibrating feedback. The received feedback is continuous and changes according to the movement and gestures of the other performer. Again it is important to mention the position of the motors on the body. For example, movement and the acceleration of the left hand is sensed as vibrations on the leg of the other performer. In addition, such creative communicative link between performers may be utilized in network performances. From the dome example above a performer can determine the shape of the dome controlling the space 'available' for the other performer to exist. .

Scenarios

As interactivity subtypes for our proposed haptic interactivity modes, we propose three different scenarios of haptic embodiment that create a creative and corporeal link between two performers and the technology that is in use:

1. Co-exist: Performers are in a state of a collaborate play. Their bodies move in unison around the space feeling a constant stream of vibration that symbolizes the union. As they move apart from each other, the intensity of the vibration decreases, and as they get closer it increases.

2. Intersection: Performers are in a state of a competing play. They compete for "ownership" of their own personal space (identified by the body tracking mechanism). Vibrations intensify as their personal space gets invaded.

3. Intimacy: In the third and final scenario, the performers are lying close to each other in an intimate position, having their body parts connected through technology. As the hand of one performer approaches the body of the other, vibrations on the second performer body intensify, creating a greater anticipation of the touch.

Haptic Interaction Grid

The previously described haptic interaction performance modes and scenarios can be combined to form an 'interaction grid' that can be used as a tool for describing or conceptualising an interactive process. This could be useful, for example in analyzing existing works or parts of works, or composing or choreographing new pieces. For example in figure 4, (above) we show a grid with four states:

1. performer-technology / intimacy
2. performer-performer / co-exist
3. performer-performer / play + performer-technology / play
4. performer-performer / intimacy

These states could be viewed as a quasi-score indicating, for example, the progression of interactivity through the course of a musical work, or within a section of a musical work. Alternatively, it could be used as a tool in the description and analysis of existing works.

Conclusion

In this chapter we highlight the importance of sensorial feedback needed by performers in order to become more immersed in a virtual playground and share the experience of technology not only with the audience but amongst themselves. Based on the theories proposed by Mark Hansen and Merleau-Ponty, we suggested that attention should be shifted, by enabling a creative approach and connection among dancers within the virtual space. This will allow performers to have an immersive experience of digital space and interactions. Furthermore, through vibrotactile feedback, the performers are now not only more aware of the space and the virtual elements that are presented to the audience but they are also aware of how other performers are interacting with the space and the technology. Three different scenarios have been chosen for experimentation and we have noted that the use of vibrotactile feedback, like any other technology, is a subject of the creative intentions of the choreographer and the artist involved. Our framework for thinking about haptic interaction in the context of live performance is designed to assist in both the analysis of existing works and the creative process of producing new works with performers and interactive media. Vibrotactile feedback is not necessarily appropriate for all technology-related choreographic pieces neither does it imply any creative outcomes on its own. Due to the tactile properties, it should be seen as being like an instrument where experimentation and practice is essential. We propose the use of vibrotactile feedback as a means of creative and corporeal link between the performers and the technology as well as between the performers themselves.

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A multimodal integration of sensory feedback modalities for dance performers

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ABSTRACT

Interactive art works that fuse the physical and the digital rely on communication between the user of the interface and the system. Many interactive choreographic installations and performances are focused on issues that explore the relationship of an individual or a group of performers with the present technology. At the same time technologies are rarely used to enhance the relationship between the performers themselves. In this demonstration we attempt to exhibit a way to create a corporeal link between performers—by giving them the ability, through haptic feedback—to become aware of each other's actions in the space. The proposed haptic feedback, which is delivered through vibration, examines the tactile experience of the performers as means of communication. Such communication can be further enhanced through the data from the performers' gestures as they enact in real time the control of sound and visuals. The aim is to enable performers to have a creative corporeal link and to better experience the embodiment of digital technologies. In addition, the audience can experience such collaboration and personal experience of the performer through the projection of a particle stream that allows visualisation of the intensity of the felt vibrations as the particles focus and release accordingly. We propose three different scenarios for such digital relationships.

1. INTRODUCTION

The use of digital technologies in performances has been extensively discussed and demonstrated by researchers through conferences such as New Instruments Musical Expression (NIME), International Computer Music Conference (ICMC), Sound Music Computing (SMC), International Journal of Performance Art and Digital Media and Digital Creativity among others. There is a sense of moving away from what we can describe as the Age of Information towards a more practical and interactive realisation of that age, the Age of Experience where we focus on the quality of our integration with the technology[1]. We view haptic feedback as a key component in enhancing user experience [5][7][16]. When interfacing with the world, and in essence with most computers and other technological created objects, we naturally experience any embedded feedback in a holistic way, visually, aurally and haptically. This includes the bespoke feedback created through computing such as audio and visual. While aural and visual experience have been significantly developed through hardware technology and programming, from mono to surround sound and from black and white visuals to 3D High Definition, experience through the modality of touch is still underdeveloped. Experiencing technologies as a whole including vision, sound and touch, enables the user/performer to transform and experience a more pragmatic realisation while being active in such digital and virtual spaces. Even though we divide our sensory modalities by their distinct roles we cannot value one modality more than another [18]. Depending on the action carried out at any given moment, unconsciously we focus our attention on different senses. Take for example the experience when entering a dark room while your hands *look* for the light switch. In regards to haptics, and touch in particular, their role is unique as they allow us to have an intimate and tactile reference of that experience [5][8][15].

In dance performances the role of haptics is vital in terms of the kinaesthetic experience as the dancer's body moves and reacts in space. Through this paper we examine how vibrotactile feedback can be artificially employed and enhance communication between performers. Enabling a creative physical link between performers that will allow them to sense each other as well as the digital and virtual spaces in which they perform. The intentions here are not to create a realistic "real world" experience but rather to create an elusive representation of bespoke experiences in the virtual word. Paterson refers to artificial haptic experience in a similar way.

> The goal then is to create the illusion of tangibility through mimetic machines, and the greater fidelity of haptic sensation the greater the user's sense of presence in a virtual space. But mimetic is not representation [16].

With computers and technology used and developed in an evolutionary fashion, haptics can enhance awareness allowing a creative approach through tactile communication. Next we examine how the three feedback modalities visual, haptic and aural are integrated in artistic performance.

2. FEEDBACK

2.1 Visual

In dance and theatrical performances, the use of visual feedback usually falls into one or more of these four categories: background setting [1], abstract ambience [11], literal/abstract visualisations [2] and digital mirroring. Choreographers and performance artists, wanting to extend their expressive range into an audio/visual orchestration, are at the forefront of theatrical and performance technology.

In *Mortal Engine*, by Chunky Move, the tracking technologies serve to drive the visual spectacle and playfully engulf the dancers by blurring the lines of where the body ends and the projections begin.

[1] http://www.webdirections.org/resources/jared-spool-the-dawning-of-the-age-of-experience/

In the performance *Seventh Sense*, by the Taiwanese-based Anarchy Dance Theatre and Ultra Combos Studio, the performers (and afterwards the audience) can get immersed into a projection-mapped stage that gives the illusion of an endless digital world expanding around their bodies. This creates a unique experience for the audience. However, like in *Mortal Engine*, the visual experience of that newly created digital space address mostly towards the audience having the performer with little to no experience of what that digital world "feels" from the inside.

Another work that puts the performer in a similar position is the performance of *Le Sacre du Printemps* (The Rite of Spring), by Stravinsky with the media artist/choreographer Klaus Overmaeir & Ars Electronica FutureLab[2]. The audience can watch the dancer, Julia Mach performing on an empty stage and at the same time an augmented 3D performance is projected on a screen where the dancer coexists and interacts with an array of digital elements. In this performance the dancer is performing without any sensorial feedback of the augmented environment or any idea of what the audience might be experiencing. Since the performed music is fixed, there is no need for additional feedback about different "cues" or any other performance status information. Even though technology is a coherent part of the creative process, it is possible that the dancer learned the choreography based on the music as a reference for feedback cues rather than using the created "digital space".

Possibly this approach comes down to the amount of technology needed to provide the dancer with a more realistic experience of his/her own performance while performing. Another reason for not including any visual feedback between the dancer and the digital world might be obtained through reference to Virtual Reality (VR). When VR became possible in the early '70s, one of the striking observations was the way visuals could alter human perception. For example, walking in the streets with hands that are two metres long, alters the way a person may experience and view their body [3]. Knowing the self and the body comes from what is known as visuo-tactile integration, the concept that visual senses are enhanced when integrated with the tactile and kinaesthetic senses [8][17]. The confirmation of such visual assumption of reality and the digital comes through the tactile feedback experience [9].

> 'What we perceive through the other senses as reality we actually take to be nothing more than a good hypothesis, subject to the confirmation of touch. Observe how often people will respond to a sign reading, "Wet Paint." Quite frequently they will approach and test the surface with their fingers for themselves' [15].

2.2 Haptics

When working in virtual and digitally created environments, haptics can enhance our perceptual experience allowing a more realistic representation of our senses in the digital realm. The developments in VR show how haptics are necessary to experience, as real as possible, such digital reality [3]. Visual representation alone leads to ambiguity, leading to an unwieldy and a non-intuitive method of design and object manipulation [17]. Dionisio *et al.* point out the desirable visual-haptic collocation needed to achieve a believable sense of interaction with visual objects [9]. In addition, the successful illusion of out–the–body experience within a VR environment has been closely related to the synchronicity of the visual and haptic perception [19]. With the integration of haptic experience the user is able to have a holistic view about her actions. This includes application in medical, teleoperations, gaming, communications, art and performing arts.

Focusing more on the integration of haptics and tactile experience between users, there is diversity in the use and approach. The artist Erik Conrad through a site specific installation *Palpable City* presents a tactile landscape while exploring the city. Participants wear a vest with custom made electronics and GPS, enabling them to feel different vibrotactile sensations as they move, allowing an embodied environment through the tactile sensation of the body [6]. A haptic networked communication system has also been employed between two music performers giving the illusion to the audience of a 'more integrated and polished performance' between the two participants [13]. A similar work has been employed in network-based performances where performers use vibrotactile feedback as means of communication over the network [14]. In CyberSM (1993) two participants in remote places wear special suits that can communicate with each other through a multisensory experience of aural, visual and tactile [20]. In a similar fashion, Chung *et al* create a peer-to-peer communication system over the network that allows anonymous users to exchange haptic messages [4].

2.3 Aural

The sense of hearing has an equally important role in our sensory experience. Aural is tightly connected with the tactile perception as well as with the ability to provide information about our surroundings and objects we encounter. For example, the sounds of footsteps when jogging provide somehow unconscious information concerning the type of the terrain or the height of stairs [18]. Of a similar significance is the aural perception of acoustics, which can provide information about the size and type of the room one is placed, such as a church or an office. Auditory perception can also be associated to physical and tactile actions. Handheld electronic devices such as mobile phones and tablets provide audible feedback artificially in order to bear a resemblance of feedback interaction that may naturally occur. The successful functionality of such digital devices relies on a combination of designing and programming where feedback modalities are integrated. When using touchscreen devices, there is no auditory feedback from the physical contact as found with the traditional typewriter or even with computer keyboards. Through software programming, designers provide auditory feedback to the user that enhance and confirm their actions. The auditory associations that were previously established with the pre-touchscreen keyboard are maintained.

In music performances the ability to correlate actions with sounds is fundamental. The time-dependence between the three perceptions, aural, tactile and visual is essential for a convincing performance [10]. This relationship between the senses and time not only reflects the way performers are able to have a fine control over their actions but also allows them to produce convincing results that the audience can experience. Apart from the ability to correlate sounds with actions, the sense of hearing is able to localise sounds in space. As with visual perception, sound can present an egocentric approach with the environment around us. Knowing where the sound is coming from is an important feature of feedback information in relation to our surroundings. For instance, through vision one must actively look in the direction where an event is taking place, whereas with aural sense, one can perceive the position of the event without looking. Aural perception is as important as vision in its own rights as there are different qualities that are driven by each sense.

Whilst visual, aural and haptic senses retain different characteristics and qualities, all senses affect the human perceptual understanding and experience. It is important not to examine these senses as different entities but through a holistic understanding providing a cross-modal integration of

[2] http://www.exile.at/sacre/

perception. The integration of multimodal approach through the technology must be artificially approached with the ability to retain humanistic elements.

2.4 Theoretical Background

So far, we have discussed a number of approaches that have been implemented with regard to perception and experience, and how these can enhance a multimodal integration of the senses within a digital space. When considering dance performances, one option is to provide the dancer—while performing and rehearsing—a form of feedback, to experience the augmented digital result. Such approaches will give flexibility, through experimentation, to adjust the choreography to get the desired results depending on the dancer's intentions. However, this is often not possible as the performer is integrated as a part of the same digital world and unable to have a realistic reference. This is not to say that all digital dance performances require the same level of the feedback experience in order to function. In addition, when two performers are interacting within the same digital space there is no feedback coming from that "world" or information about how it can be integrated within the digital space. Our proposal aims to address how performers view and experience their embodiment in the virtual space. Instead of relying on external feedback to inform dancers about their actions, such as the identification of specific 2D or 3D gestures that triggers an interaction, the performer can experience the virtual space and interact with the virtual world from *the inside*. We suggest that by providing vibrotactile feedback, the performer's body with bespoke devices and mapping approaches, the performer will be able to sense and experience the virtual space. In addition to the already existing gestural mapping approaches that can trigger the performer's actions, a similar mapping approach can trigger and control the vibrotactile feedback experienced by the performer.
Mark Hansen who based his ideas on phenomenological theories suggested by Merleau-Ponty, argues that technologies can enhance our sensory experiences consequently affecting our view of embodiment [12]. Hansen argues that "Motor activity" holds the key to fluid and functional crossing between virtual and physical realms. By coupling the sense of touch, other senses can be "synthesized", therefore transforming the digital perception into experience [12]. When a system however encompasses a virtual space, and it is the intention of the dancer to create experiences which not only accept the existence but rather accommodate a feedback from it, then it is imperative that the "perceptuo-motor activity" is not lost during the technological mediation as this is the only way to have a direct connection between the true intention or the "body schema" of the dancer with the space.

3. CONCEPT

We would propose that instead of concentrating the majority of the resources in investigating gestural analysis, more attention needs to be diverted in exploring ways to replicate and use, in real time, the uninterrupted movement of the performer which uses the embodied potential of the body schema. The proposed approach would still involve technological mediation; the data however would retain its raw, un-fragmented form. A digital copy of the performer can generate its existence in the digital realm performing the choreography as intended and interacting and experiencing the space from the inside. For example, digital objects, such as particles, can collide with the material body, footsteps can leave a mark on the virtual space, and the performer can push, pull and shape malleable architecture.

3.1 The technology

In order to allow the flexibility and freedom of movement of the performer, we provide a wearable wireless device. In addition, the device allows vibrotactile feedback information to be transmitted to the performer. The x-IMU[3] device is capable of providing up to 4 PWM outputs over Bluetooth. The vibrating motor[4] (figure 1) is attached on top of the device. The device weights a bit over 50 grams including the motor, the battery and the plastic housing as shown below. It is easily attached around different parts of the body with a Velcro strap.

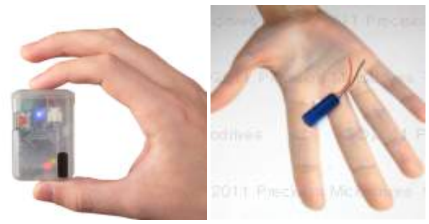

Fig 1: The x-IMU device in plastic housing on the left and the vibrating motor on the right

The data are managed through a bespoke software IMU2OSC[5] created by one of the authors that bridges the functionality of the device with OSC to allow flexibility and diversity in its use. Apart from controlling the PWM that is used to drive the vibrating motors the device incorporates full IMU capabilities that are also used as input data from the movement of the performer. In addition, a Microsoft Kinect is use to provide a virtual skeletal image in space that will represent the performer in the virtual world. Both the Kinect and the IMU data are use in separation but also in parallel depending on the desired outcome.

3.2 Possible scenarios

In order to commence our investigations we propose three different scenarios of haptic embodiment that create a creative and corporeal link between two performers and the technology that is in use:
(1) Co-exist: The performers are in a state where it is possible to co-exist inside a digital space. Through the use of kinect, vibrations are felt along the body, as virtual bodies interact with objects and the space itself. For example having a virtual ball that can bounce off the virtual body and at the same time vibrate physically against the body. To visualise the intentions of the felt vibrations through the vibrotactile experience we use a 3D mesh by generating a particle cloud that populates the virtual space. In addition, the particles can give a sense of the 3D space to the observer. In the case of two performers, the exchange of virtual objects result in experiencing, through vibrations, their existence of virtual objects without the need to visualise them through a screen monitor. As the dancers move in the physical space, the virtual skeletons follow their movements and react to any digital objects they might encounter with as well as with the space itself.

(2) Collaboration/Play: The performers are connected through the vibrotactile feedback, as both experience it at the same time. The signal might come from within the virtual space or through the data gained from the wearable device. For example, the intensity of the acceleration is received and translated into

[3] http://www.x-io.co.uk/products/x-imu/

[4] http://www.precisionmicrodrives.com

[5] http://birminghamconservatoire.github.io/IMU2OSC/

vibrations. In this way the movement of one dancer is felt and experienced by the other dancer. In a similar manner through the use of Euler angles it is possible to have the position of the dancer in the space as well as to record gestures in order to be felt end experienced by the other performer in the form of vibrations.

(3) Intimacy: In the third and final scenario, the performers are lying close to each other having their body parts connected through technology. This scenario assumes the existence of a third digital performer. Any performer is able to initiate an action by physically touching the other performer or in the case of the digital performance, by providing vibrotactile feedback to one of the other performers. As one performer touches the body of the other, a closed feedback loop is created between the real and the digital. Through their virtual representation, the audience can see particles as the intensity of the felt vibrations of the touched body part (figure 2).

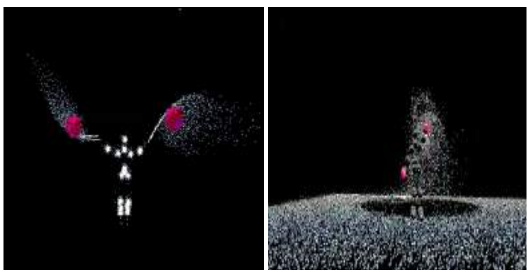

Fig 2: Example of the visual representation and touched positions in red.

4. CONCLUSION AND DISCUSSION

In this paper we highlight the importance of sensorial feedback needed by performers in order to (1) become more immersed in a virtual playground and (2) share the experience of technology not only with the audience but amongst themselves. Based on the theories proposed by Mark Hansen and Merleau-Ponty, we suggested that attention should be shifted, by enabling a creative approach and connection among dancers within the virtual space. This will allow performers to have an immersive experience of digital space and interactions. Furthermore, through the tactile feedback, the performers are now not only more aware of the space and the virtual elements that are presented to the audience but also aware of how the other performers are interacting with the space and the technology. Three different scenarios have been chosen for experimentation and this paper identifies two main questions and aims to invite further discussion. Firstly, does the shared technological state and the haptic feedback help the dancers to feel more connected and immersed? Secondly, does the audience, by seeing the visual representation of these connections, feel closer to the performers? As this work is still at its early stages, further experimentation is planned in order to reach more tangible results, which the authors hope will greatly contribute to the digital dance and embodied interaction communities.

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IMPROVING PERFORMERS' MUSICALITY THROUGH LIVE INTERACTION WITH HAPTIC FEEDBACK: A CASE STUDY

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ABSTRACT

Physical interaction with instruments allows performers to express and realise music based on the nature of the instrument. Through instrumental practice, the performer is able to learn and internalise sensory responses inherent in the mechanical production of sound. However, current electronic musical input devices and interfaces lack the ability to provide a satisfactory haptic feedback to the performer. The lack of feedback information from electronic controllers to the performer introduces aesthetic and practical problems in performances and compositions of live electronic music.

In this paper, we present an initial study examining the perception and understanding of artificial haptic feedback in live electronic performances. Two groups of trumpet players participated during the study, in which short musical examples were performed with and without artificial haptic feedback. The results suggest the effectiveness and possible exploitable approaches of haptic feedback, as well as the performers' ease of recalibrating and adapting to new haptic feedback associations. In addition to the methods utilised, technical practicalities and aesthetic issues are discussed.

1. INTRODUCTION

This paper presents an overview of a study that investigates whether incorporating haptic feedback into musical input devices can result in creative musical outcomes for composers and performers working with computers and sensor-based technology.

Traditionally, instrumental performers require an intimate relationship with their instrument, developed through a long process of development and exploration of this bidirectional relationship [1]. This relationship creates a cause-and-effect feedback loop between the performer and instrument, which is constantly developed and adjusted while playing. The instrument reacts to the energy it receives from the performer by producing both, aural and haptic feedback. Through instrumental practice, the performer is able to learn and internalise these responses.

Appraisal of current musical input devices and controllers shows that the received haptic feedback information is often limited, and does not provide the necessary level of *feeling* required from performers as happens with traditional instruments [3]. An experiment conducted by O'Modhrain and Chafe shows how force feedback improves the ability of the performer to control digital musical instruments such as the theremin [8]. Electronic controllers capture the performance gestures and process them through a computer that reacts to the prior decisions of the composer or programmer. The physical nature of such controllers or devices does not allow a bidirectional relationship with the performer, due to a physical decoupling of controllers and sound producing components. Furthermore, the mapping strategies employed between the controller and the audio processing can change arbitrarily, increasing the difficulty of constructing a relatable familiar feedback channel for performers.

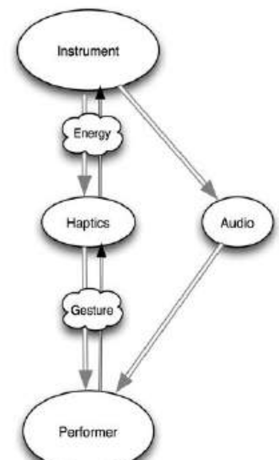

Figure 1. Shows the cause-and-effect feedback loop between the performer and the instrument.

2. CONTROLLING SOUND

Electronic controllers provide the means by which performers' physical gestures are converted into data accessible to use in conjunction with computers. Components like sensors, switches, faders and video cameras might be used individually or in combination with each other. For example, the widely-used Nintento Wii remote offers a combination of sensors, switches, an infrared camera and a wireless connection with which to transfer data to a computer. Bonger provides further discussion of the most commonly-used sensors for music applications [1].

In most cases, electronic controllers are made of plastic, a material that is unlikely to react to the energy provided by the performer. This raises concerns about the performers' experience and related feedback. Chu mentions additional concerns about computer-generated sound being disembodied from the physical object, problematising the formation and control of the sonic properties by the performer [4]. In addition, Tanaka suggests the importance of haptic feedback in creating music coherence in performances [9].

Complications arise upon considering the mapping relationship between the controller and the sound source. This significant aspect of electronic music has been addressed extensively by Hunt, Kirk, Miranda, and Wanderley [5]. Mapping strategies and the possibilities of sound control in real time introduce additional difficulties in the development and use of *controllers as instruments*. Looking at the mapping strategies and sonic possibilities, there are no conventions as to what electronic controllers can affect. However, this flexibility provides opportunities for composers to use the same controller over and over again with different sound results. Consequently, performers face a situation where the development of performance skills, based on the audible feedback, is very unlikely. The creators of such devices often perform with their custom made controllers because they are able to familiarise themselves most to the relationship between controller and created sound [1].

With traditional instruments, the laws of acoustics play a major role in regards to their construction, functionality and sound quality. The physical properties of the instrument, in relation with the aural and haptic feedback, allow detailed exploration of their sonic properties. Two main concerns emerge from this investigation of electronic controllers in music performances:

- The absence of haptic feedback encourages a situation where the performer is only able to have a passive understanding of the sound generated, and
- the constant remapping approaches that the performers experience do not contribute toward a deeper understanding of the relationship of gesture to sound.

These two situations greatly reduce the ability of the performer to effectively realise the musical requirements of the composer.

3. CASE STUDY

3.1 Hypothesis

It is common for composers to combine live electronics with other instruments to create their desired musical result. However, hardware and space requirements of such live electronics components create rehearsal difficulties, especially if the performer does not have their own equipment for the electronics or is unfamiliar with the technology involved. As a result the electronic aspects of pieces receive limited rehearsal. The rehearsal time available for live electronic aspects can often be as little as 2-3 hours 'on the day'. This study will test if incorporating haptic feedback in performances can improve the overall control, perception and musicality of the electronics by instrumental performers—taking into account the limited amount of time available.

3.2 Method

This study is aimed towards a practical utalisation of live electronic performing practice through sensor technology via haptic feedback channels. Different qualitative methods, like interviews and discussions, were employed in this study to examine participants' performing experiences. Six trumpet players, divided into two groups of three, volunteered to take part in a series of semi-open interviews and performing tests. All participants, were undergraduates studying at the Birmingham Conservatoire (Birmingham, UK), were in different academic years, and of both classical and jazz backgrounds. They were from 19 to 22 years of age, and spent between 15 and 25 hours playing their instrument each week. None of them had any prior experience in performing with live electronics. This excludes the possibility of a priori knowledge from influencing the outcome of the study. Each interview, including the performing tests, was approximately one hour and thirty minutes long, after which each participant was compensated with £5. All interviews were recorded with their permission.

Figure 2. (Top) Inputs and outputs of the Arduino prototype box, (bottom left) glove with pressure sensors attached and (bottom right) vibrating motors with and without rubber shield.

3.3 Hardware Implementation

The prototype box, created by one of the authors, uses an

Arduino Diecimila[1] board, an open source prototyping device. The board is capable of receiving up to six analogue inputs and thirteen digital inputs. The thirteen digital inputs also serve as outputs, of which six can provide Pulse Width Modulation (PWM). Connectivity with a computer is through USB, allowing both power to the board as well as data transfer. The board is housed within a plastic box fitted with female mini-jack connections [see Figure 2].

A pressure sensor glove was created with three sensors attached to the fingertips. As an output source, the PWM function is used to individually control vibrating motors. All sensors and motors use an 1/8" jack adaptor to connect to the Arduino box. Rubber covers were attached to each motor to create a larger surface area as well as to protect them from damage the while in use. The three vibrating motors are attached on the left hand of the performer in different places wrist (inside), forearm (inside) and bicep (inside) [see Figure 4]. The placement was determined through experimentation with a trumpet player (who was not included in the study's participants) in order to ensure comfort, effectiveness, and recognisability of the vibrations produced. In addition, a microphone, sound card, laptop, and speakers were used.

Figure 3. Music excerpts composed for the performance test.

3.4 Methodology

3.4.1 Preliminary Interviews

The subjects were interviewed before and after a performance test. First, general questions were asked regarding the performance background of each participant, including the amount of weekly practice, how long they have played trumpet, the genre of music they usually perform, and if they play any other instruments. Following this were questions addressing their understanding of live electronics and computer music in general.

3.4.2 Performance Test

The performing portion of the study was divided into two tests, A and B, performing the six musical examples in each test. Both tests use the glove having the pressure sensors controlling the effects. Test A was indicated to be as a standard approach using live electronics while test B utilised haptic feedback. Group one played first the example with the standard approach and then all examples with the haptic approach. Group two performed first the haptic approach and then the standard approach [see Table 1].

	TEST	
Group 1	A	B
Group 2	B	A

Table 1. Shows the order of the tests for each group.

This enabled us to compare the result of adding haptic feedback to both new and previously-learned systems. The brief musical examples provide a range of musical variables, including articulation, note range, phrasing and dynamics [see Figure 3]. The tempo of the examples was unspecified, allowing for free interpretation, which was explicitly encouraged. The composition process was influenced from the trumpet fingerings, as they affected the relationship of the sensors by the notes being played. In example 4, the music requires the performer to use only fingers one and two that control the reverb and frequency shifting effects. In combination with the long notes and the absence of timing the performer is expected to concentrate on how the effect changes with the vibrating relationship. Example 3 was composed to examine how the vibrating functions might work in fast musical passages, and to test the performer's awareness of the vibration.

Max/MSP[2] programming environment was used for receiving sensor data and transmitting data to the vibrating

[1] www.arduino.cc/

[2] http://cycling74.com/

motors. Incoming sound was processed through Abelton Live[3], modified by the values received from the pressure sensor glove. A one-to-one mapping was implemented between sensor input and sonic effect. Three different effects were used throughout the study. The participants wore the pressure sensor glove on their right hand, which also operated the trumpet's valves. The pressure sensor on the first finger correlated to the amount of reverb added, the second finger affecting frequency shifts, and the third finger controlling the amount of a chorus effect.

The vibrating motors also make use of a direct one-to-one mapping of input to output. In test B, where the haptic feedback layer was added, each sensor's data received from the glove correspond linearly to one vibrating motors. This relationship was explained to the participants as "the more you press, the more it vibrates". A calibration function was created to provide the maximum and minimum values received from each trumpet player before the tests began. This allows the individual calibration of the motors according to the pressure that was applied to each value from the performer. Sound received from the trumpet was monitored in the computer through the microphone. The performer controlled all the parameters of the effects in both tests. Each performing test lasted around 25 minutes, and included two play-throughs of each musical example.

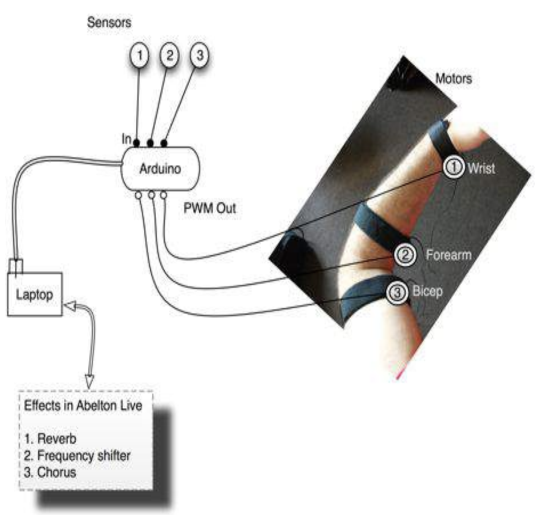

Figure 4. Overview of entire haptic feedback system.

3.4.3 Final interviews

The final set of questions was about the performers' understanding and experience they had while performing the two tests. Participants were asked a variety of questions, including: which system (that with or without haptic feedback) they would prefer to practice with; the difficulty of the two tests; the usability of the technology and hardware used; and their understanding of the sensors' mapping to sound processing and vibrating feedback. In addition, they were asked to evaluate how fast they could adapt, if possible, to the artificially-created haptic relationship and which approach they would prefer to use in concerts.

[3] http://www.ableton.com/

4. RESULTS AND DISCUSSION

All six participants strongly agreed that haptic feedback created a more understandable relationship between their actions and the ensuing electronics. Apart from the ability to measure the amount of effects processing through vibrations, the participants all mentioned one essential difference between the two tests: the use of haptics allowed them to know definitively whether the electronic effects were active or not. This observation is important in that none of the performers had previous experience with live electronics. Additionally, the lack of audible confirmation about their action, in this case controlling the effects, was evened out through the haptic feedback channels. As mentioned previously, instrumental performers are used to the sensing feedback when they play their instruments. All performers mentioned that the calibrating effect was important in order to accommodate the amount of vibration received from the motors.

Four performers immediately became aware of the expressive possibilities while using the sensor glove with the vibrating feedback. They noticed that while the expression generally comes from the mouth, having the glove one is also expected to think about the pressure applied on the valves. One performer commented that "…expression comes from the mouth and you have to think not only how use the mouth but also the finger pressure to allow expressive changes of the sound". Another performer observed that "…with a bit of practice (using the vibrating motors) I can learn to manipulate it properly". They also noted that "you had something coming back, you could feel and you know physically if something was happening or not". One musician indicated that he could not hear the individual effects in test A but when he could feel it, in test B, he could then press the valves more-or-less accordingly. Another performer suggested the following during the interview: "From doing this now, I don't think that I will need additional practice time to get used to the motors. You could feel individually the effects through the vibrating feedback where in the run without the motors I was not able to know what was happening".

Four of the six performers indicated that, given the option, they would choose to use haptic feedback in the preparation and performance of live electronic works. To them, there was a substantial difference between test A and test B. Specifically, they mentioned the awareness of control they had through experiencing haptic feedback. With the remaining two performers, one preferred to focus only on the notated music having someone else to control all aspects of the computer processing. The remaining one had no distinct preference between the two systems.

Furthermore, results of this study support the hypothesis that incorporating haptic feedback in live electronic performances may improve the overall control, perception and musicality of the electronics by instrumental performers. Even though we had two different groups with no prior experience in live electronics insufficient evidence was acquired to provide statistically significant results regarding the amount of improvement, control and perception in performances. However, qualitative responses illicited through interview give an early indication that the application of the haptic feedback system significantly improved the way the performers respond musically to the live electronics. The performers displayed an improved understanding of their actions in relationship with the pressure sensors and resulting sound produced. Consequently, our findings support the theory that haptic feedback can enhance musicians' expressivity in performances involving live electronic music.

The performers were questioned about how they perceived the basic understanding of the data flow from the controller, the sensor glove, to the resulting sound. Interestingly the performers having the haptic approach (test B) first, formed a clearer understanding overall. In addition, the participants were also asked if they thought that an understanding of the technology involved could improve their approach in performances. None of the performers were able to fully confirm this theory given the short amount of time available.

The results of this study suggest that haptic feedback has the ability to provide a framework for experimentation and improvisation with live electronics. After completing the tests, four of the performers asked us to further explore the haptic relationships. At one point, a performer realised that pressing the valves halfway through, the sensors were activated providing data to the computer. When asked, the performer mentioned that the vibrating feedback made him aware of the sensitivity of the pressure sensors. He was then able to slide between notes, using the half valve technique, creating interesting and unanticipated musical results with the effects. Another performer realised that it was not necessary to press the valves to activate the pressure sensors. Consequently, the performer was able to play with all three effects by pressing on the hard surface of the trumpet. However, this also meant the performer was only able to play notes within the trumpet's natural harmonic series.

Overall participants reported that the glove was comfortable enough and did not produce any problems while performing even in fast passages.

4.1 Future work

Future work will develop the technical aspect of the device used in order to minimise minor technical issues as well as increase functionality. On the current hardware an external driver should be added between the Arduino's PWM output and the vibrating motor in order to securely provide more power to the motors, as power management was not optimised in the current device. Additionally, a new version is planed that includes a wireless Bluetooth connection as well as battery power [7]. The wireless hardware will provide flexibility of movement in performances with no need to wear the glove or attach the motors while on stage. The issue of latency between the sensors and the vibrating feedback should be explored further to minimise the response time as well as creating a more consistent device. However, it should be noted that none to the participants reported any noticeable latency problems when asked. Latency issues might be more apparent when vibrating feedback is used to indicate sections, cues or tempo in the score, as this would require temporal synchronisation to be accurate.

It is anticipated that using the sensor glove with the trumpet, composers will explore creative ways of musical expression in relationship with the fingering, the effects processing, and the haptic feedback provided to the performer. In addition, providing haptic feedback regarding electronic effects, composers can utilise vibration as a channel of communication between the performer and the computer to inform them of specific temporal cues, duration of events, functionality of running computer processes, as well as the positioning of electronic sound in space. Moreover, vibrating motors can be attached on more that one performer creating a haptic feedback network channel that can provide information to the performers independently or allow the exchange of information and gestures within the ensemble.

As discussed earlier, another study using the same hardware could examine the difference, if any, in the performing aspect of a piece with and without haptic feedback from the audience's perspective. Additionally, audio input could be utilised as another method to control the haptic feedback provided to the performers.

5. CONCLUSIONS

In this paper we have presented a study that attempts to establish whether adding haptic feedback to live electronics control improves the musicality of performer interaction. Our results suggest that adding haptic feedback to a glove-based controller can significantly improve a performer's understanding the relationship between control sensors and resulting sound produced. Additionally, the use of haptics suggested new musical possibilities not previously considered by the performers using non-haptic systems. Although using haptic feedback introduces an additional layer of complexity in live electronics systems, we consider it essential to pursue further research in this area so that standard methods of providing haptic feedback can be established. With haptic feedback in the control path, interaction is enriched allowing performers and composers to develop new relationships with live electronics practice.

Acknowledgments

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[10] www.crackle.org/ (Michel's Waisvisz web site)

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TACTILE FEEDBACK TOOL: APPROACHING THE FOOT PEDAL PROBLEM IN LIVE ELECTRONIC MUSIC

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ABSTRACT

Foot pedals can be problematic in performances of live electronic music since they do not provide direct feedback to the performer as to their state. Performers expect such feedback since their action affects the composition through triggering different computer functions. It is essential for performers to know how their actions affect sound, just as they do with acoustic instruments. In computer music, electronic devices are not able to replicate this feedback, creating a gap in sensory experience. This gap has the tendency to create insecurity with performers about their actions regarding the computer functionality. This paper details a proposed technical solution that could help performers and composers overcome these issues.

1. INTRODUCTION

The relationship between a performer and their acoustic instrument is bidirectional [3,8,10]. Physical interaction with instruments allows performers to express and understand music based on the nature of the instrument. Through instrumental practice, the performer is able to learn and internalize the responses inherent in the mechanical production of sound. The instrument reacts to the energy it receives from the performer by producing both audible and tactile feedback [2]. However, current electronic musical input devices, instruments and interfaces lack the ability to provide similar haptic feedback to the performer. The missing feedback information introduces practical problems in performances and compositions of live electronic music. For example, consider the sustain foot pedal, a common communication device used in live electronic performance due to its overall simplicity, flexibility and compatibility with MIDI devices. Through the use of the foot pedal, the performer does not necessarily receive any immediate aural feedback depending on the nature of the composition. Additionally, the tactile feedback provided is unnoticeable due to the construction of the pedal. Consequently the performer may not be confident if the foot pedal has articulated anything, leading to distracting feelings of insecurity while performing.

Commonly used pedals in live-electronic music are sustain pedals and expression pedals. Guitar effect pedals, in comparison to sustain foot pedals, can provide additional haptic resistance. However, they are not suitable in live electronic music because the spring and switch mechanism generates unwanted noise. Sustain and expression pedals produce no additional sound when pressed.

This paper aims to address this issue by providing vibro-tactile feedback from the foot pedal to the performer. In this way, the performer is able to be aware of the current state of the live-electronic element of their performance.

2. BACKGROUND

Foot pedals are one of the many approaches by which computers can be controlled in performances. The use and functionality of the foot pedal varies according to the decisions made by the programmer/composer. The design and execution of such a performer-computer relationship can prove challenging in a performance situation [6]. Regardless of the level of complexity in any given system, performing with computers can be seen as a form of interaction between the musician and electronics [1]. In consideration of foot pedals, composers require the on-stage performer to follow notated cues. However, it is common practice that in live electronic performances another musician is monitoring the computer to fix any missed cues when the on stage performer fails to do so. This situation not only contradicts the idea that the on-stage performers determine all temporal aspects of the composition, but also removes the authority of said performers.

The foremost problem with foot pedals is that the performer has no evidence regarding what he has just articulated. This leaves the performer with little to no confidence in creating a dynamic system between the controller and the audible result. Foot pedals can trigger a range of computer functions. This could include everything from activating the playback of an audio file to changing the configuration of speakers in the performance space. Additionally, foot pedals may act as switches preparing the computer software to accept another form of input—in most cases, microphones. This approach results in a foot pedal with no predetermined functionality, making it very difficult for the performer to create a relationship with it through the sound feedback channel.

For example, piano pieces by Gorji [4] and Tutschku [11] use the foot pedal to start recording a section. This action does not yield any audible feedback, leaving the performer on stage unaware of whether the computer received this crucial instruction. A common solution by composers is to provide the performer with an additional computer screen that gives visual feedback about the articulated action. From the interpreter's view, however, this is not recommended, since it is distracting because the performer already has to change visual focus between the keyboard, the inside of the instrument and the score.

Through practice, the performer is able to develop a sensory-feedback relationship with their instrument because of the existence of haptic and aural feedback. As has been proposed by Chafe [3] and O'Modhrain [8], adding haptic feedback to a controller will improve the ability of performers to control electronic instruments. Similarly, Tanaka also stresses the importance of tactile feedback in creating musical coherence in performances [10].

Results from one of the present author's ongoing research suggests that instrumental performers can easily adapt and use the new relationship between their actions on a sensor-based interface and the resulting sound while experiencing analogous sensory inputs [7].

3. TECHNICAL APPROACH

3.1. TFTool

In response to the feedback issues inherent in the use of foot pedals, the authors examined ways of improving the current situation, with the intent to provide composers as well as performers a tool that allows transmission of such information.

To this end, the proposed resolution to the issue of mis-triggering a foot pedal is a tactile sensing device called *Tactile-Feedback-Tool* (TFTool). Using the foot pedal in combination with TFTool, the performer is able to receive haptic confirmation about articulated actions via vibrations. TFTool acts as a device that converts the outgoing signal from a variety of sustain and expression pedals into MIDI data. This approach does not require any additional MIDI devices for conversion, an issue which can increase portability of equipment needed.

The prototype created by the authors uses a Seeeduino V2.2 (Atmega328P) board, based on the Arduino open source prototyping device. The microcontroller on the board is programmed through the Arduino programming language [12]. The board is capable of receiving up to eight analogue and fourteen digital inputs. The fourteen digital inputs also serve as outputs, of which six can provide Pulse Width Modulation (PWM). Connectivity with a computer is through a mini USB port, allowing programming and powering of the board, as well as exchange of data information. Once the code is uploaded into the microcontroller, it stays there until a different code is uploaded.

The board is enclosed in a small plastic box to provide easy transportation as well as allowing it to be self-contained [See Figure 1]. There are four inputs and four outputs on sides of the box. As most foot pedals use a ¼ male jack, this standard is maintained with the ports on TFTool. The four inputs are configured to use two expression pedals (or other similar analogue sensors) and two sustain/switch pedals. The outputs of TFTool are four ⅛ female jacks—the differing size due to the limited space of the box. Through the use of four PWM from the board, TFTool is capable of simulating voltage control for the vibrating motors.

A 10 mm shaftless vibration motor is used for every output. The delicate vibrators are enclosed in a rubber enclosure to provide protection during use.

Figure 1. TFTool.

3.2. Placement of the vibrating motors

In order for TFTool to be effective, the vibrating motors need to be placed in optimal positions on the performer's body. Von Békésy demonstrates that vibrations can be sensed not only from the skin of the body but also through deeper receptors in the joints, suggesting that sensing vibration is a variation of kinaesthesia [5]. The authors have explored the positioning of the vibrating motors on the performer's body through assessing practicality, effectiveness, and discretion during performance. In this examination, the performers were limited to solo pianists. From these trials, the optimal placement for a single vibrating motor was determined to be on the ankle of the left foot of the performer. Placement of two vibrating motors on the same ankle, inside and outside, tends to create confusion because of their close proximity. When using two pedals, therefore, the expression pedal connects to a vibrating motor placed halfway up the shin. This allows for a clear distinction between the two motors when both pedals are working together. The vibrating motors are attached to the body with reusable elastic straps, making it flexible and adjustable to different parts of the performer's body. Rubber covers were attached to each motor to create a larger surface area as well as to protect them from damage the while in use [See Figure 2].

3.3. Software implementation

All software implementation for TFTool is conducted in Max/MSP. Communication with the device is established through a software serial port. Incoming data messages are transformed into MIDI signals, allowing them to be manipulated with Max/MSP or any other MIDI compatible device. These MIDI signals are then rerouted within the software back to TFTool to provide the analogous vibrating feedback. When the foot pedal triggers a MIDI signal, feedback confirmation is sent back to the user through the vibrating motor. The expression pedal, which uses an analogue input, is scalar, controlling the MIDI values and resultant vibration continuously. A calibration function exists in the Max/MSP patch to allow any type of analogue sensor input to be used, as expression pedals and sensors provide differing incoming data. To drive the motors, the board is able to provide voltages between 0 and 5 volts.

Figure 2. The vibrating motors with and without the rubber covers.

As discussed previously, different functions of the foot pedal are often required from composers. Therefore, the vibrating feedback provided through TFTool is adjustable to reflect the functionality of the pedal. For example, to indicate the MIDI toggle on/off function through the use of a sustain pedal, the authors posited the following: When the sustain pedal is pressed ON, the motor vibrates at maximum until the performer release the foot pedal. When the pedal is pressed again to activate the OFF function, the motor vibrates at maximum, indicating successful deactivation, as well as vibrating for a second time, incorporating a fade out function of the vibrating motor for one second [See Figure 3].

4. TESTING AND RESULTS

The device was tested with two compositions, performed multiple times by one of the authors. In the aforementioned composition by Hans Tutschku [11], the pedal is pressed to set the computer into a waiting state for the next loud incoming audio signal received from the microphone. This means that the pianist has no direct response from the triggering action. During previous rehearsals and performances, the author had to rely on help from another person to check and correct any mis-triggered pedal cues by monitoring the software on the computer screen. The composer confirmed that this is the case with every performer he worked with thus far[1].

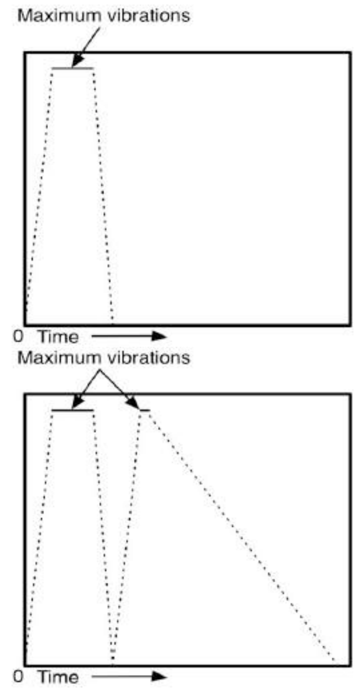

Figure 3. The toggle on/off function of the vibrating motors.

A foot pedal prepared with the TFTool was easily integrated into the practice routine and allowed the performer the necessary feedback for effective performance. Thus, vibration became part of the implicit memory used for practicing the piece. The performer, although still not hearing a direct audible result, felt much more comfortable and confident.

In Enno Poppe's composition *Arbeit* for virtual hammond organ [9], the performer is required to press the sustain pedal 45 times to change between different sounds. The changes take place in short pauses between the different sections of the piece. Although the performer immediately hears the altered sound when he begins to play, it would then be too late to correct any mis-activations from the sustain pedal. This requires the performer to look at the computer screen for confirmation of the triggered action. As mentioned previously, this is a distraction for the performer, who needs to focus on the score and concentrate on the upcoming music. Although a partial setup was used during testing, the vibrating confirmation provided enough confidence for the author to allow him to not have to look at the computer screen. This ultimately led to a more focused interpretation of the composition.

The vibrating motors were found to be comfortable, not requiring any prior experience or practice. The motors used are inaudible, making them suitable for use in quiet

1 Private conversation between Sebastian Berweck and the composer in 2010

musical passages. TFTool can be integrated easily into most existing compositions that require foot pedals.

4.1. Future work and approaches

Further research needs to be conducted to explore the practical uses of tactile feedback in computer-performer contexts. As one alternate approach, proximity sensor controllers can gain more accurate results when tactile feedback is present. In addition to notifications of information directly related to foot pedals, TFTool could also serve as a tool to inform the performer about the current state of the computer, including marking thematic sections or the type of effect currently active. Through further extension and the use of more motors, TFTool can inform the performer about the position of the sound in space by imitating a surround sound system. As the device evolves, new notation can simultaneously be developed, allowing the vibrations felt to act as a conventional point of reference for the performer.

TFTool is a device capable of providing vibrating signals to the performer. In consideration of the problems that foot pedals may cause during performances, we suggest a solution through the use of vibrating feedback channels.

Acknowledgments

Tychonas Michailidis would like to thank Murphy McCaleb for his fruitful thoughts and discussions during the study.

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[12] http://www.arduino.cc/

Barbaróphonos

for Trumpet and Interactive Electronics
2012

Tychonas Michailidis

Barbaróphonos

for trumpet and interactive electronics

Performance notes

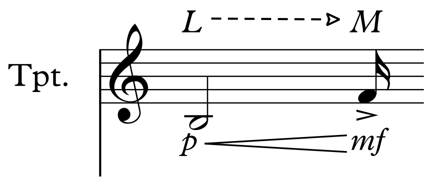
Score written in Bb.
Accidentals hold for the full bar.
All other notation as standard unless otherwise stated.

Microphones

Three microphones are required for the performance placed in a semi-circle in front of the performer (refer at the layout of the performance). Letters above the bars in the score shows which microphone the performer should face when playing. The microphones are configured from the performer's point of view.

Left: L
Middle: M
Right: R

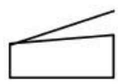
The dashed line between letters indicates the movement towards the new position while playing the notes. The example on the right shows the changing of the position from the left microphone to the middle microphone while holding a note. This allows a seamless integration of different audio effects that are assigned to each microphone. The performer's microphone position is the last indicated in the score unless otherwise stated.



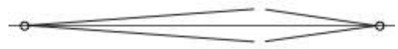
Pedals

The performer uses the footpedal device *Line6, FBV Express MKII* (pictured) for the control of the electronics. The device is currently configured for the patch. If other footpedal devices is used, the patch needs to be reconfigured. For further information please refer to the Max patch.

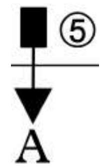
The icon indicates the use of the expression pedal.



Hairpins in the Interactive Electronics stave shows the control of *open* and *close* positions of the expression pedal. The duration is determined by the tempo, bars and time signature in the score. *Use freely,* refers to the free interpretation of the use of the pedal.



The use of the switch pedal icon (pictured) in he score shows information about three elements of the score. The letter below the arrow shows which of the four switch pedal to press from the device. The arrow indicates when to press the pedal based on the time signature and the beats of the bar. The number shows how many times the pedal is pressed at any specific time in the composition.



The waveform icon shows when the audio playback is active as well as the duration of the playback. In the example on the right, the switch pedal A, trigger 4, activates the audio file which lasts for 1:18 minutes.

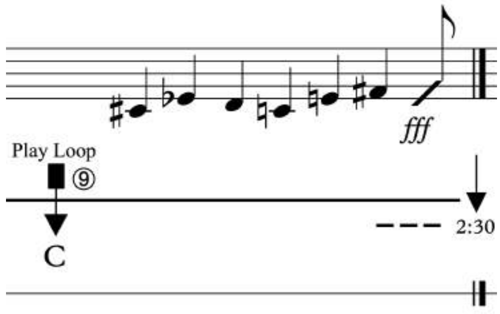
Shows the fadeout function (*Active Off*) towards the end of the playback.

Rehearsals

During rehearsals pedal B resets all functions and prepares the software to start from beginning. Vibrating confirmation is received on both legs of the performer to indicate that. Pedal D is used as a panic button and mutes all audio.

Improvisation section (rehearsal mark E)

The performer prepares the section in advance based on the given melodic lines and ideas from the score. The three subsections provide the performer with a timed structure as well as with the melodic content of the improvisation. At the end of the first section, which lasts for 2:30 minutes, three vibrating pulses inform the performer about the end of the section. This is presented in the score are three dashes (pictured). The vibrations are felt on both legs. When the second section finishes at 4:00 minutes, two vibrating pulses are felt and for the third section



at 4:30 minutes, one vibrating pulse informs the performer for the end of the section. The last subsection is open to any musical interpretation from the performer. During the improvisation the performer can perform on any of the three microphones or a combination of them.

Stage performer
The expression pedal can be used freely during the improvisation section. It controls a particular set of live processing effects. The optional use of switch pedal C enables the live recording and looping.

Electronics performer (optional)
If needed, an electronics performer can control the electronics during the improvisation. MIDI messages are configured with the Korg nanoKONTROL device (pictured). If a different device is used then the appropriate mappings should be made in advance.

Vibrating motors

The *TfTool* device provides vibrotactile feedback to the performer when using the pedals. The vibrating motors are plugged into outputs 2&3.

TfTool device

The motors should be placed half way up the shin of the performer’s legs, either inside or outside a trouser. There are two vibrating motors each one assigned to the switch pedal and the other to the expression pedal. A reusable velcro strap is used for securing the vibrating motors on the performer’s body. The straps should be attached before going on stage. The performer places the motors when on stage. The vibrating confirmation associated with the switches is placed on the left leg, physical output 2 on the *TfTool* device. For the expression pedal, the motor is placed on the right leg, physical output 3.

Placement of the vibrating motors

Every time the pedals are used a vibrating pulse informs the performer about his action. The pulse might vary depending on the nature of that function.

Suggested equipment list

Soundcard: RME Fireface 800 (3 mic inputs and 2 output minimum)
Loudspeaker: 2 Genelec 8040 or similar depending on the venue
Laptop: MacBook Pro running Abelton Live 8.2.2 and MaxMSP 5.1.9
Microphones: 3 Dynamic, cardioid
Pedal: Line 6-FBV ExpressTM MkII+ USB cables
Controller: Korg NanoKontrol (for the electronics performer only)
Associated cables
TfTool box with the vibrating motors obtainable from the composer.

First performed by Ben Murray on 19 April 2012 at the Adrian Boult Hall, Birmingham Conservatoire, Birmingham City University, Birmingham, UK.

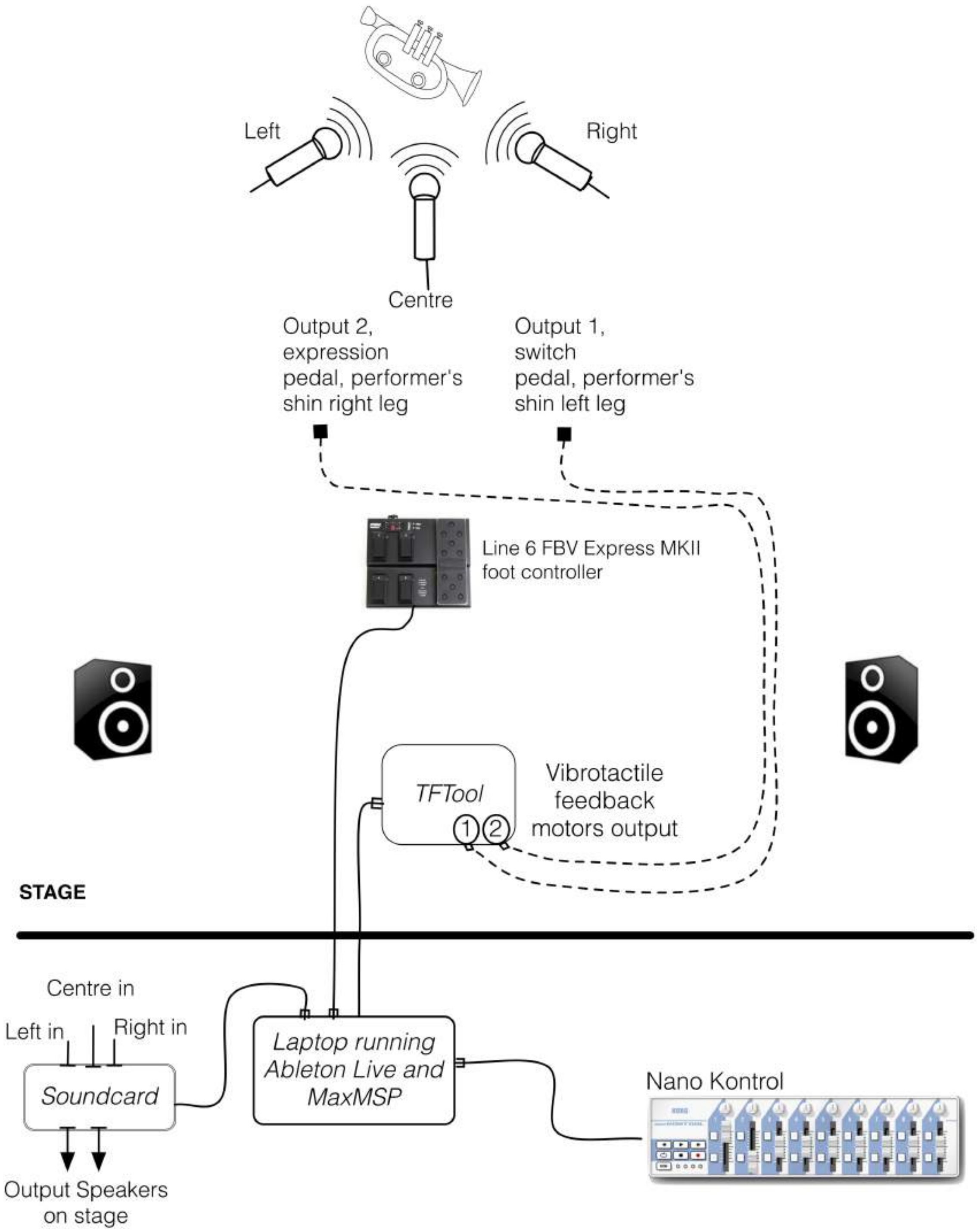
Program Notes

The word *barbarophonos* appears in text through Homer when he needed to describe those who spoke a non-Greek language or those of incomprehensible speech. The origin of the word comes from *βάρβαρος*, *barbarian*, meaning uncivilised and the word *φώνος, phonos*, meaning voice. The exact translation refers to a person with barbaric voice.

The piece explores further the idea of being *barbarophonos*. The performer engages in a three person conversation through the use of the three microphones. Each microphone has its own voice. The performer's own voice can change and become the barbaric character that gives him the opportunity to speak out a personal and an inner reflection of the piece.

The performer controls the electronics through foot pedals. Vibrating feedback communicates different functions between the technology and the performer.

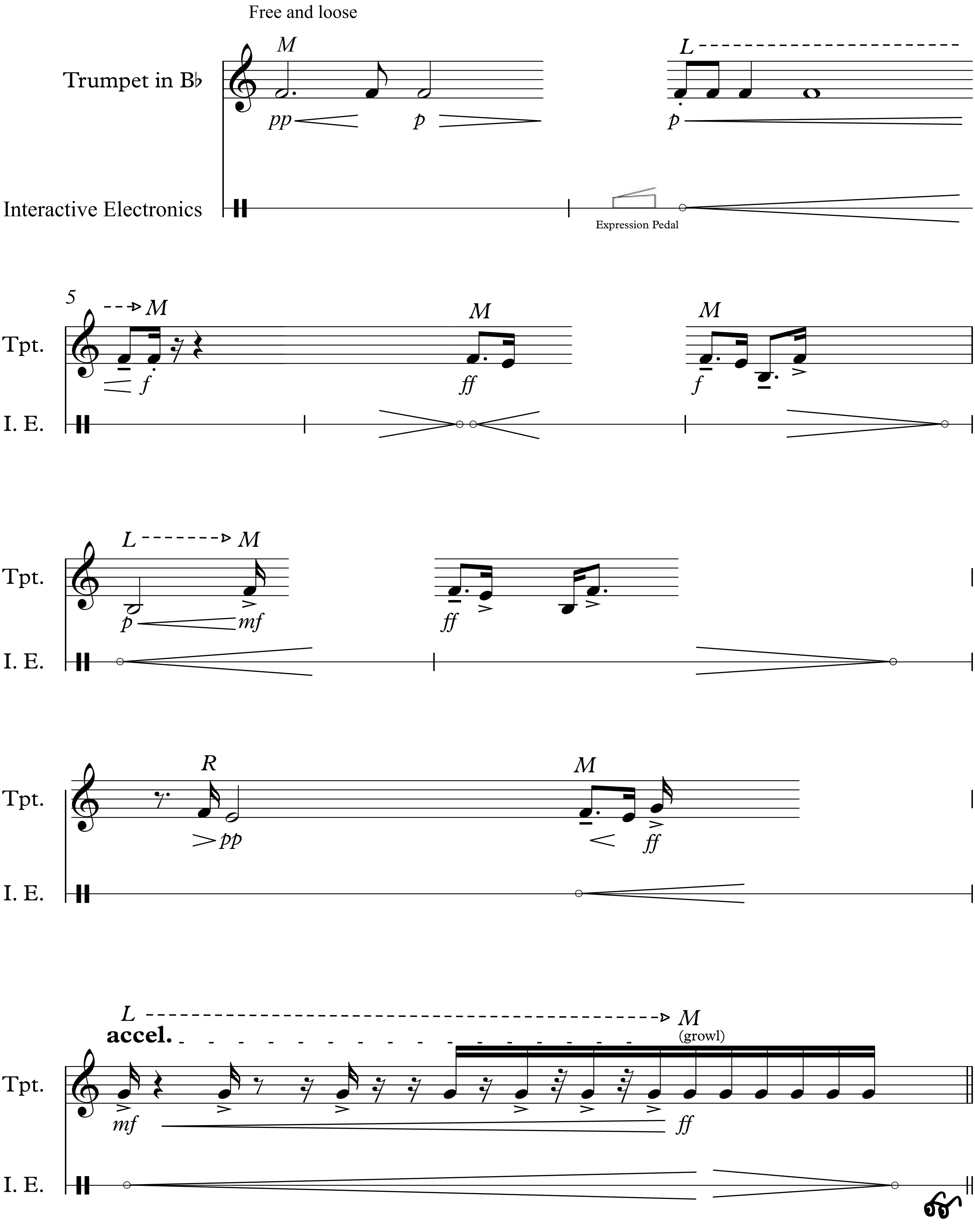
Layout of *Barbaróphonos*



Barbaróphonos

for trumpet and interactive electronics

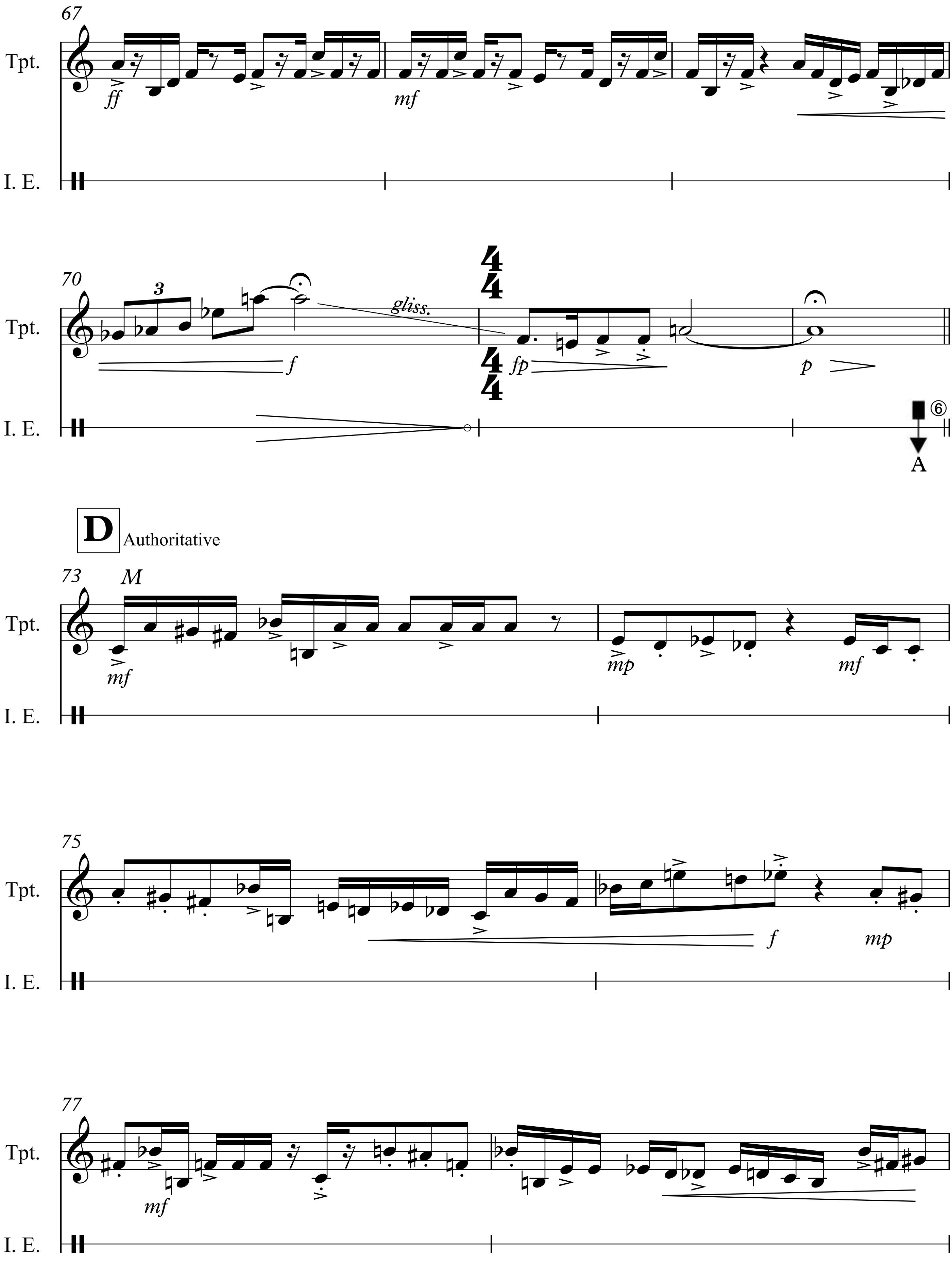
Tychonas Michailidis



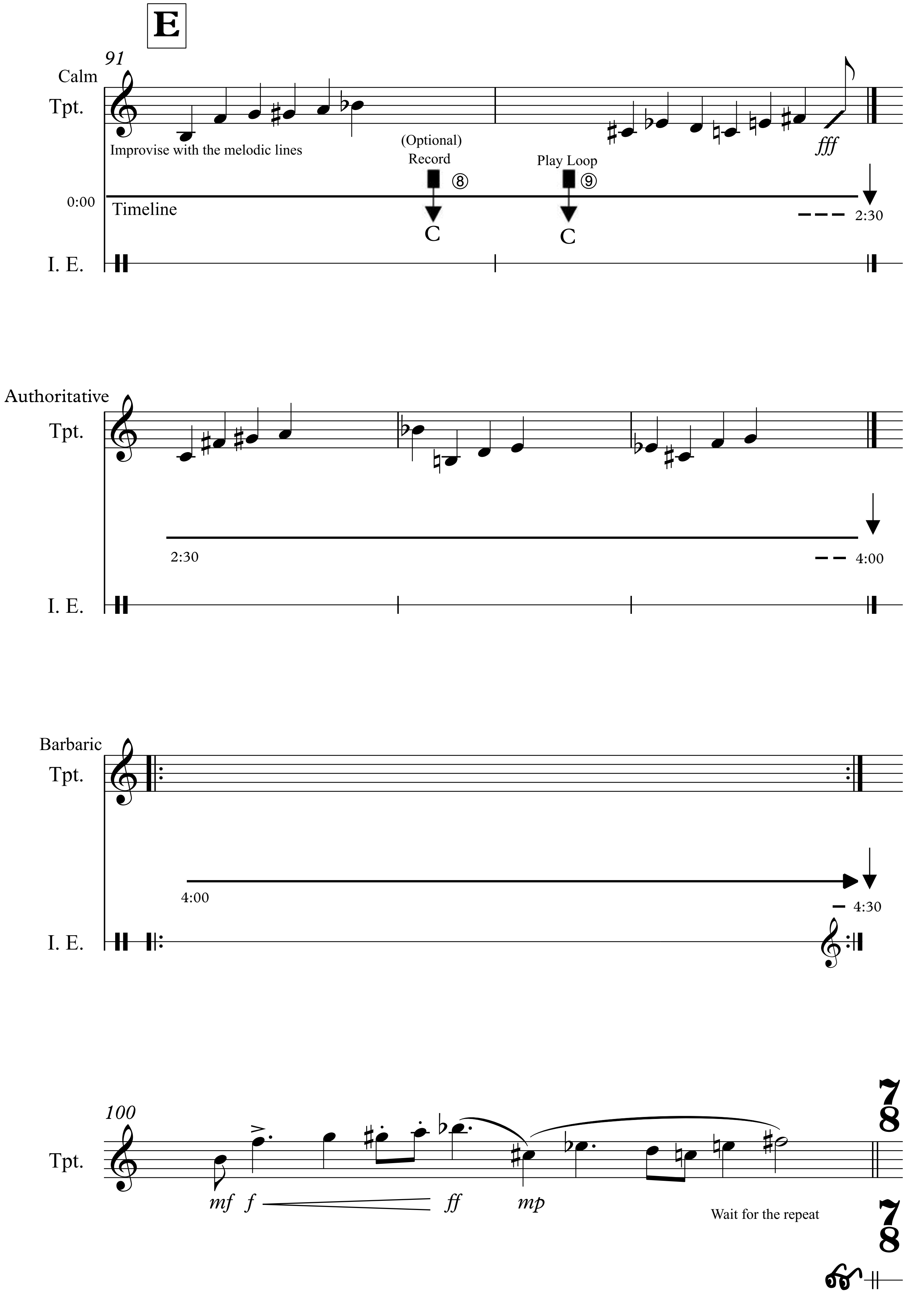

A
♩=100
Tpt.
I. E.
Optional
(growl)
Use freely
24
R (growl)
Optional
R
M
L
(growl)
28
31
R (growl)
R (growl)

B
♩=120
Loud and clear
36
R for the whole section
Tpt.
I. E.
mf
ff
mf
p
40
f
ff
f
44
mf
ff
mf
47
3
p
mf
fp
④
A
Tape playback 1:18


50
Tpt.
f
mp
fp
p
55
Tpt.
p
f
60
Tpt.
mf
f
p
p
C
♩=100
Dirty talking
M
63
Tpt.
f
p
mf
mf
A
Use freely

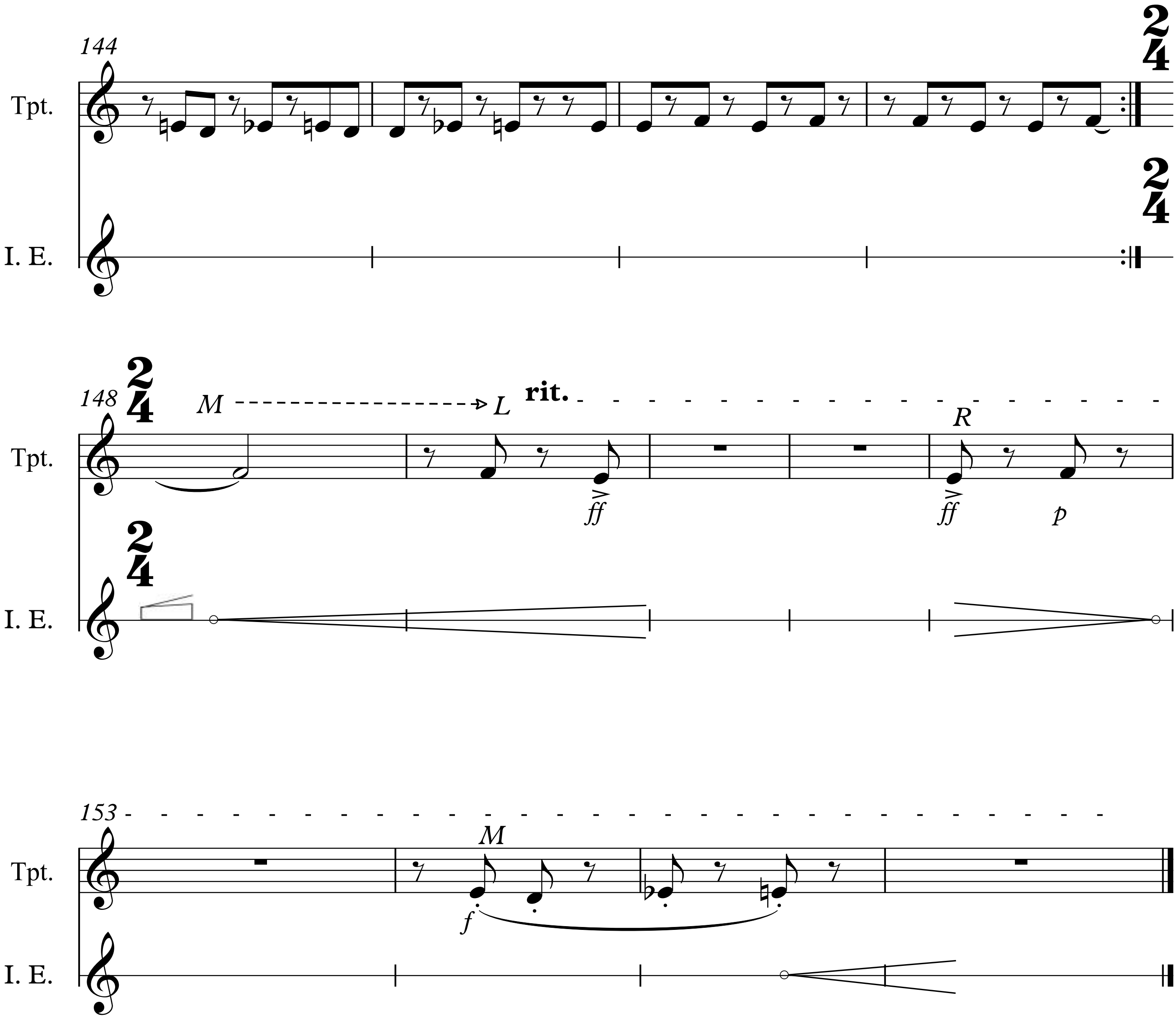

67
Tpt.
I. E.
ff
mf
70
3
gliss.
f
fp
p
A
D
Authoritative
73
M
mf
mp
75
77

79
Tpt.
f
f
mp
f
I. E.
81
Tpt.
mp
f
mp
ff
I. E.
83
Tpt.
I. E.
85
Tpt.
I. E.
87
rit.
Tpt.
mf
3
I. E.
89
Tpt.
p
sfz
I. E.
⑦
A


E
91
Calm
Tpt.
Improvise with the melodic lines
(Optional)
Record
⑧
Play Loop
⑨
fff
0:00
Timeline
C
C
2:30
I. E.
Authoritative
Tpt.
2:30
4:00
I. E.
Barbaric
Tpt.
4:00
4:30
I. E.
100
Tpt.
mf f ff mp
Wait for the repeat
7/8
7/8


F
♩=100
101
Tpt.
I. E.
L
M
mf
f
p
A
106
R
mp
ff
111
116
120
pp


G
♩=110
125
Tpt.
I. E.
M
3
p
mp
accel.
mf
129
Free articulation
Use freely
132
136
140
accel. on repeat


144
Tpt.
I. E.
148
M
L
rit.
R
ff
ff
p
153
M
f

Big Bang...

for Bass Trombone and Interactive Electronics

2011

Tychonas Michailidis

Big Bang...

for bass trombone and interactive electronics

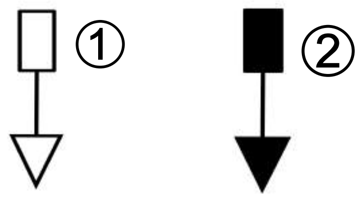
Performance notes

Score written in C.
Accidentals hold for the full bar.
All other notation as standard unless otherwise stated.

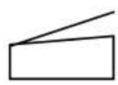
Pedals

The piece requires two pedals, a switch pedal and an expression pedal. This is used for triggering and controlling all audio processing. Any switch and expression footpedal will work with some minor modification depending on the type and brand of the pedal. The *Boss FS-5U* switch pedal (pictured) and the *Boss FV-50 L* (pictured) were used and tested with the composition.

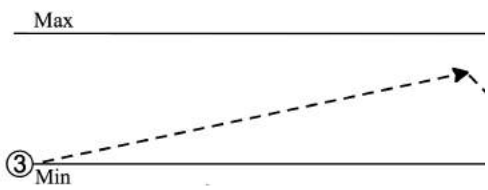
The two icons shows different functions of the switch pedal. The arrow indicates when to press the pedal based on the time signature and the beats of the bar. The number shows how many times the pedal is pressed at any specific time in the composition. The full pedal icon indicates the activation of an audio process. When icon is empty it indicates the deactivation of the process. The vibrotactile feedback is different depending on the full/ empty icon.



The icon indicates the use of the expression pedal.



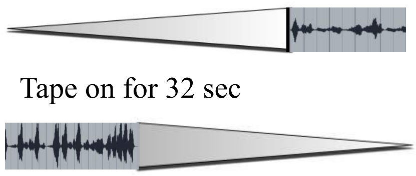
Shows the control of the expression pedal. The top line represents maximum range (fully open) and the bottom line the minimum (fully closed). The doted line shows the duration of



the action, based on the tempo and time signature. Through vibrotactile feedback the performer senses and feels the amount of control of the expression pedal that is applied to the system.

The icon indicates free interpretation of the control of the volume of the prerecorded audio loop.

Shows the duration of the audio file with fade in and fade out function. The performer senses the fade out function as vibrations.



Vibrating motors

The *TfTool* device is used to provide vibrotactile feedback when using the pedals. The pedals (1/4 jack) are plugged into inputs 1&2 (see picture). The vibrating motors are plugged into outputs 1&2 (1/8 jack).

TfTool device

The motors should be placed half way up the shin of the performer's legs, either inside or outside a trouser. There are two vibrating motors one for each pedal type, switch and expression pedal. A reusable velcro strap is used for placing the vibrating motors. The performer attaches the strap before going on stage and place the vibrating motor when on stage. The vibrotactile feedback provides confirmation every time the performer is using the pedals. The vibrating confirmation associated with the switches, should be placed on the left leg, physical output 1 on the *TfTool* device. For the expression pedal, the motor is placed on the right leg, physical output 2.

Placement of the vibrating motors

Suggested equipment list

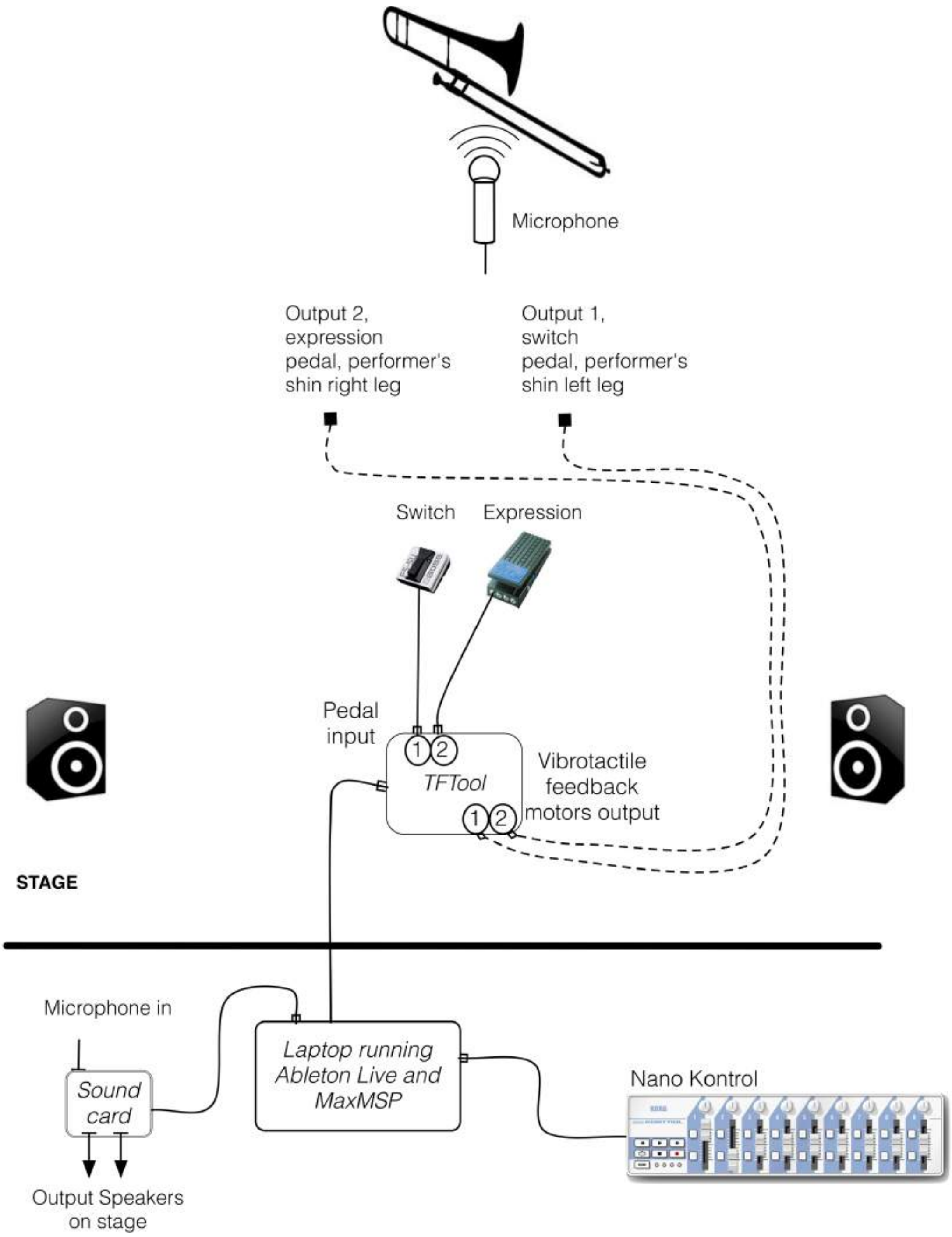
Soundcard: RME Fireface 800 (1 microphone inputs and 2 output)
Loudspeaker: 2 Genelec 8040 or similar depending on the venue
Laptop: MacBook Pro running Abelton Live 8.2.2 and MaxMSP 5.1.9
Microphones: 1 Dynamic, cardioid
Pedals: Boss FS-5U & Boss FV-50L
Associated cables
TfTool box with the vibrating motors obtainable from the composer.

First performed by Murphy McCaleb on the 16 January 2012 in the Recital Hall, Birmingham Conservatoire, Birmingham, UK.

Program Notes

'The idea of this piece comes from the theory of the Big Bang, which can be described as the ever expanding universe eventually stopping and reversing its process into a singularity known as the Big Crunch. This in turn, will lead us again into a new Big Bang. In my composition, this is translated into fast and slow sections, loud and soft sections, where echo and resonance suggests a sense of space. The performer controls the electronics through the two footpedals while sensing the actions through vibrotactile feedback.

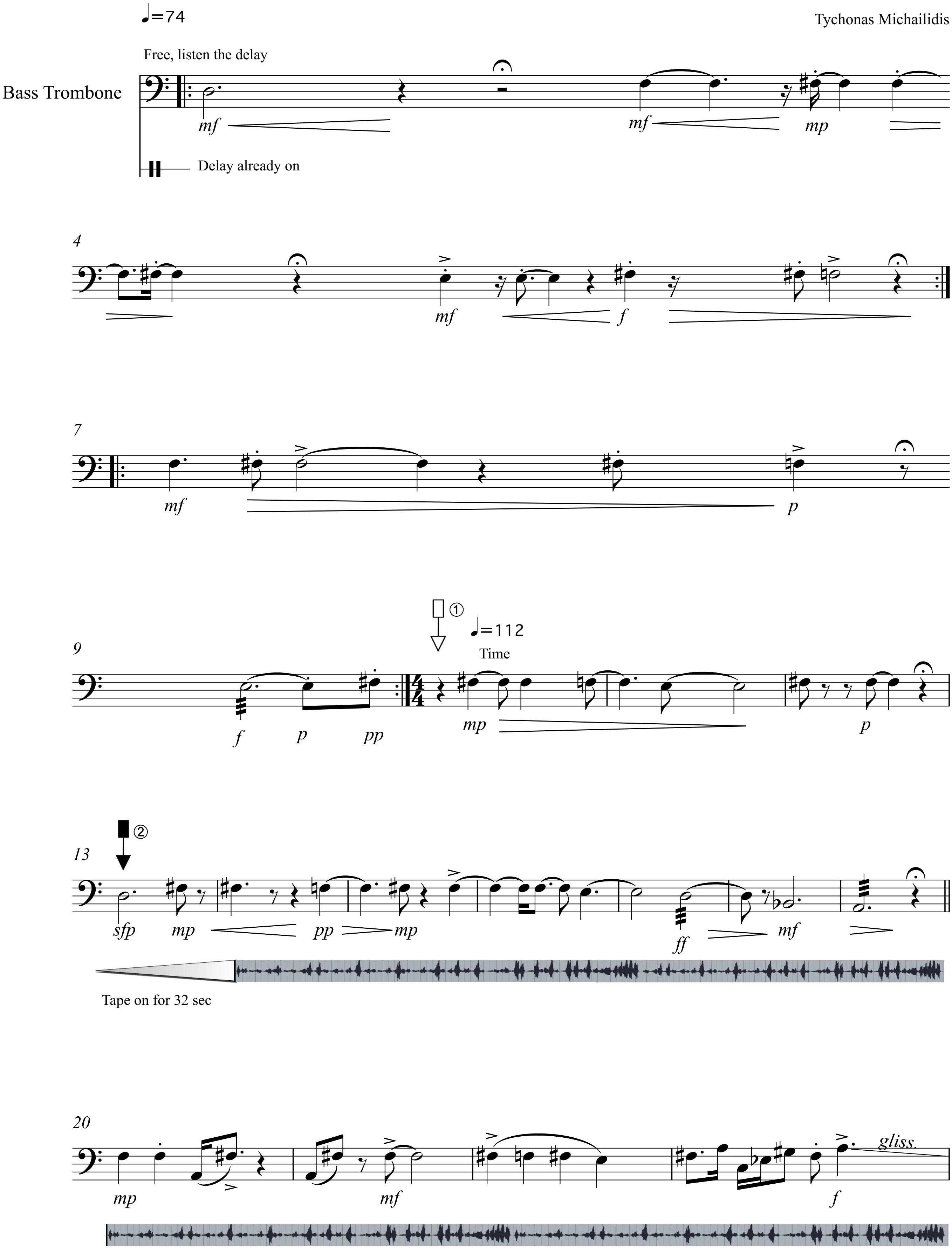
Layout of *Big Bang…*

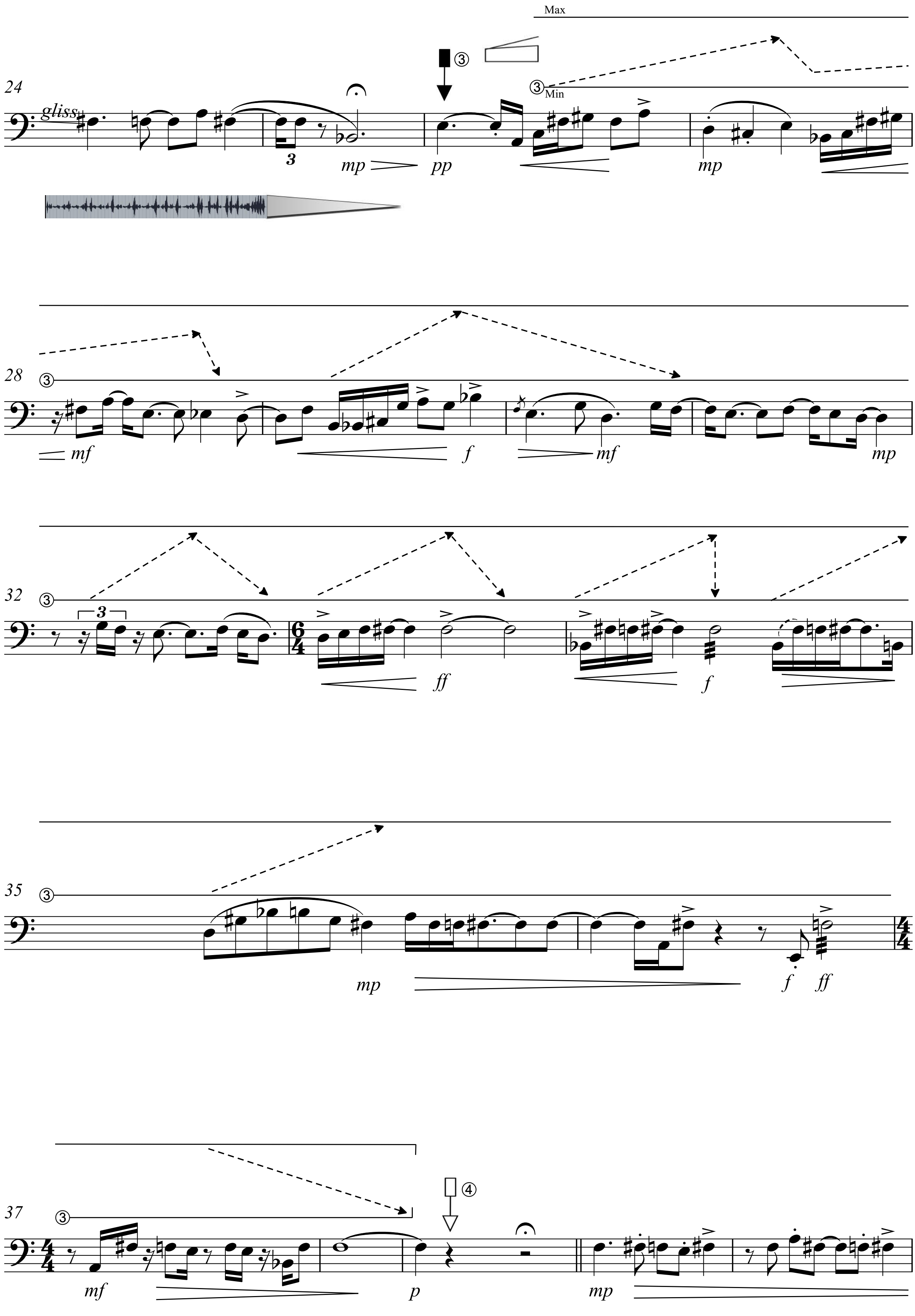


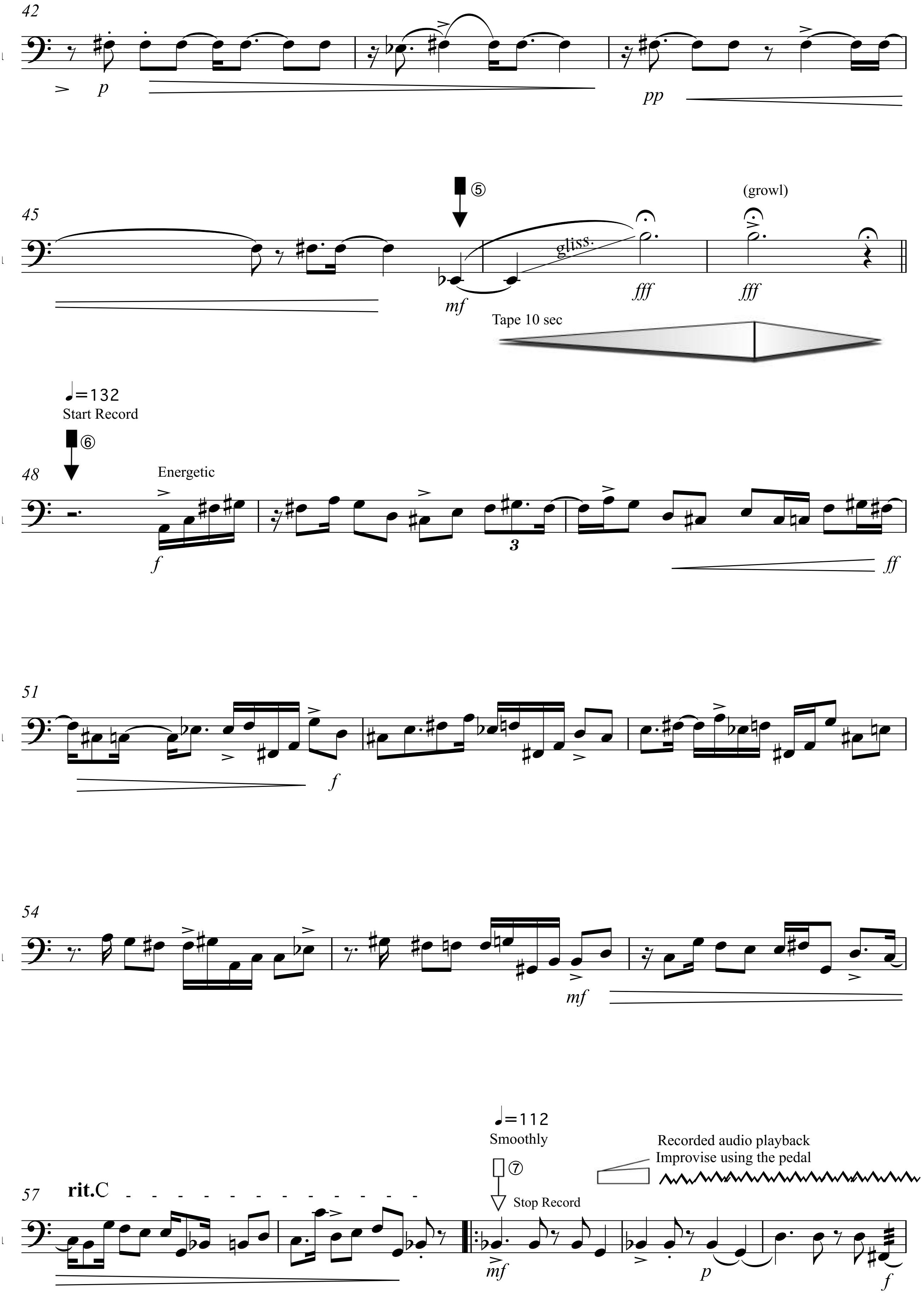
Big Bang...

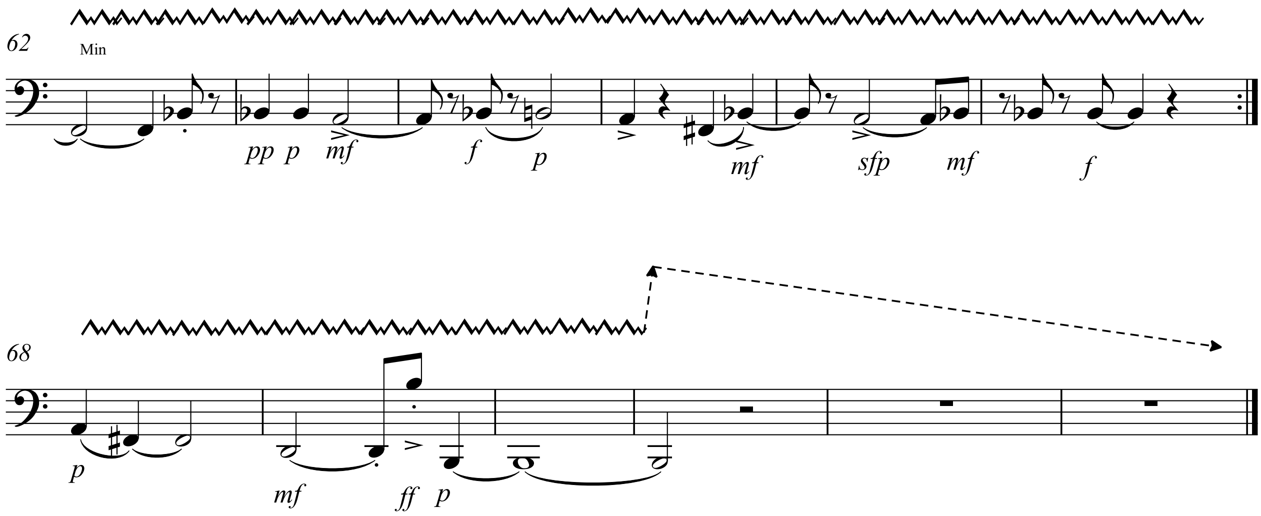
For bass trombone and interactive electronics

Tychonas Michailidis




Max
Min
24
gliss.
mp
pp
mp
28
mf
f
mf
mp
32
ff
f
35
mp
f
ff
37
mf
p
mp


42
p
pp
45
⑤
gliss.
(growl)
mf
fff
fff
Tape 10 sec
♩=132
Start Record
⑥
48
Energetic
f
3
ff
51
f
54
mf
57
rit.C
♩=112
Smoothly
⑦
Stop Record
Recorded audio playback
Improvise using the pedal
mf
p
f


62
Min
pp p mf f p mf sfp mf f
68
p mf ff p

...Big Crunch

for Clarinet and Interactive Electronics
2011

Tychonas Michailidis

...*Big Crunch*

for clarinet and interactive electronics

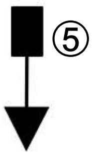
Performance notes

Score written in Bb.
Accidentals hold for the full bar.
All other notation as standard unless otherwise stated.

Pedal

The piece requires the use of a switch pedal for triggering and controlling of the audio processing. Any switch footpedal, including sustain pedals, will work with some minor modification depending on the type and brand of the pedal. The *Boss FS-5U* pedal (pictured) was used and tested with the composition.

The icons shows the use of the pedal in the score. The arrow indicates when to press the pedal based on the time signature and the beats of the bar. The number shows how many times the pedal is pressed at any specific time in the composition. For every successful trigger the performer feels a vibrating pulse confirmation.



Vibrating motors

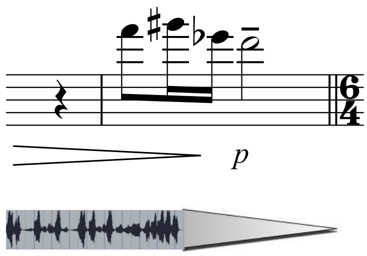
The *TfTool* device is used to provide vibrotactile feedback when using the pedal. The switch pedal (1/4 jack) is plugged into input 1 (see picture). The vibrating motor (1/8 jack) is plugged into outputs 1 (available on the other side of the *TfTool).*

TfTool device

The vibrating motor should be placed half way up the shin of the performer's leg. Preferably to the same leg that is used to trigger the pedal. It can be placed either inside or outside a trouser depending on the performer. A reusable velcro strap is used for securing and placing the vibrating motor. The performer attaches the strap before going on stage and place the vibrating motor when on stage.

Placement of the vibrating motors

During the playback of an audio file a waveform is showed in the score. When finished the performer feels vibrating fadeout buzz that indicates the end of the audio file. This takes place automatically without any action from the performer.



Suggested equipment list

Soundcard: RME Fireface 800 (1 microphone input and 4 output minimum)
Loudspeaker: 4 Genelec 8040 or similar depending on the venue
Laptop: MacBook Pro running IntegraLive 1.7 and MaxMSP 5.1.9
Microphones: 1 condenser, cardioid
Pedals: Boss FS-5U
Associated cables
TfTool box with the vibrating motors obtainable from the composer.

First performed by Jack McNeill on the 29 September 2011 at the Integra Festival, Royal Danish Academy of Music, Copenhagen, Denmark.

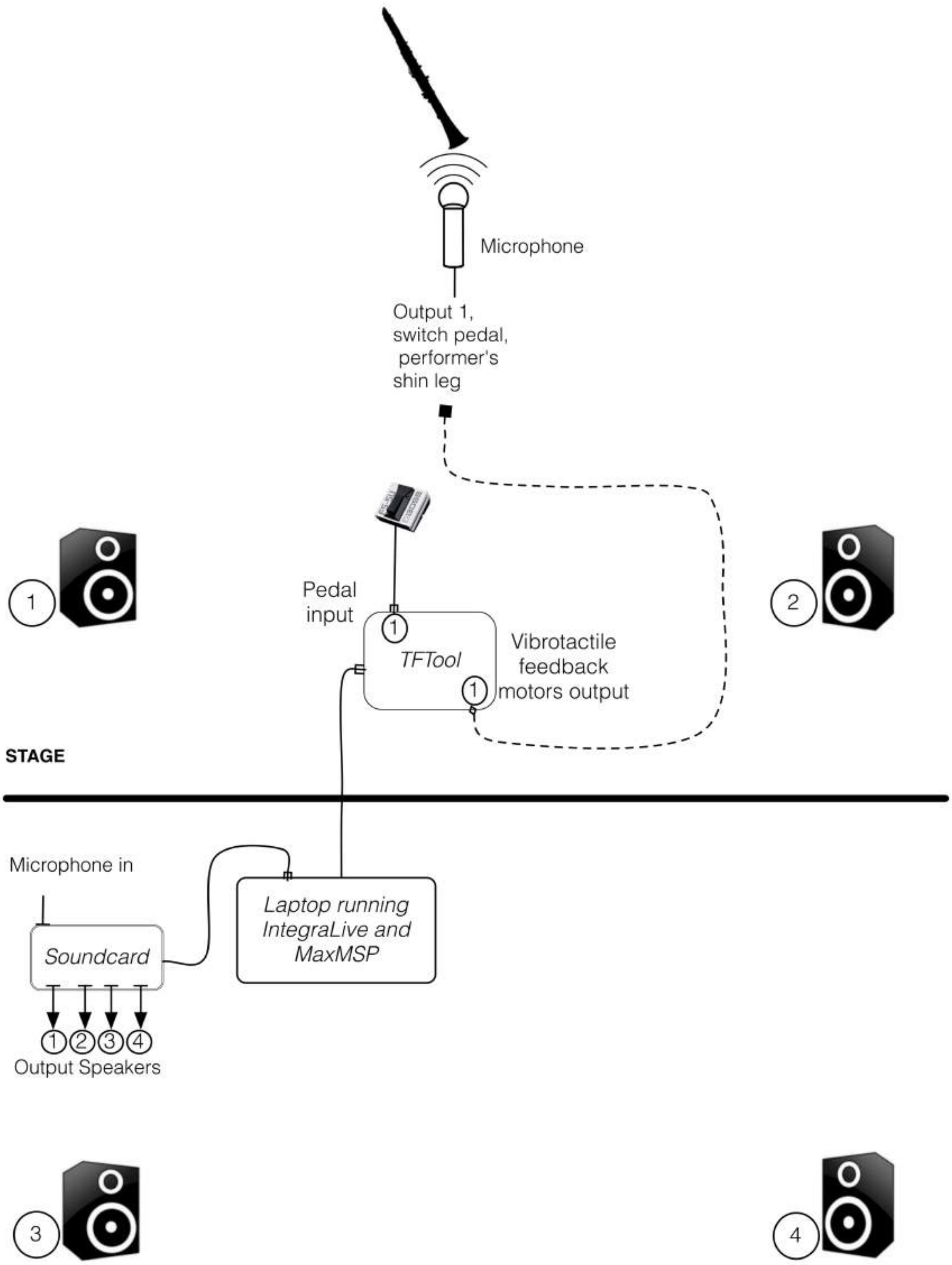
Program Notes

...Big Crunch includes a combination of live processing and prerecorded material using Integra Live. The whole idea of the piece comes from the Big Bang/Big Crunch theory, which suggests that the expanding universe will eventually come to a singularity.

The compositions aims towards a palindromic function, not only from the score and the notes but also through the audio effects and other functions. This artistic interpretation of the …Big Crunch is achieved through different approaches and relationships giving the illusion towards that singularity. The use of surround sound and moving objects resembles the spiral movement of galaxies and matter before the Big Crunch.

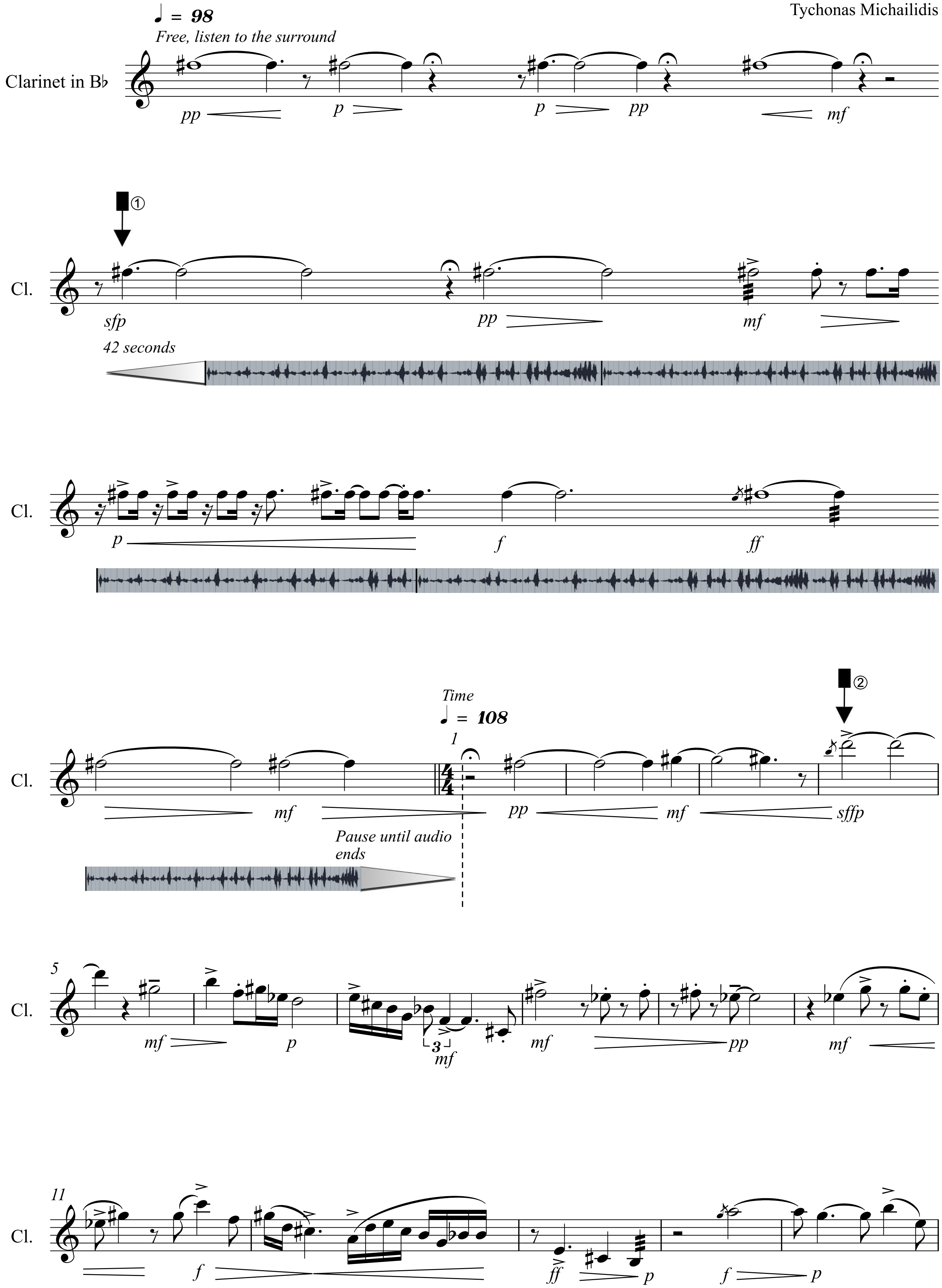
The piece uses vibrotactile feedback to inform the performer when controlling the live processing and the different audio files.

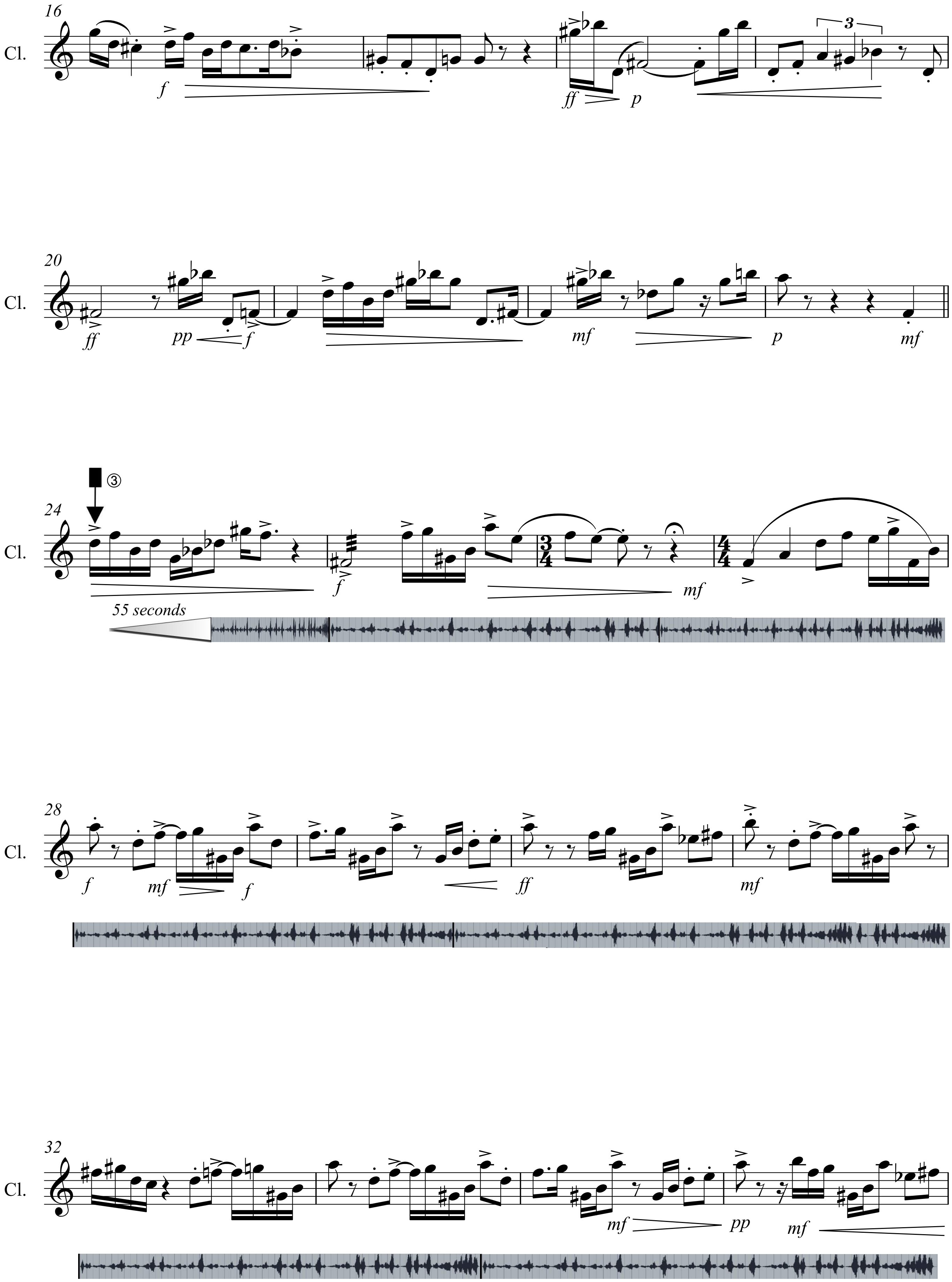
Layout of *...Big Crunch*



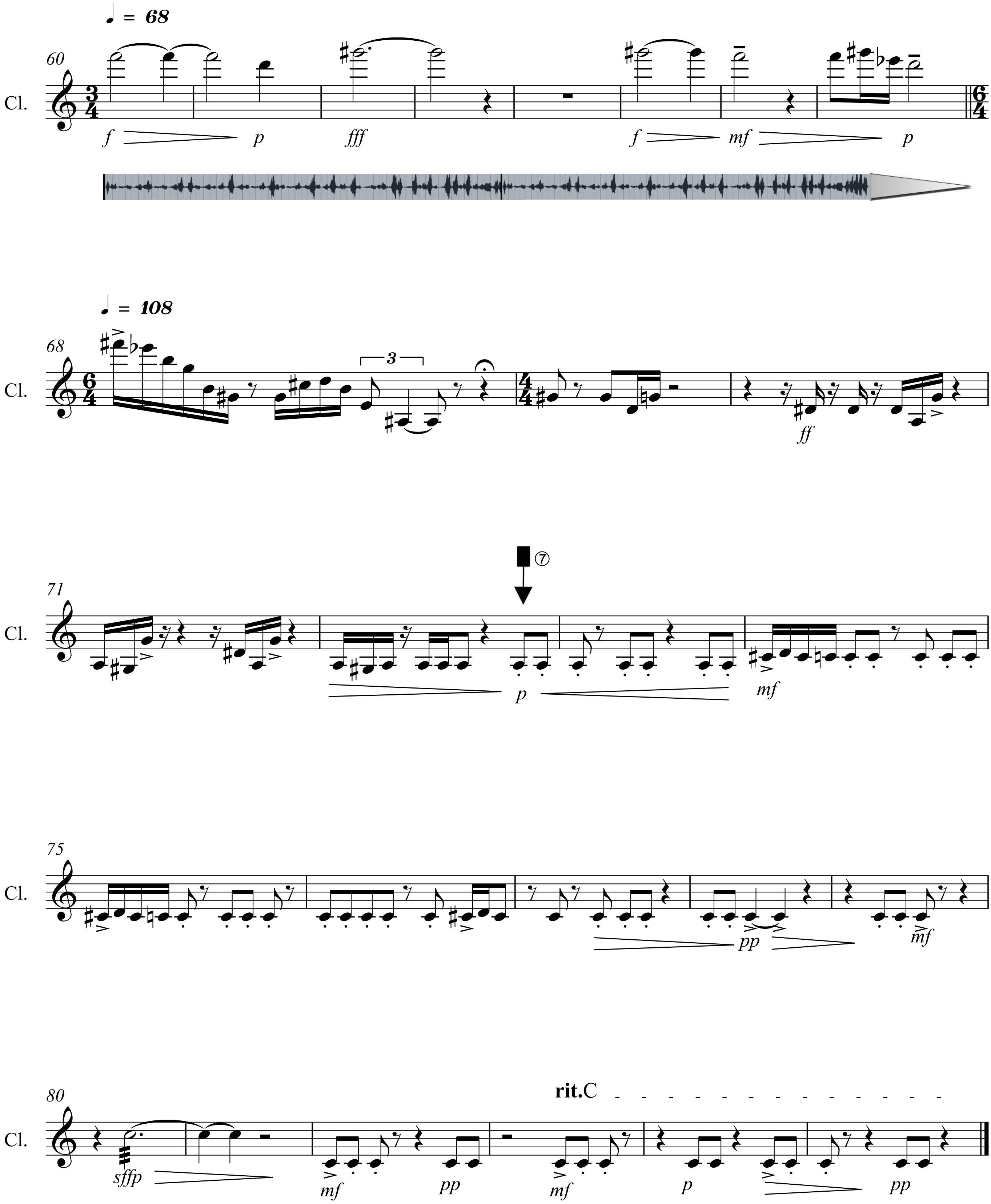
...Big Crunch

Tychonas Michailidis




16
Cl.
f
ff
p
3
20
Cl.
ff
pp
f
mf
p
mf
24
Cl.
③
f
mf
55 seconds
28
Cl.
f
mf
f
ff
mf
32
Cl.
mf
pp
mf

36
Cl.
pp
Pause until audio ends
④
39
Cl.
f
p
f
ff
p
43
Cl.
ff
mf
ff
mf
49
Cl.
p
gliss.
3
pp
ff
⑤
mf
54
Cl.
f
gliss.
⑥
17 seconds


♩ = 68
60
Cl.
f
p
fff
f
mf
p
♩ = 108
68
Cl.
3
ff
71
Cl.
⑦
p
mf
75
Cl.
pp
mf
80
Cl.
rit.C
sffp
mf
pp
mf
p
pp

Live Mechanics

for Piano and Interactive Electronics
2012

Tychonas Michailidis

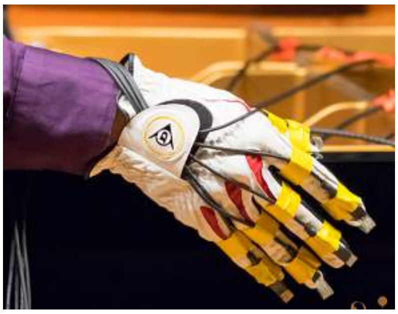
Live Mechanics

for *piano* and interactive electronics

Technical notes

There is no notated score.
The performer is responsible for recreating, learning and performing the composition. The suggested duration is between 10-12 minutes.

Glove

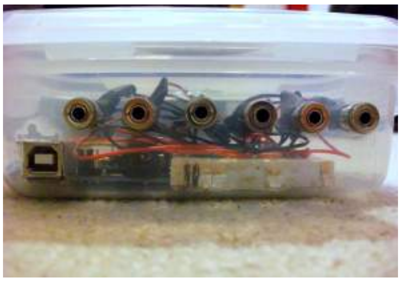


The glove, worn on the right hand, consists of five pressure sensors attached to the fingertips of the glove. Each pressure sensor controls one vibrating motor. The more the pressure that is applied to the sensors the more the motors vibrate. All sensors uses a 1/8 jack male connector. The glove has five cables numbered 1-5 starting from the thump (1) to the little finger (5). The glove should be worn on stage as a part of the performance.

Motors

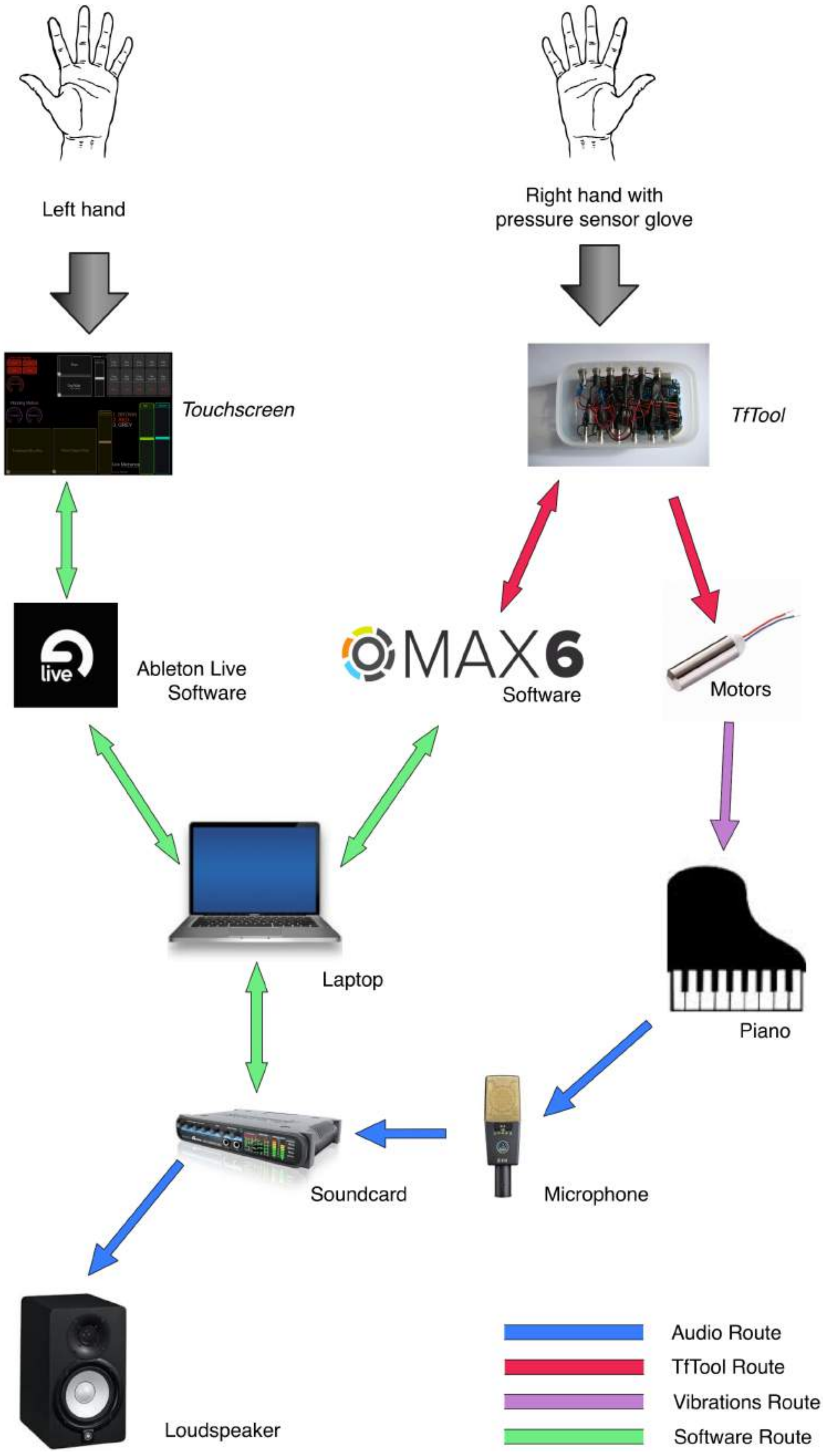
There are 5 vibrating motors. The different sizes of the motors affect the intensity of vibrations and thus the sound produced from the strings. The motor in the picture is the larger of the five. The motors are placed loose on the strings of the piano. Tape may be used to secure the cable on the frame of the piano to prevent them from falling off. When vibrating, the motors must move freely on top of the strings. The placement is entirely up to the performer. Each motor should be connected to the output side of the arduino box.

Arduino Box



The motors are plugged into the 1/8 jack female output of the Arduino the on USB side (pictured). The glove connects to the Arduino box opposite to the USB side (input side). The Arduino box is connect to the laptop through a USB cable. All inputs are numbered from left to right. The 6th input/output should not be used.

Layout of *Live Mechanics*



How to load the Live Mechanics file on the iPad

An iPad is required for the control of live audio and signal processing.

1. Go to http://hexler.net/software/touchosc. Download and install the **OSCulator** software on the laptop. The software will be used as an intermediate for the control of Ableton Live and Max software through the iPad.

2. Download **TouchOSC** from Apple App Store to use it on the iPad.

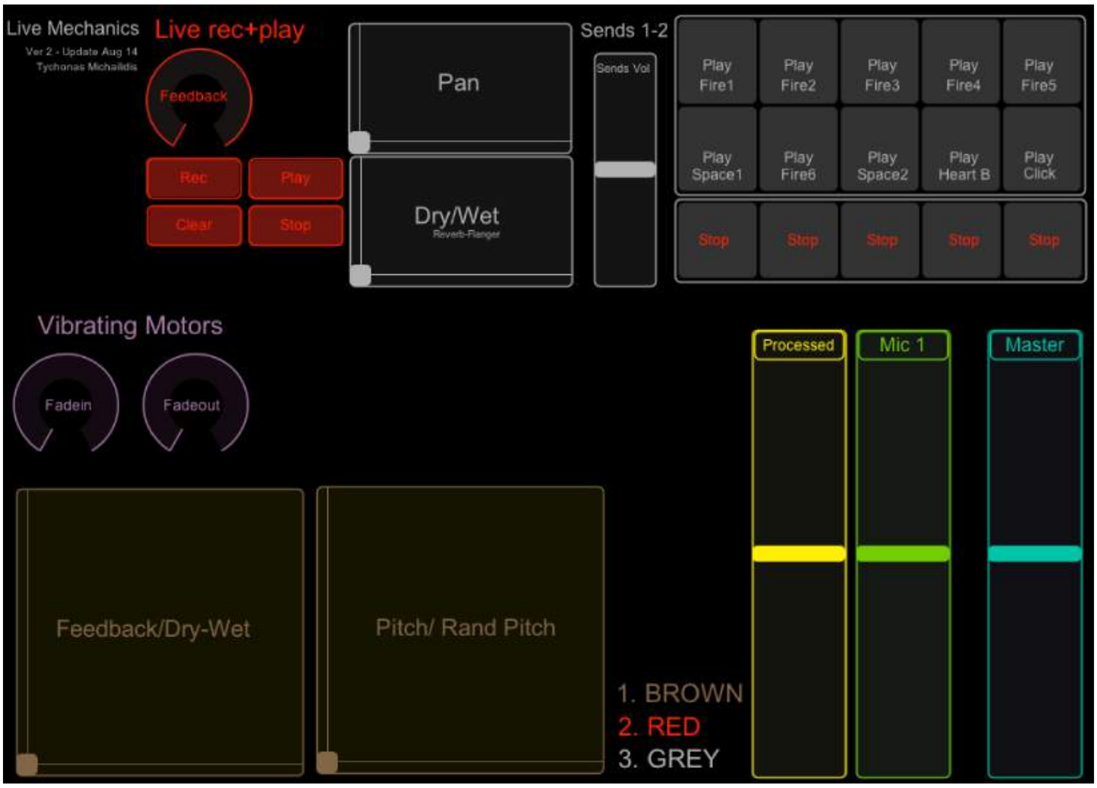
3. Go to http://hexler.net/docs/touchosc-editor-sync and upload the layout ***Live Mechanics-V2.touchosc*** from the ***2.Live Mechanics_Osculator*** folder to the iPad.

4. Create a network on your laptop (use password if you like).

5. On the iPad got to *System* and select the created network.

6. Go to http://hexler.net/docs/touchosc-configuration-connections-osc and follow the instructions on how to connect the iPad with the laptop.

Layout of the TouchOSC patch



How to run the composition

1. Load the ***Live Mechanics V2.als*** file found in ***Software-1.Live mechanics_Ableton*** folder.
2. Load the ***Live MechanicsOSCV2*** file found in ***Software-2.Live Mechanics_Osculator.***
3. Select the ***Live Mechanics-V2.touchosc*** file on the iPad through the TouchOSC application.
4. Load the ***Live Mechanics.maxpat alias*** file in the ***Software-3.Live Mechanics_Max*** folder. Follow the instructions within the patch.

Performance notes

The iPad is placed inside the piano, flat and close to the high register of the piano. During the performance the right hand (pictured above) uses the side of the piano to apply pressure. The left hand controls the iPad. The performer should be in a standing position. The sustain pedal on the piano should be used to allow the string to resonate.

Three main sections are controlled thought the iPad. All functions are colour coded.
Starting from bottom right, the *Master* gain controls the overall output volume of the system.
Mic1 fader is the gain control for the microphone input on the piano, Channel 1 in Ableton Live.
Processed fader is the gain control for the processed sound of the piano, Channel 2 in Ableton Live.
The *Brown* section includes 2 x-y pads that controls a combination of effects.
The *Red* section includes the controls for the recording and playback of the processed live audio. When record is enabled, the duration acts as a buffer. When played back the audio is looped once and overwrites the buffer. *Feedback* controls the amount of audio that is included from the previous to the new playback. When 100% then the old loop will be included within the new loop at the volume of 100%. When 0% then old loop will not be included within the new loop since the volume is at 0%.
The *Grey* section controls the playback and functions of audiofiles. There are 5 columns and each one includes 2 playback buttons with different audiofiles and a stop button. The pressure sensor on the glove controls the volume fader for each channel. Each channel is sent to buses channels 1-2. The *Pan* x-y plane controls the panning of those sends, and the Dry/Wet x-y plane controls the reverb and flanger effect.
The *Vibrating Motors* (purple) control the time that it takes for the motors to reach the value set by the pressure sensor. The fade in is the time that it takes to reach ascending values and for the *Fadeout* is the time that it take to reach descending values. For example if the fade in is set at 500 then the time that it take the motor to reach from 0 to 127 it will take 500ms. The same applies for the fade out function. It allows a smoother performance of the motors.

Video performances can be found here:
https://youtu.be/ktJhhHrEdVI
http://youtu.be/8AnkWhwhXtM

Program notes

The composition looks at new sonic sounds of an acoustic piano through human gestures without performing on the keys of the piano. It reverses the process of getting data from electronics sensors and uses them to create the sounds mechanically. The performer controls through a pressure sensor glove the vibrating motors that are placed on the strings of the piano. The motors produce a distinctive piano sound. The glove controls the amplitude of the vibrating motors that affects the overall sonic outcome of the piano. The piece uses live processing and prerecorded sound from the piano.