CONFIGURING CORPOREALITY

Performing bodies, vibrations and new musical instruments

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Abstract

How to define the relationship of human bodies, sound and technological instruments in musical performance? This enquiry investigates the issue through an iterative mode of research. Aesthetic and technical insights on sound and body art performance with new musical instruments combine with analytical views on technological embodiment in philosophy and cultural studies. The focus is on corporeality: the physiological, phenomenological and cultural basis of embodied practices. The thesis proposes *configuration* as an analytical device and a blueprint for artistic creation. Configuration defines the relationship of the human being and technology as one where they affect each other's properties through a continuous, situated negotiation. In musical performance, this involves a performer's intuition, cognition, and sensorimotor skills, an instrument's material, musical and computational properties, and sound's vibrational and auditive qualities. Two particular kinds of configuration feature in this enquiry. One arises from an experiment on the effect of vibration on the sensorimotor system and is fully developed through a subsequent installation for one visitor at a time. The other emerges from a scientific study of gesture expressivity through muscle physiological sensing and is consolidated into an ensuing body art performance for sound and light. Both artworks rely upon intensely intimate sensorial and physical experiences, uses and abuses of the performer's body and bioacoustic sound feedback as a material force. This work contends that particular configurations in musical performance reinforce, alter or disrupt societal criteria against which human bodies and technologies are assessed. Its contributions are: the notion of configuration, which affords an understanding of human-machine co-dependence and its politics; two sound-based artworks, joining and expanding musical performance and body art; two experiments, and their hardware and software tools, providing insights on physiological computing methods for corporeal human-computer interaction.

I hereby declare that the work presented in this thesis is entirely my own.

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This work has been made possible by the countless amount of people I have interacted with, in varying degree of familiarity and intimacy, at some point throughout my life. This includes family members, friends, colleagues, artists and strangers. I like to think that each person has left a mark on my body, and those marks have informed myself as a human being, and by extension, the way this work has been realised. I am particularly grateful to both my first supervisor Prof. Atau Tanaka and my second supervisor Prof. Matthew Fuller, who have guided me, with rigour, enthusiasm and thoughtfulness, through three intense years that have significantly shaped my way of thinking and working. The continuous and inspiring exchange with my colleagues in our Computing Department has been fundamental to this research, and I am particularly grateful to Dr. Baptiste Caramiaux and Alessandro Altavilla for the exciting conversations we have had, whether sitting in our office in London or in a bar in Seoul. The feedback of my examiners, Prof. Lisa Blackman and Prof. Sergi Jordà, has been an invaluable help in making this thesis more precise and compelling, and thus they deserve my earnest gratitude. A heartfelt thanks goes to those researchers, artists and makers with who I have consistently exchanged ideas, doubts and projects in the past years, whether in person or on the Net. It is with great joy that I dedicate this work to my parents who have taught me to be respectful, humble and daring, characteristics which I hope to be able to bring forth, and who have instilled in my young self an insatiable curiosity and a fierce determination. Finally, my most sincere gratefulness goes to Margherita; a splendid woman, talented artist and wise human being, who has had the strength to restlessly support me during these years and a healthy dose of criticism to discuss the ideas expressed in this work.

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Chapter 1

Introduction

1.1 Sketching the Origins: A Few Personal Notes

1.1.1 Discovering the physicality of sound

I grew up during a time where computers, video games and the Internet were integral to everyday routine. I actually rarely played any video game on my first computer, but rather learned all I could about making sound and music with it. As a youngster,

Figure 1.1: The 2001 New Year's Eve Teknival in Aprilia, Italy.

I would play my own music at illegal raves through massive sound systems in so called T.A.Z., temporary autonomous zones (Figure 1.1). These, in rave culture, were massive free dance music events. They would take place in buildings illegally occupied by 'crews' of DJs, sound engineers and endless crowds of ravers for several days. Hundreds, and sometimes thousands, of people would participate in sonic dancing rituals in a strenuous attempt to create new territories, geographically, temporally and perceptually.[1]

Rave culture has long gone now, and I will be always grateful to that experience because through it I could develop a significant aspect of my present practice, a passion about the physicality of sound, the material power of sonic vibrations to alter and sculpt bodily perception. The ridiculous amount of hours I spent with my ears in physical contact with a speaker and my torso literally touching the cone of a subwoofer have left me with a damaged hearing, with which I am still dealing today. But it also gave me something incredibly fertile. It has engraved in my body an inexhaustible need of, and passion for, the capacity of sound, properly treated and amplified, to physically affect the human body and perception. This is how I came to understand for the first time, even if through the ingenuous eyes and ears of an adolescent, that human bodies and machines are not only made to sit in front of each other, but they can touch each other, resonate together through vibrations and create alternative ways of knowing. I will come back to the experience of raving on different occasions in this text, for it can helps us grasp some of the concepts which are key to this work. I will also dedicate full attention to my hearing damage later in section 4.1.

1.1.2 Making and Performing

Now, about fifteen years after, the physicality of sound and the physical interactions of human bodies and machines lie at the core of both my artistic and research practice. Thriving for the discovery of new sounds and new ways of playing them, I began, about ten years ago, to make and play with my own musical instruments. It is now for a little over a decade that I write software and make hardware to build, and perform with, my own instruments. In 2011, in the context of a Master by Research in Sound Design at the University of Edinburgh, I created a biophysical wearable instrument called XTH Sense (Donnarumma, 2012b). I have been performing with it since then, and the instrument itself has informed the way I think about and use human bodies and technological systems in artistic performance. In this thesis however, the XTH Sense is only one of the instruments I will use, for the scope of this enquiry is not the development of a single musical instrument, but the creation of analytical and practical strategies to extend technologically-mediated performance. The activity of

[1] See Akim Bey (1985) for the originary context of T.A.Z.

making instruments is integral to my artistic practice, but, eventually, it is the performative aspect that most interests me. Thus, I refer to myself as a performer. Although I indeed program software and build hardware to play sounds, I do not conceive of myself as either a programmer, a technologist or a sound designer, because everything I do is focused towards the act of performing. This is a needed premise because it put this research in perspective; the questions that this research will ask emerge from my continuous investigation of the art of performing sound in front of, or with, a live audience.

1.1.3 Art as a Critical Means

As media theorist Matthew Fuller has put it, when making art there is no 'correct answer', but rather 'the generation of a field of possibility in which a particular set of potentials are themselves becoming thought and sensed through.' (Fuller, 2005, 87). Years ago, I used to be an activist and did artworks that were explicitly political. Later, I realised that what those works tried to do was to state some truth. I felt constrained by that kind of straightforward approach and decided thus to take a step back and reconsider my artistic practice. I began to look for ways to make artworks that would emphasise political issues by applying critical concepts to the use of the body and technology. I am still highly engaged with political issues. I am concerned with social strategies involving power, ethics and belief and so is this present research and artistic practice. But, what I do today is artworks which have an inherent political meaning without it being clearly stated or immediately apparent. This, it is hoped, creates room for the audience to interpret critically what they hear, see and experience.

Paraphrasing poet Jerome Rothenberg, the function of art is not 'to impose a single vision or consciousness, but to liberate similar processes in others' (Rothenberg, 1981, 105). Through their art, artists contribute to initiate, channel or disrupt processes of reflection in others, reflective processes that would have not taken place otherwise. At the same time, an artist's aesthetics is hardly impersonal. Creating an artwork is a matter of consolidating a person's individual vision of the world into an artefact that is meaningful to others, meaningful in the sense that it means something in the context of other people's lives. An artwork is embedded with the strongly personal vision of an artist, hence the message it conveys and the reflective process it initiates are vectors of the artist's original vision. This, in my view, is an important responsibility, which seems to be too often overlooked in the current panorama of technologically-mediated performance.

1.2 Where it all begins: Bodies, Sound and Machines

> "If our goal is musical expression we have to [...] engage with the system: power it and touch it with our bodies..." (Waisvisz, 2006a)

This dissertation is about human bodies, sound and electronic musical instruments, instruments made of sensors, transducers, circuits and algorithms. It is about musical expression as the result of a physical engagement of the player's body and the instrument's parts. It emerges from the experience I have gathered in the past five years as a touring performer and a researcher working at the crossroad of sound art, performance art, music performance and new musical instruments design. While creating instruments and performing with them, I kept coming back to the same questions: How to define the relationship between a human performer and an electronic musical instrument? How does the material force of sound influence that relationship? How can a deeper knowledge of this relationship inform music performance?

1.2.1 Aims and Starting Points

Defining the relationship of performer and instrument is a challenging task because music performance is a highly complex activity that combines the specialised motor skills, perception and intuition of a human performer, the physical affordances and musical possibilities of an instrument, and the auditive and haptic feedback of sound (Leman, 2008). With so many elements at play, the relationship of performer and instrument is open to different readings, ranging from embodied music cognition approaches that see the instrument as a natural extension of the performer's body (Leman, 2008; Nijs et al., 2009), to phenomenological views where the instrument, rather than an extension of the body, is an object with which the performer perceives, and opens up to, the performance environment (Schroeder and Rebelo, 2009). What is common to these approaches is that the performer's body is usually considered central to music performance, while the instrument is described as an object that relates to the performer's body in a more or less mediated degree; it is an epistemic subject-object relationship where the performer is the knower and the instrument is the object to be known. In addition, sound is frequently regarded as an informational channel; it is described in terms of timbre, pitch and loudness, and these characteristics are analysed on the basis of their relevance to the delivery of musical meaning. This epistemic subject-object view of the performer and the instrument where sound is a vector of musical meaning overlooks two things.

First, technology does not only do things for us, it does things *with and to* us. It senses, responds to and alters human embodiment to the point where our bodies are technological bodies (Haraway, 1985; Shilling, 2005); amalgams of technology and flesh where a *particular* body incorporates a particular instrument, rather than pairing with it as if they were two unbiased separate entities (Shildrick, 2013). Second, sound is not only about meaning, it is also about physical energy shared across the performer's body, the audience members' bodies and the instrument's parts. Sound as a vibrational force (Goodman, 2009) links human bodies and instruments at a material level by physically resonating them. Sound in the form of rhythm, repetition, and vibrations enables corporeal mode of knowing (Henriques, 2011). The concept of the *technological body*, firmly rooted in gender studies and cultural studies of the body, and that of *sound as a vibrational force*, influenced by feminist epistemology, ethnography of sonic practices and phenomenologies of sound, form the backbone of my work. I will elaborate on them later in this section. Based on these points, I will argue that the performer and the instrument are not in a prosthetic relationship, for each has different capabilities and different modes of operation, nor are they in a primarily cognitive relationship, for sound does not only help us understand meaning but it also alters our embodied being. Rather, I will argue that they are in a relationship of *configuration*. Configuration is an analytical device I created to help us see the technological body in sound and body art performance as an ecology of physiological, experiential, psychological and technical components; elements which are always in tension against each other. I will detail my notion of configuration and its application to sound performance in section 4.1.

Key to this argument will be an analysis of the corporeality of the technological body and its implications for musical performance. Corporeality is a concept rooted in the work of Marcel Mauss (1936) and Maurice Merleau-Ponty (1978) that refers to the physiological, phenomenological, psychological and cultural basis of embodied practices; practices that rely on conscious and pre-conscious performance, forms of psychic attunement and entrainment, bodily action-perception loops and the physical effort that comes with it. I chose to tackle the issue of corporeality because it is a crucial aspect of music performance (Leman, 2008). It is through the corporeal encounter between performer and instrument that a musical performance can lead to the experience of 'flow' (Csikszentmihalyi, 1990), a complete immersion and near isolation from the environment which provides the best conditions for musical expression (Leman, 2008).

To talk about corporeality however, means to confront what is often proposed as a universal understanding of embodied practices with the specific questions raised by issues of gender and sexuality (Grosz, 1994). Bodily practices are performed differently according to gender, race, class and age, and thus have distinct implications. Stressing the importance of the materiality and corporeality of human-machine interaction encourages modes of research that recognize the difference and multiplicity of the human body across all kinds of sexual and physical embodiments. Specific issues of gender and sexuality, which would be central to a broad discourse on corporeality, exceed the particular scope of this research and its analytical framework. Nonetheless, this work is concerned with ways to displace and undermine normative models of corporeality in artistic performance. Thus, this enquiry follows in the path of other studies of corporeality, such as those by Lisa Blackman (2001), Margret Shildrick (2002) and Erin Manning (2009), in that it examines a specific embodied practice, in this case musical and body performance with electronic instrument, to raise more general theoretical questions on the normative dimensions of both the human body and the technologies which are created for it.

But this will not be only a discursive contribution. Being myself an artist and performer I have created two live performances which embody the theoretical concerns described thus far, and function as a practical test bed for inventive experimentation with hybrid forms of corporeality. Thus, this enquiry examines what it means, culturally, technically and artistically, to create sound and musical performances where the instruments and the player perform through each other, so that the two co-constitute each other in the creation of new modes of musical expression. Here, to 'perform through each other' is meant literally and physically. The two performances I have created, and which will be discussed later, are based on the exchange of acoustic vibrations and electrical voltages from the muscles of the performer to the sensors and transducers of the instrument, and vice versa, from the instrument back to the performer. The physiological processes of a performer's body are shared with the instrument, which augments them and feeds them back to the performer in the form of new sound and light stimuli. It is a process of iterative negotiation between the performer and the instrument from which musical expression arises.

This research project creates a dialogue between 1) a theoretical analysis of the corporeality of the technological body through vibration, 2) the technical implementation of physiological tools and 3) the artistic development of performance works. The chief aim is to extend the breadth of technologically-mediated musical performance by offering an alternative to epistemic subject-object views of performer and instrument. As this thesis will show, a dialogue between theory, technique and artistic practice is less destined to produce an agreement and more inclined to generate multiple and often contrasting perspectives. This is the methodological grounding of the present research. In contrast with other types of practice-based research, which focus on one technique and work it through to the finest of the details to build a stronghold, this work humbly dares a different approach. It brings into conversation distinct analyses, techniques and aesthetic issues to find and walk all the way through a path (one of the possible) to *explore and experience* the relation of corporeality and computation in the arts. Many other paths are possible and this thesis does not attempt to deny or eliminate them.

To some, the amount of theory discussed in this thesis will be a signal of a dubious approach to practice-based research. To me, it is about experimenting with practice-based research itself. I want to break free from the insulated building which artists working in academia have built around themselves. Despite practice-based research has taken its own place in the academic arena, the idea of having a practitioner artist doing scholarly research is often perceived more as *allowing* the artist to do so, rather than trusting her capacity to make a contribution to knowledge, beyond artistic practice. There is not much work by artist-researchers in fields other than art, like philosophy or human-computer interaction, and their work is often seen as 'arty' and, well, sometimes it is. This however in no way means that an artist cannot or should not engage fully and systematically with other fields. The beauty and usefulness of art is its intrinsic transdisciplinarity, and artists are those who know this best. My background is in the performing arts, I graduated in sound design, I taught myself biomedical engineering and body theory, and the PhD for which I submit this work is in computing. This research project is an effort in performative experimentation. It makes a meaningful contribution to cultural studies of the body and human-computer interaction by using artistic practice as a test bed, a living site and a speculative ground for theories and techniques. Thus, this thesis serves as a benchmark for future research on the relation between corporeality, sound and physiological technology in electronic musical performance by providing a consistent set of ideas and findings which other artists and researchers can build upon. Since the project is transdisciplinary, its contributions span across three research areas, which are introduced here in logical order. First, the project contributes to the cultural study of the body (Blackman, 2008) by extending existing analytical tools to investigate the corporeality of the body when coupled with technology. I have developed arguments, which will be discussed throughout this text, that posit the relation of materials, expression, context, and experience to the corporeality of the technological body (Haraway, 1985; Shilling, 2005), a human body intimately altered by technology. I will develop further an account of the technological body in the next subsection.

Second, this project contributes to the fields of human-computer interaction (Dourish, 2004) and physiological computing (Fairclough, 2009) by creating a set of sensing and computational tools to analyse the expressiveness of a performer's body through physiological signals and processes. Through those tools, I have conducted user studies to test the physiology of both gestural movement and self-perception, and I have used the related findings to develop an approach to human-computer interaction in artistic performance with sound that builds upon corporeality.

Third, the project contributes to both electronic music performance and performance art. Building on the contributions described above, I have produced two new performances that extend the relationship between corporeality and computation by using sound as a material force. The two performances consists respectively of: a solo body art performance using an octophonic surround sound, interactive light, paint and physiological sensors; and a performative installation for one visitor at a time using a quadraphonic surround sound, interactive light, high-power infrasonic transducers, a mirror and physiological sensors. I will elaborate on this contribution by discussing how these artworks compare to and extend some of the existing approaches to the body and sound in technological artistic performance, and how they help inform some cultural concepts from body studies. The backbone of this work is formed by two notions which I introduced above and will develop in the remainder of this section: the *technological body* (Haraway, 1985; Shilling, 2005) and *sound as a vibrational force* (Henriques, 2011; Goodman, 2009). The former refers to the understanding that the corporeal qualities of the human body have been modified by technologies that increasingly operates on and within the body. The latter indicates an understanding of sound as a material force that, by resonating both human and technological tools, and by creating rhythmic cycles of experience connect the human and the technical at an individual and cultural level. However, before elaborating upon my reading of those notions, I will contextualise the present research within the broader frame of my artistic and technical work prior to my doctoral studies. This will help us localise the origins of my interest in the issues discussed so far and will contribute to clarify the meaning of the argumentation which I will offer in this thesis.

The remainder of this chapter is structured as follows. The next section offers a succinct view on my prior work. In the next two subsections I will elaborate on the notions of technological body and sound as a vibrational force. That discussion will allow me to lay out the set of concepts which frames this research. Following this, I will introduce the research questions and then provide an outline of this manuscript.

1.2.2 Flash Back: Prior Work

As mentioned earlier, the present inquiry emerges from several years of artistic practice and technical development of new musical instruments. Here I want to give more details on the work prior to my doctoral studies so as to better contextualise the current research project. Although I started working professionally in the art world in 2004, the relation between body, sound and technology became an explicit focus of my practice in 2011, when I created the XTH Sense;[2] a DIY biophysical instrument which I have been using since then in my performances. The XTH Sense consists of an arm band containing an electret condenser microphone which captures acoustic

[2]See http://www.xth.io/

perturbations from muscle contraction (known as mechanomyogram), blood flowing, heart beating and any other kind of sound produced within the body. These sounds are digitised and sent to a computer software, coded by the author, where they can be live sampled in real time so as to modify their pitch, timbre, loudness and rhythm through customisable sound effects and digital signal processing (DSP) chains. The bodily sounds are particularly interesting for they are tightly related, at once, to physical movement, amount of effort and physiological processes. More importantly, in contrast with other kind of sensing devices which capture data to be later sonified through algorithms, the XTH Sense uses sounds from the body as the audio source of the musical composition. The sound world which can be produced via the XTH Sense is thus quite idiosyncratic and, in the case of my own work, it relies heavily on the use of the low frequency vibrations which can be captured from the body. Furthermore, the XTH Sense software analyses the bodily sounds in order to extract features, or high-level information, that reflect different aspects of movement, such as strength of a limb contraction, rate of strength over time, and so on.[3]

The reason why this is important is that my interest in the body (in combination with sound and technology) came about through my training with the XTH Sense. I do not have a training as a dancer, and everything I know about performing with one's own body I learned by training and performing with the XTH Sense for the past five years. In these years I have been creating a series of performances where I work through different concepts or artistic visions by using the XTH Sense in a variety of ways. The very first piece in this series is entitled *Music for Flesh II* (2011) and, technically, it is a piece of gestural music, electronic music composed and performed live through physical gestures (Donnarumma, 2012c). The piece is performed in a concert setting with a circular array of subwoofers and loudspeakers.[4] I wear two XTH Sense on my forearms and perform a series of gestures following a graphical score; this allows me to produce a sonic composition and manipulate it in real time. My interest in composing this piece was simply to create new kinds of sounds and to focus the audience's attention on the expressive nuances of the performer's body. The scenography for this piece is very basic, something which has gradually changed in the

[3]Because the XTH Sense is not the subject of the present research project I will not provide too many details here. However, I recommend the technically-inclined reader to look at my early publications on the subject, in particular (Donnarumma, 2011b) and (Donnarumma, 2011a).

[4]See http://marcodonnarumma.com/works/music-for-flesh-ii/

following performances. In *Hypo Chrysos* (2012), I began reflecting more consciously on the relation of the human body and technology through a particular interest in physical strain and effort (Donnarumma, 2012d). This is a twenty-minute action art piece using real-time processed sounds and live visuals.[5] I pull two blocks of concrete in a circle; the combined weight of the blocks is 50 Kg. Initially they are not extremely difficult to pull, but on the long run, the resistance of the my very thin body is truly stretched to the limits. My motion is oppressively constant for I have to force myself into accepting the pain until the action is ended. The increasing strain of the muscular tissues produces continuous bioacoustic sounds. Using the XTH Sense, the sound of the blood flow, muscle contraction bursts and bone crackling is amplified, distorted, and played back through eight loudspeakers. Data extracted from the bodily sounds 'excites' an OpenGL-generated swarm of virtual entities, lights, and organic forms diffused by a panoramic, high-definition video projector. The scope of the work is to transmit my own sensory alteration (provoked by the intense strain) to the bodies of the audience members. When the muscle vibration of my body becomes tangible sound breaching into the outer world, it invades the audience members' bodies. The intense sound makes their bodies resonate, establishing a direct link between player and audience.

As it should be clear from this description, in this piece I began developing an interest in the notion of the 'vexed body', likely due to my long-lasting passion for the early performance art of the 1960s and 1970s. I found a greatly inspiring field of exploration in thinking how strain, tension, conflict and struggle, intended both physically and psychologically, can become expressive means of interaction between the body, sound and technology, and how this kind of aesthetics can convey particular messages to an audience. Since the creation of *Hypo Chrysos* I have created a number of other performances and live installations,[6] and, with hindsight, I can say the interest in the vexed body is still vivid in my artistic practice. In the three years of my doctoral studies, I further developed this kind of theoretical, aesthetic and technical interest by engaging with a variety of issues, such as entrainment, sensory deprivation, psychic attunement, normative body models and fear of others, which constitute some of the notions at the core of the present thesis. I trust the details of the relation between

[5]See http://marcodonnarumma.com/works/hypo-chrysos/

[6]All my works are documented in detail at my online website, see http://marcodonnarumma.com.

my previous work and the present research will soon become apparent, but I do not want to spoil the pleasure of discovery by revealing too much just before starting.

1.2.3 The technological body

The notion of the technological body, together with the concept of sound as a vibrational force, form the backbone of this work. But what is a technological body? And why it is of interest? According to Chris Shilling (2005, 173), contemporary technology has moved inward. What he means is that, through technical methods and applied knowledge, technology has modified the body's organic properties by literally occupying its own space on and within it (Shilling, 2005). The term I take to indicate both this process and its physical instantiation is the technological body. Following Shilling (2005), we can provide a partial definition of the technological body as a human body that has been opened up to techniques of production.

However, after Shildrick (2013) and Iris Marion Young (2005), I want to stress that the notion of the technological body should not be taken to imply that all technological bodies are the same, that the form and nature of the body can be universally and absolutely defined. Whose body are we talking about? Is it the body of a man, a woman, a child, a transgender or intersex person, a differently-abled person, or any combination of them? And in which context is this particular technological body situated? The notion of the 'technological body' with which I will work in this thesis is that of a particular, gendered, and situated assemblage of human and technology, which can nonetheless serve to destabilise normative models of corporeality.

Furthermore, I see the technological body not as a condition, but as the current phase of a relationship between human and technology that can be traced back to the very beginnings of human life. Authors like Ortega y Gasset (1941) and Leroi-Gourhan (1964) argued that the human has always been technical, a notion that, after Jacques Derrida (1976) and Bernard Stiegler (1998), is known as *originary technicity*. The human, for Ortega, comes into being carrying a fundamental need to form itself, to realise its own existence rather than only satisfy its biological necessities. For this reason, Ortega y Gasset (1941, 116) argued, the human being finds itself forced to become an engineer and create the technical instruments that will help its full realisation. The role of technology, for Ortega y Gasset, is not much in the functionality of

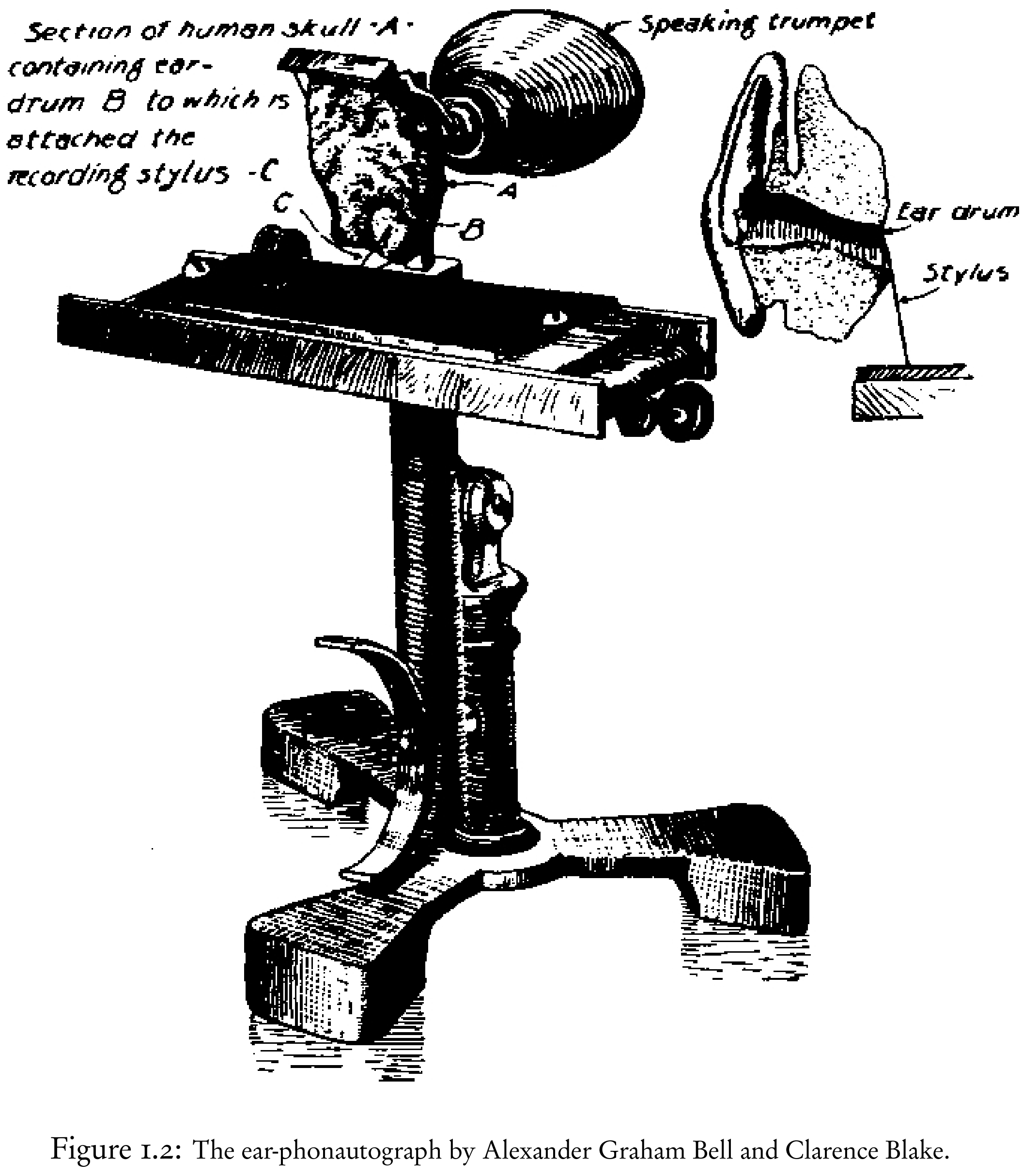


Figure 1.2: The ear-phonautograph by Alexander Graham Bell and Clarence Blake.

an instrument *per se*, but rather in its constitutive role in the formation of the human being. Leroi-Gourhan (1964, 80) traced the originary technicity of the human being in the nature of their embodiment. He noted that the ability of hand-grasping that characterises the bodies of primates and humans had originally come about with a concurrent development of their sensorimotor system. These changes in their embodiment, he argued (Leroi-Gourhan, 1964, 60), had enabled some species not only to learn how to build and use technical instruments but also to establish and evolve their social life on the basis of their technical skills.

This relationship between technology and human embodiment has evolved through a history of experiments where the parts of a human body and the parts of a technical object were put together to form experimental assemblages. The origin of many commonplace technologies can be traced in series of experiments were corpses were taken apart, not to consider the scientific knowledge acquired through human dissection as a medical practice. For the sake of the argument I will make one example. The telephone, or better, the communication of human speech through electrical wires which is at the base of many other telematic technologies, was created as a by-product of a series of machines originally designed to visualise sound (Ronell, 1989). Alexander Graham Bell, one of the many researchers working in the field of mechanical sound visualisation at the time, spent several years attempting to reliably visualise users' speech. His early experiments consisted of attaching a small wooden stick to the membrane of an excised human ear whose vibration traced sound on a piece of smoked glass (Sterne, 2003, 31). His hope was that his human-mechanical assemblage, called ear phonautograph (pictured in Figure 1.2), would be able to allow deaf people to see sound. In order to realise his experiments, he and his colleague Clarence Blake, systematically dug graves to recover corpses and take their ears apart (Sterne, 2003, 67-69). Although it may seem a rather unorthodox practice, this was instead a common practice for scientists around that time (*ibid.*).[7] It was then that the study of the body began to gain currency because scientists started drawing on the physical and physiological mechanisms of the body to create new technologies.

In the past decades the inverse process has taken place. Our bodies have been exposed to technologies that have actively altered our embodied being, and this has affected the cultural and political understanding of what it means to be human, as

[7] Although they would often employ others to carry out the task.

posthuman authors including Donna Haraway (1991), Katherine Hayles (1999) and Rosi Braidotti (2013) have argued. In their views, the increasingly intimate relation of the human body with technology enacts new kinds of relationships that take place at a material level and affect culture and politics (Braidotti, 2013). A few examples include the implementation of physiological sensors to examine electrical human biosignals; the storage and categorisation of the entire human genome heritage in digital database accessible via the Web; the use of DNA to perform computations in test tubes; and the creation of artificial organs to replace malfunctioning human organs (Figure 1.3). These are practical realisations of technological bodies. These technological bodies

Figure 1.3: The Jarvik-7 was the first artificial heart successfully implanted in a human body.

have cultural and political implications, for they encourage the commodification of human bodies (Braidotti, 2013) through the extension of methods of production of knowledge.[8]

[8]See also Sullivan and Murray (2009) for an analysis of this problematic from the viewpoint of queer studies.

Essentially, the technological body is the evidence that the human body is not as closed as a humanist view would have it, but rather it is open enough to take in technology in intimate ways which change its very own nature (Haraway, 1991). Particularly useful to my work is Hayles's take on this last point. She asserts that the material arrangement of electronic instruments with the human senses and organs creates modes of experience and expression that would be impossible otherwise (Hayles, 1999, 291). Following Hayles, in this work I will argue that the materiality of human-technology relationships, that is, their physical contact and exchange of informational data, enacts new corporealities in sound performance, new ways of experiencing and expressing sound and music. I will also stress that these new modes of experiencing and expressing sound through technology cannot be neutral, for they are inherently political. They are political because, as I already suggested, they are founded on methods of labour production and commodification of the human body. The essence of technology is to extend both work production and creative processes in ways that are rarely exclusive and mostly intermingled (Shilling, 2005).

The technologies used in music performance, as in all the arts, retain this essence. Hence, the technology an artist chooses, the relation of that technology to the production of labour and wealth, and perhaps more importantly, the way in which an artist uses that technology are inherently political. What I want to suggest with this is that it is the artist's responsibility to use technology in ways that extend it as a vector of creativity, beyond its labour-bound function. This means to be conscious that the configuration of a human body and a technology, what I have referred to as a technological body, has a political history and political implications. This involves societal models against which human bodies are assessed by institutional organisation, the uses of technology for the construction of social categories and accumulation of capital, and the way in which body technologies are designed and exploited to reinforce, undermine, or suppress certain kind of moral and ethical values. Recognising this endows artists working in technologically mediated music performance with the potential to change, reinforce, or weaken aspects of the cultural understandings of technology. This work rests on the assumption that the way an artist conceives of and actually uses a technological body in a public performance has a cultural and political value. It has a cultural value in the sense that it is the active means by which specific societal ideas, custom, and social behaviour related to technology are conceived and realised. It is political because it can be used to support or embody power strategies and initiate questions of social change.

By creating a range of methods that amplify, transform, or disrupt the relationship of performer and instrument, I will use the technological body as a critical artistic means to realise a culturally and politically informed approach to artistic performance. On one hand, I will use physiological tools to implement corporeal technologies for expressive sonic interaction. On the other, I will use analytical tools from philosophical and cultural studies of the body and technology to investigate the technological body, to understand how to define its corporeality. My approach is to inform technical implementation through theory and vice versa, to inform theory through technical implementation. As I already indicated in the beginning of this section, my approach will not rely on the technological body alone, but it will explore the corporeality of the technological body by deploying sound as a vibrational force (Goodman, 2009). Hence, the next subsection is dedicated to unwrap the notion of sound as a physical energy vibration. The following analysis, together with the arguments discussed above, will provide me with the full set of concepts needed to define the research questions of this project.

1.2.4 Sound as a vibrational force

For the human being sound is sound when it is either heard or physically felt. It is in our body that acoustic waves become a discernible event that we can feel, listen to, and define as a sound. From this point of view, sound is an effect of the human nerves caused by our perception. Sound does not however originate only outside of the human body, but rather the organs of the body themselves are a source of sound, a sound which can be amplified and diffused, as I have done in the performances that I will discuss later. The use of the sonic capability of bodily organs can be traced back to the early diagnosis methods of physicians. Auscultation is a medical method where a physician listens attentively to the sounds produced by mechanical and physiological processes of the body, like the sounds of heart and lung contractions (Figure 1.4). According to Jonathan Sterne (2003, 94), in the case of auscultation, sound acts as a sign which based on its qualities such as timbre, amplitude, and dynamics helps recognise specific pathologies, like closure of the heart valves or perturbations in the

Figure 1.4: *La Premiere Auscultation*, lithograph print by Felicien Victor Joseph Rops. In Le Medecine, no. 5, 1, March 1857.

lung's branching airways.

Auscultation shows how sound originates within the body, traverses the organs and emerges on the outside. But sound also moves in the opposite direction: from the outside it traverses body organs and reaches the cavities and fluids composing our inner body. Authors like Goodman (2009) and Henriques (2011) have investigated this material capacity of sound and its cultural implications. They have developed rich accounts of how acoustic waves, unlike any other energy waves, affect the human body at different levels, from intangible emotion arousal to physical induction of resonances, from pleasure to pain, and from stillness to dance. Henriques (2011, xv) suggests that, beyond our ears and bodily receptors, sound becomes a physical vibrational vector through which memories arise, pleasure is felt and meaning is expressed. When acoustic waves produced by machines or other human beings 'touch' our bodily organs through resonance, Henriques (2011) argues, a form of embodied expression takes place. What I want to emphasise here is that the vibrational energy of sound allows bodies and technologies to participate in the creation of embodied modes of expression. In other words, embodied modes of expression emerge from the configuration of human bodies and technologies which share vibrational energy.

The physical qualities of sound have not always been understood as an important aspect of human experience. As Sterne (2003, 94) notes, for centuries the human voice and music have been privileged over other instances of sounds, like the sounds produced by the body or the effect of sound on the body, whose recognition has largely derived from their construction as objects of knowledge in the development of acoustic and physiological technologies. The history of sound has developed through the coupling of human bodies and machines, Sterne (2003) outlines, and therefore is enmeshed with that of scientific and medical discovery. To elaborate on this point, I will come back to auscultation - the physicians' use of listening for diagnosis which I have introduced above - whose historical development is a good example in this sense. Although already in use centuries ago, as reported by Hippocrates (Rappaport and Sprague, 1941), it was not until the nineteenth century that body sounds, and the advantages of listening to them, gained more recognition across the scientific community thanks to the work of Rene Laennec (Sterne, 2003). Laennec invented the original stethoscope (Figure 1.5), an instrument that critically improved the reliability of auscultation, and which is still in use today. Before the invention of Laennec's

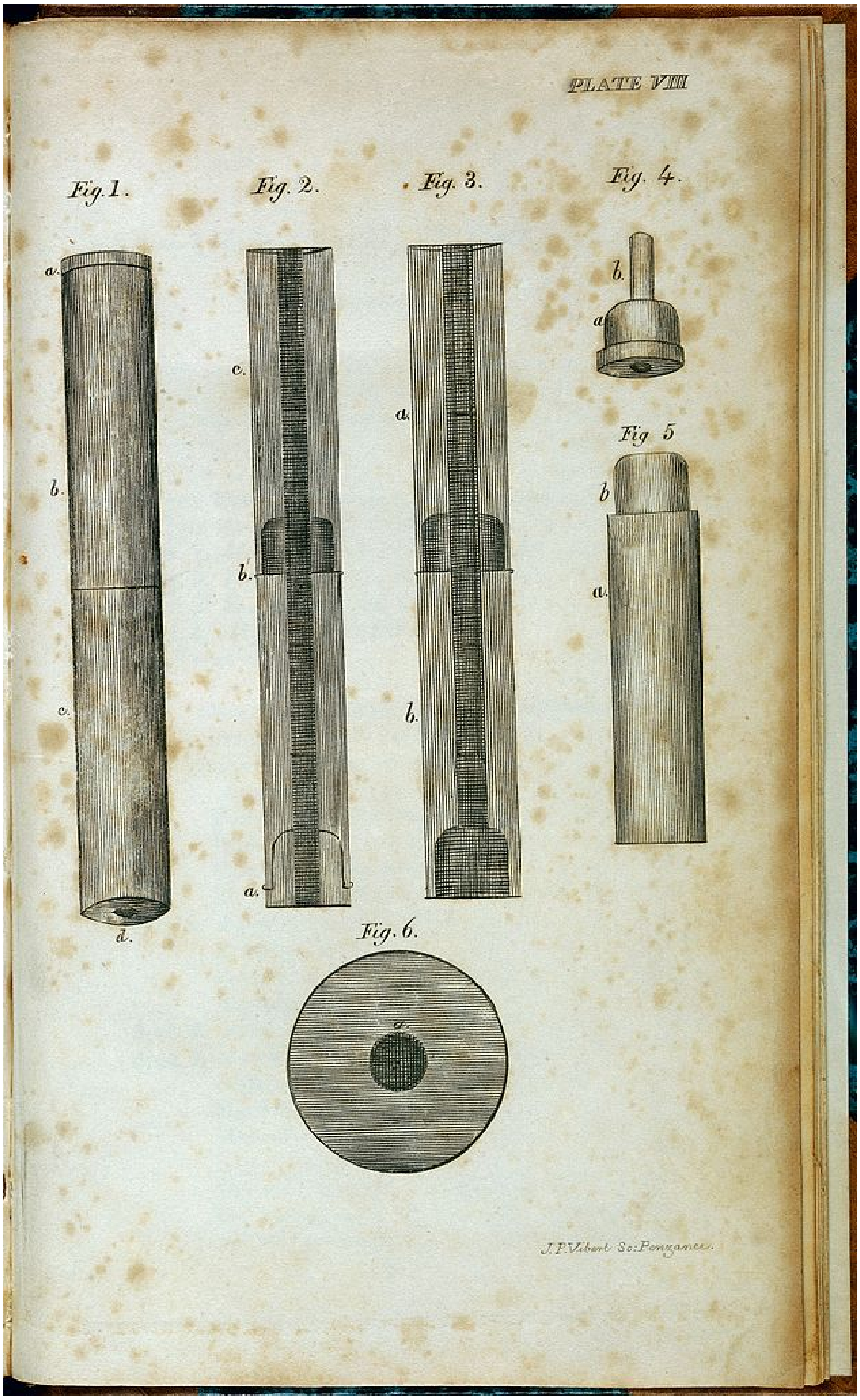


Figure 1.5: Rene Laennec's stethoscope in different views and angles, Rare Books..

stethoscope, physicians had to place their ear in direct contact with the patient's skin. One day Laennec found himself not able to precisely diagnose a heart disease due to the corpulence of the patient so he rolled a piece of paper and applied one end to the patient's body and the other to his ear (Rappaport and Sprague, 1941). He realised that in this way the body sounds could be heard much more clearly and distinctly than before and so developed a tool in the form of a wooden hollow cylinder to be placed between the physician's ear and the patient's skin (*ibid.*).

Despite the great efficiency of the stethoscope, it took a long time before the invention became accepted by prominent physicians (Sterne, 2003). This is because, according to Sterne, the superior effectiveness of Laennec's stethoscope had proved the healthy hearing of a doctor inadequate for the task. Physicians had to acknowledge that a technical instrument was needed in order to diagnose and properly treat their patients. Laennec's invention not only constructed sound as a scientifically valuable object, but also redefined the understanding of the healthy human body by showing its limits (*ibid.*). This reading of auscultation helps understand that sound, beyond its capacity to convey meaning, has material capacities that can inform a cultural milieu, as I already suggested earlier. It illustrates how the material interaction of sound, technology and the human body has the potential to produce new sociocultural experiences of corporeality; but it also shows that that potential may be hindered or blocked unless the new experiences of corporeality it produces become established.

The relation of sound materiality and corporeality deserves further discussion. What we perceive as an auditive stimulus comprises of just the tiny audible range of frequencies that the human ear can handle. Acoustic vibrations have a much richer spectrum that extends well beyond the human audible range. Goodman (2009) and Henriques (2011) suggest that the inaudible frequencies of acoustic vibration yield the capacity to affect physically and perceptually the human body, especially when those frequencies are manipulated and amplified through sound technologies and situated in particular contexts. Practical examples range from the repeated use in modern warfare of sonic booms (Figure 1.6),[9] whose extremely loud low frequencies induce a sense of fear and anxiety (Goodman, 2009), to the skilful song selection of Jamaican dancehall Djs, who play with frequency ranges to induce a sense of euphoria and flow (Henriques, 2011). These active encounters of human bodies and technologies

[9] The sound caused by the shock waves created by supersonic aircraft.

through acoustic vibration open up new conceptions of the quality of sound as a medium. Following Goodman and Henriques, I take that to understand sound as a vibrational force is to recognise that the whole range of material phenomena that acoustic vibrations yield produces physical, perceptual, psychological, and corporeal experiences. In other words, sound as a vibrational force is a vector of affect, which at a basic level is, after Spinoza (1677b), the relational capacity of a body to affect another. To understand sound as a vibrational force means to move beyond the limits of the symbolic meaning we associate with sound, and engage with the full range of *affective experiences* that acoustic vibration enables. Following Lisa Blackman (2012),

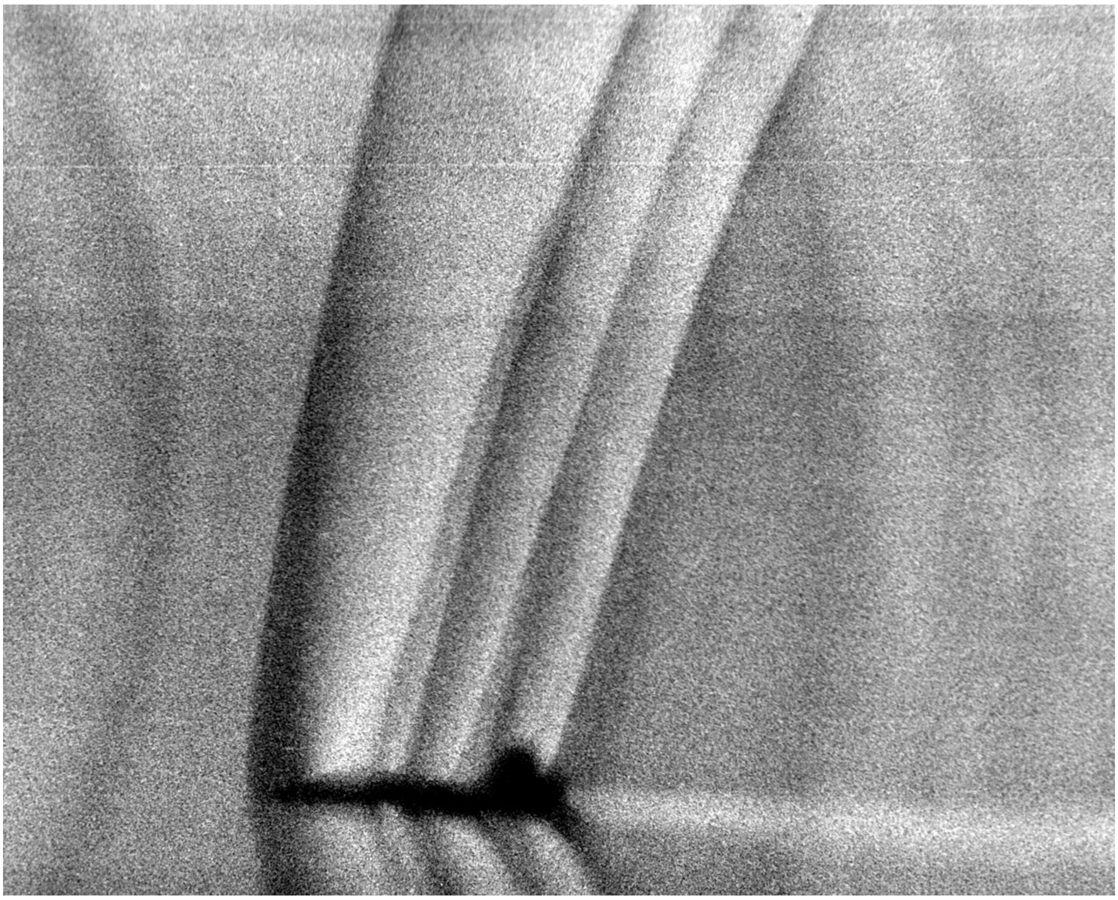


Figure 1.6: A picture took by Dr. Leonard Weinstein using a NASA-funded experimental device called Schlieren camera. The picture shows the shockwaves produced by a T-38 Talon aircraft on December 13, 1993 at Wallops Island..

an affective experience is a corporeal experience that emerges from complex, situated relations between the cognitive, the physical, the psychical, the conscious, and the preconscious. As such, an affective experience cannot be easily described or represented dialectically, but has to be actually enacted in order to be fully grasped. This understanding of affect - elaborated by Blackman and which I wish to develop further in this thesis - critiques and extends the views of those theorists who relegate affect to the role of either a pre-cognitive registering of sensations or an individual's capacity to affect another body. Drawing on Bracha Ettinger (1995), Blackman argues that affective modes of experience are not limited to the body they emerge from but rather move between human and non-human bodies and across space and time; in other words, they are trans-subjective, in the sense that they expands beyond the physical, psychological and temporal limits of an individual body and circulate across many bodies, spaces and historicities. For this reason, Blackman (2012) refers to these affective processes as immaterial.[10] Drawing on this analysis, I will argue for an understanding of a technologically mediated musical performance as an affective experience: an experiential event which comes forth through a negotiation between a technology and a human being in a particular context and time; a mediation performed through the vibrational force of sound which enables psychic attunement and forms of entrainment.

This allows me to bring this introduction to a close by linking back to my initial discussion of the performer-instrument relationship. In section 1.2 I suggested that performer and instrument form a performative assemblage, that is, they are corporeally arranged in particular forms to perform specific processes. In the remainder of this work, I will use the notions of the technological body and sound as a vibrational force to elaborate that idea further. I will research the ways in which musical expression emerges from a negotiation of affect (Spinoza, 1677b) in the form of the vibrational force produced and shared by the performer and the instrument. A negotiation which, I will argue, is possible because performer and instrument are corporeally fitted to each other, and so they inform and influence each other at a material level through the energy of acoustic vibration. They are corporeally bounded by it. This will be the drive of this investigation. Sound, in this work, will be not solely applied to artistic practice in virtue of its symbolic qualities. Here sound will be used to construct artistic interventions that affect the technological body by means of physical

[10] Each time I will use this term throughout the thesis, I will refer to Blackman's conception.

resonance and sympathetic vibrations. Sound will be used as an acoustic force, whose frequencies will be diffused literally in and out of human bodies and instruments to resonate them and let musical expression emerge.

1.3 Research questions

Now that we have explored the concerns where this research stems from, it is possible to concretely define the core research questions that this work will investigate.

Q1: How to think forms of technological embodiment in sound and body art performance beyond the dichotomy human-subject versus instrument-object?

Q2: How to use sound to create artistic performances which impact and heighten the sensitivity of both performer and audience to the cultural and political implications of the technological body?

Q3: And how can this particular kind of aesthetics extend our understanding of the relation between corporeality, expression and technology in sound and body art performance?

In the following section, I will elaborate on the research questions by providing an outline of this thesis. This will also provide an overall view of the research approach and the resources it will draw upon.

1.4 Dissertation outline

Chapter 2 will map out a selection of the key artworks that have investigated the relation among sound, body, technology and performance. An important criteria of this selection is the aesthetic nature of the artworks; they, each on its own terms, create challenging artistic experiences using elements ranging from intense bodily strain, sensory alteration through sound and light, and strategies for markedly physical performance and musical improvisation with computers. This cartography of artistic approaches will thus show the heterogeneous body of artistic ideas, aesthetic principles, cultural approaches and technical insight which this project rests upon. The review is sorted according to themes that I will identify across those works. The review will begin with two installations, respectively by Seiko Mikami (1997) and Christopher Salter (2012), where sound vibrations and light stimulations have been used to influence the visitor's perception in two different ways. This will lead to the use of biofeedback in music performance. Biofeedback consists of translating physiological signals into audible or visible responses that allow one to become aware of physiological mechanisms. I will discuss the use of biofeedback in the musical performances of Alvin Lucier (1976), David Rosenboom (1976), Manford Eaton (1971) and in the body art pieces of Stelarc (2015b) and Yann Marussich (2008). The review of their works will present different uses of electronic instrument and physiology for artistic experience. Whereas in Lucier and Rosemboom's works, the electronic instruments are driven by raw signals resulting from the performer's brainwaves, in Eaton's work, the instrument is used to provoke a state of sensory deprivation, in an attempt to control the physiological and perceptual processes of the participant. In Stelarc's suspension performances, biofeedback is used to sonify electrical signals of the performer's body as it is hung from the ceiling using hooks. On the other hand, Marussich's body art piece involves the performer sitting still in a glass box, while his body's internal thermoregulation is externalised by a blue chemical substance emerging from his skin. The analysis of these works will afford an understanding of how the use of physiological technology in musical and body art performance is bound to create a tension between controlling an instrument and being (relatively) controlled by it.

A concurrent aspect of this tension will be explored in the following section, where I will review the use of physiological signals in the gestural performance of electronic music. I will focus on the work of Atau Tanaka (1993b), who has used biosignals resulting from muscle contraction as a means to interact with musical hardware and software. This use of muscle signals is at the base of what he has described as a visceral interaction with the instrument (Tanaka, 2011), a notion that this thesis will expand further. This will guide the review to the work of George Lewis (2000), who has created and performed with an instrument, Voyager, that listens to the music played by a human performer and responds autonomously, either by imitating, opposing or discarding the musician's input. I will conclude the review by looking at the work of Stelarc (2015a) with prosthetic devices and that of Michel Waisvisz (2006b) with gestural controllers. They have used electronic instruments to extend, each on his own terms, the physical capacities of the performer's body. Although their practice is situated in different disciplines, the work of the former in the field of body art and that of the latter in electronic musical performance, they share, as we will see, an approach to electronic instruments in artistic performance as means for new modes of embodiment, where the corporeality of the interaction is paramount. To conclude this chapter, I will outline the aspects of the reviewed works that I draw upon and the research gaps that this investigation will fill.

Chapter 3 will deal with **Q1**: How to think forms of technological embodiment in sound and body art performance beyond the dichotomy human-subject versus instrument-object? To answer this question, I will review of a range of resources that afford an understanding of the cultural and political implications of the relationship of human bodies and technology. Specifically, the review aims to show how the materiality of this relation engender specific kinds of corporealities and affects. As any literature review which is aimed at connecting different resources towards the creation of a new viewpoint on a research issue, this review will be selective and constrained to the purpose of this research. It does not aspire to provide a fully exhaustive review on the topic. Rather, it will develop a particular understanding of human-machine relationships by drawing together specific notions from philosophy, phenomenology and cultural studies of the body; resources that I want to weave together also because of their importance in developing the artistic strategies that I will elaborate throughout the thesis. The resources I will discuss provide the grounding for the notion of configuration, which has a twofold role in this enquiry: on one hand, it is an analytical 'knife' to break down the relation between corporeality and computation; on the other it functions as a design template, a blueprint for my artistic works.

The literature review will necessarily result in some omissions and possibly bring forth debates on the choice of the resources. On the other hand, it is hoped, it will also provide as much openings as it can onto the related literature which, even though it does not directly contribute to this research, represents important material for the interested reader. The resources I will draw together have been chosen according to the following criteria: first, their ability to show the human body and technological instruments as unstable and incomplete entities; second, their capacity to provide a viewpoint where human embodiment and technological properties relate to and influence each other in positive and negative respects; third, their ability to engage critically and constructively with notions from natural science and cultural theory. With 'critically and constructively' I mean they can engage life science and cultural theory without reducing the human body to its materiality (physiological or biological processes), thus rejecting its capacity for affect, trance, and corporeal alteration; or rendering the body as an exclusively theoretical or discursive construct, dismissing thus its materiality.

Initially, I will look at the notion of human unfinishedness. I will begin by discussing the philosophy of individuation and the notion of technical milieu in the work of Gilbert Simondon (1992) and Bernard Stiegler (2011b). They elaborate distinct, yet interlaced views on the becoming of human being, a process of transformation that is fuelled by pre-individual potentials and co-constituted by technological instruments. Some of the limits of their work will be confronted via a critique by sociologist Couze Venn (2010). This will guide us to a discussion of some of the particular readings of threshold and rhythm in body theory. I will look at the distinct views of Brian Massumi and Lisa Blackman on the subject and then relate their views to the concept of rhythm and technical milieu in the work of Henriques (2010). In turn, this will lead us to examine how states of entrainment can emerge through particular, situated modes of listening in the context of rave and dancehall; these kind of 'peak' states, in contrast with conventional readings, arise through training and discipline, a form of becoming that, following Vinciane Despret (2004), I will call 'learning to be affected'. This will be a key concept throughout the thesis. Then, I will look at Deleuze and Guattari's argument on the nature of beings as stratified entities (Deleuze and Guattari, 1987), which resonates with and extend the previous resources. Here I will focus on their notions of expression and sensation and how they relate to rhythm and repetition in the process of human becoming.

This will bring us back to the core problematics of the technological body, its embodiment and its cultural and political stakes. I will conduct this analysis by discussing how posthuman authors, including Donna Haraway (1995), Katherine Hayles (1999) and Rosi Braidotti (2013), have elaborated their views on the matter. The take away message here will be the importance of technical incorporation in technological embodiment; or, how technology becomes part of the human body in complex ways involving physiology, experience, psychology and forms of attunement, and how this affects embodied practices. The discussion will be then extended by looking at the concept of cyborg; how from its roots in cybernetics and space travel (Clynes and Kline, 1960) it has evolved into a significant cultural components of society with a dedicated set of studies, including Haraway (1985) and Chris Hables Gray et al. (1995). In order to contrast some discourses on the cyborg which produce the technological body as an almost exclusively material body, I will look at the auto-ethnographic analysis of living with a prosthesis by feminist scholar Vivian Sobchack (2010). Her work, combined with observations by other feminist writers such as Margrit Shildrick (2013) and Gail Weiss (1999), will emphasise the role of lived experience and context in defining, altering or disrupting bodily integrity: the way particular kinds of human bodies experience and deal with changes in their condition through methods of incorporation.

Taking the cue from this analysis, the discussion will narrow down its focus to consider human embodiment, the human use of technology and the mediation of the two. First, I will conduct a phenomenological analysis of human's use of instrument through Maurice Merleau-Ponty and Shaun Gallagher's work (Merleau-Ponty, 1978; Gallagher, 2001). To confront their approach where the body is universal, ungendered and without age or physical diversity, I will call upon the feminist engagements of Shildrick (2002) and Iris Marion Young (1980). Their work will help us stress the importance to acknowledge that different kinds of embodiments require distinct methods of analysis which do not discard differences, but build upon them. This will be of particular importance as it resonate strongly with my intent to radically experiment with normative models of human embodiment through my own body and the bodies of others experiencing my works. The discourse on phenomenology will bring to the fore the issue of automaticity; pre- and subconscious mechanisms where one 'is moved' by an extra-personal force, which usually is identified with a technical instrument. I will discuss how this form of automatism blurs the distinction between self and others by looking at jazz improvisation (Sudnow, 1978; Berliner, 1994) and experimental psychology (Blackman, 2014; Solomons and Stein, 1896). In these cases, training to surpass certain threshold through sound, rhythm and repetition is key.

Finally, I will look more in depth at the mediation of the body, the technical instrument and the milieu in embodied practices. I will examine the theory of the embodied mind in the work of Francisco Varela and Humberto Maturana (Maturana and Varela, 1980; Varela et al., 1991); this is the capacity of human beings to know and make the world through their embodied nature and their use of instruments. Some problems with this theory will be confronted by drawing on the discourse on biomediation by Patricia Clough (2008) and Keith Ansell-Pearson (1999). Biomediation analyses how particular kinds of affective experiences emerge from the co-constitution of human and machine through biological media and new media.

In **Chapter 4** I will elaborate on the theoretical contribution of this research: an analytical device that I refer to as *configuration*, which stems from and extends the existing analytical tools discussed in the literature review. I will formulate some initial questions about the corporeality of the technological body. In our physical interaction with technology, are the capacities of our bodies the object or the subject of the action? In the combination of human bodies and technology at the level of physiology and biology, what happens to the expressive capacities of the body? To tackle these questions I will detail my use of the term configuration, which serves to think the technological body as an embodied ecology; a set of relationships that enable the human and the technical to form a living, psychological and cognitive body. A specific kind of configuration is determined by the modalities whereby the human and the technical affect each other, at a physiological, psychological, cognitive and experiential level. Multiple kinds of configurations can exist; they can take place as the result of a prior embodiment, or they can be created on purpose, in the sense that one can purposely configure human and technical parts into a new kind of body. In this research, I will use configuration to look at the ways in which human bodies and technologies can be arranged together to create new forms of embodiment, and how as a result alternative kinds of corporealities and affective experiences emerge.

To exemplify this understanding of the technological body I will describe my own configuration with a pair of hearing aids, battery-powered, electronic devices which improve (or better, alter) a deaf person's hearing and communication by amplifying particular range of sounds. I will discuss how I learned to listen again through the hearing aids and how the experience of my body, the space around me and sound, of course, has changed, giving me a new sense of embodiment as fluid, open and mediated. This discussion will provide us with the needed resources to define the main analytical features of the notion of configuration and the different ways in which a configuration can exist in sound and body art performance, what I call 'configuration modes'. This modes will draw upon the previously discussed notions of sound as vibration, flow or entrainment and automaticity and lie at the core of the artistic performance I have created. Configuration is not a theory of the world, but rather a specific analytic device I developed to analyse technological embodiment in sound and body art performance. Therefore, to conclude this chapter, I will analyse some of the limitation of the concept of configuration and how it provides some openings towards context of analysis which differ from the one I am examining.

Chapter 5 and **Chapter 6** will elaborate on **Q2**: How to use sound to create artistic performances which impact and heighten the sensitivity of both performer and audience to the cultural and political implications of the technological body? First, I will present two experiments, conducted with different collaborators, and the relevant findings. The experiments, after a process of translation which I will discuss, have been combined with the notion of configuration, and its theoretical grounding, to create two performative artworks, *Nigredo* and *Corpus Nil*. At a scientific level, the experiments contribute to extend the understanding of the link between physiology and expression in the fields of human-computer interaction and physiological computing. They also provide a toolset for the implementation of instruments which use sound to influence the perception of one's own body and sense aspects of gesture expressivity. However, the artistic performances move beyond the purely scientific contribution, by working through what exceeds the physiological body which is analysed in the experiments. *Nigredo* and *Corpus Nil* build upon a 'deep coupling' (Malina, 2006) of science, art and theory, a process which requires a careful translation of and critical reflection on the distinct methodologies of each discipline so as to understand differences, contrasts and modes of integration among them. The artworks resulting from this process use sensory deprivation, sound as a vibrational force and uses and abuses of the performer's body to establish forms of technological embodiment which displace normative models of the human body and its relation to technology. They help establish a corporeal bond between an instrument and a performer through the configuration modes of vibration, flow and automaticity. In so doing, the artworks provide insight into the use of configuration as a design template, a blueprint for the creation of sound and body art performances which forcefully provoke a questioning of the cultural and political implications of the technological body.

In each of these two chapters, I will first review the related experiment and summarise the results that are most useful to the research. I will provide references to the complete publications (attached in section D.1) where the format, protocols and results are detailed in their entirety. Then, I will reflect on how the experiments have informed my artworks, what the theory can speak back to the science, and vice versa, what the science can speak back to the theory. Finally, I will present the artworks, the related toolset and describe the experiences they offer. I will situate the artworks within the broader context of this research and then elaborate on the realisation process, including descriptions of the hardware and software systems, the composition of sound, light and haptic stimuli, and the lived experiences which they produce.

More precisely, in Chapter 5, I will initially discuss an artistic experiment that looked at the effects of low frequency vibration on the sensorimotor system. Then, I will consider the related artwork, *Nigredo*. This is a live installation for one visitor at a time, surround sound, light and high-power infrasonic transducers. In Chapter 6, I will describe three scientific experiments on the understanding of gesture expressivity through muscle sensing. This will lead to the presentation of the related piece, *Corpus Nil*, a solo performance for biotechnologies, surround sound and light. Throughout the sections describing each of the artworks, the reader will be invited to listen to audio recordings or watch videos that help detail particular aspects of the artworks. The audio recordings and videos, and further materials documenting the artworks, are included in the DVD attached to the back of this manuscript, and they can be found by browsing the folders named 'audio-samples' and 'videos'. The contents included in the DVD can also be found online at my personal website.[11]

In **Chapter 7**, I will tackle **Q3**: How can this particular kind of aesthetics extend our understanding of the relation between corporeality, expression and technology in sound and body art performance? Here I will discuss the artworks in the context of both the literature review and the core research question of the dissertation. Initially, I will re-state the core concern of my thesis and summarise the research questions. Then, the discussion will elaborate upon aesthetic, cultural and political implications of the performer-instrument configurations created in the two artworks. I will provide further answers to the research questions by examining four interwoven themes:

[11] http://bit.ly/1MgaxM7

a) the use of human bioacoustics as a medial energy that extends the capacities of both human bodies and machines; b) the understanding of physiological electronic musical instruments as organs of affect; c) the role of shared control and constraint in embodied musical performance with electronic instruments; d) the use of the performer's body as a material that can be sculpted through physical and vibrational force.

Chapter 8 will bring the thesis to a close by first, stating the contributions to knowledge offered by the research, that are: the analytical device of configuration; two sound-based performances which create particular configurations of a performer and an electronic instrument; a set of artistic and scientific experiments, and the related hardware and software toolset, which provide insight into the relation of vibration, self-perception, gesture expressivity and muscle sensing. Then, I will reflect on the genesis of the research and its limitations. The chapter will conclude with some final thoughts on the higher level implications of the configuration of technology and the human body.

Chapter 2

Key Works

2.1 Introduction

There is an essential difference between traditional and electronic musical instruments.[1] The former are originally made to play music. The latter are engineering constructs originally made to compute any kind of data. Only through specialised modification they can be used to play music.[2] This implies that a player's corporeal engagement with a traditional instrument is necessarily different than that with an electronic instrument. In the design of traditional musical instruments, the corporeal interaction of the performer's body and the instrument is a given. A player injects energy into the instrument, which in turn, responds by vibrating and so transmits energy back to the player's body in the form of physical vibrations and audible sounds (Hunt, 2000, 234). It is a corporeal bond that calls upon the trained motor skills, perception and intuition of the player, the physical affordances and musical possibilities of the instrument, and the auditive and haptic feedback of sound (Leman, 2008). Hence the centrality of the corporeal bond between performer and instrument to the conception, practise and analysis of traditional musical performance (Berliner, 1994; Sudnow, 1978; Godøy, 2003). In the design of electronic musical instruments, this is often not the case because their essential function is to compute input-output data flows. To them, the physical action of a user is a control input to be mapped to a variable output. Therefore, the capacity for corporeal interaction has to be explicitely embedded in an electronic musical instrument.[3]

This bears an important implication. The design and performance with electronic instruments is most often conceived on the basis of the degree of control that a performer has over the musical parameters of the instrument. As a result, the kind of corporeal engagement afforded by the physical interaction of performer and in-

[1]With the latter term I indicate instruments made of sensors, transducers, circuits and algorithms, as specified at the onset of this thesis. This is an important distinction in the context of the argument I am weaving here. My use of the term electronic musical instrument does not include electronic instruments such as analogue synthesisers for instance, because they generally lack physiological or motion sensors and computational capabilities.

[2]A process that Sergi Jordà (2005) has aptly called 'digital lutherie', or the development of techniques and strategies for musical performance with computers.

[3]If it is needed. In fact, one can play an electronic musical instrument with as little effort as a keystroke. I do not argue that a successful musical performance with electronic instruments only depends on how much corporeal interaction they afford. Here, I focus on corporeality because it is the core subject of my own investigation on, and artistic approach to, musical performance.

strument is often overlooked. This is evident in the fact that the (ongoing) debate on the nature of electronic musical instruments has been consistently approached from a control-based perspective. Pioneers such as Richard Moore, David Wessel and Matthew Wright have argued that electronic musical instrument cannot be played as traditional instruments because they struggle to provide the level of intuitive and physical control that traditional instruments offer (Moore, 1988; Wessel and Wright, 2002). On the other end, innovators such as David Rokeby, Christopher Dobrian and Daniel Koppelman, have stressed that electronic musical instrument should be designed to give away some of the control they offer (Rokeby, 1985; Dobrian and Koppelman, 2006). Either way, a perspective that posits a focus on corporeality is rarely adopted in this debate. This research aims to fill this gap.

I will start by mapping out the key artistic approaches that have focused on corporeal engagement in technologically-mediated sound performance and performance art. In addition to the sound-based works of Mikami, Salter, Lucier, Rosenboom, Eaton, Tanaka, Lewis and Waisvisz, this review will include the technology-informed body art performances of Stelarc, Marussich, Marcel.lí Antúnez Roca and Orlan, which are not primarily based on, or do not use at all, sound. This will allow to extend the pool of ideas and themes that my own work will draw inspiration from. The review will serve to make the reader familiar with some of the artistic strategies and aesthetic principles that I have repurposed and extended in the realisation of my own artworks, which are examined later in chapter 5 and chapter 6.

At the onset of the review, I will discuss the works of Mikami and Salter where the interaction between visitors and instrument relies primarily on perceptual stimulation through sound and vibrations. Their works explore, with different aesthetics, the threshold of perception and its role in the creation of technologically-mediated immersive experiences. In Lucier's and Rosenboom's biofeedback works, the musical instrument is influenced by the fluctuations in the performer's brainwaves that may be intentionally provoked, but are not completely under the performer's conscious control. A different, yet related approach is that of Stelarc and Marussich, where biofeedback is used not as a process to be intentionally modulated by the performer, but as a means to make tangible the inner activity of the performer's body who, from external view, is still. Tanaka's performances with the Biomuse are characterised by an interaction where the instrument is played through evident physical gestures as well as through the articulation of muscular force. Using muscle biosignals for gestural interaction implies, for Tanaka, to acknowledge that the noisiness of those signals may produce glitches and imperfection that are integral to musical expression. Tanaka's questioning of the notion of an absolute control of the performer over the instrument will be then extended by reviewing Lewis' work. His work with digital algorithmic 'players' will help detail a notion of musical interaction with electronic instrument where sharing the stakes in the outcome of the piece between the performer and the instrument affords for rich musical expression. Lewis' work is of particular importance to this research for its explicit political take of human-computer interaction in musical performance. Being African-American and fully conscious of issues of racial hate, his technical and musical work explicitly attacks the Western stereotypes of technological control and the homogenisation of interactive technologies for the sake of the normative 'white man' model. A view that I share and which is embodied, in different ways from Lewis, in my two final artworks. I will discuss his political view in this chapter and extend it throughout the thesis.

Having elaborated on a view of musical performance where a certain degree of control over the musical outcome is shared with the instrument, I will look at works where technology has a high degree of control over the performer's body. I will review the works of Stelarc, Marcel.lí Antúnez Roca and Orlan who, using a range of technologies including an exoskeleton, pneumatic devices and cosmetic surgery devices, have focused their investigation on the drastic alteration of their own bodies. Taking the cue from the use of prostheses in live performance, the review will then discuss the work Waisvisz, who has extensively performed with a set of custom handheld gestural music controllers. His work will help us constructing a perspective of electronic musical performance where music is the result of an intuitive, physical process of engagement involving performer and instrument. Crucially, his work is important to this research for its emphasis on error and miscalculation as integral aspects of human-computer interaction for musical expression, a view that I will elaborate further in the theoretical literature review (see section 3.3). This selection of artistic works offers a diverse combination of artistic strategies, technologies and objectives whose development have been informed by multiple scientific and cultural milieux. What they share is an underlying understanding of the arrangement of technology and the human body as means to extend artistic expression.

2.2 Sounding the Body Out

2.2.1 Listening to Vibrational Matter

In Seiko Mikami's *World Membrane and Dismembered Body* (1997) the sounds of the heart and lungs of a visitor laying on a clinical bed inside an anechoic chamber are

Figure 2.1: The première version of Mikami's installation *World Membrane and Dismembered Body*, as exhibited in the permanent collection of ICC-InterCommunication Center, Tokyo, 1997.

captured with a stethoscope, amplified, manipulated and diffused in space with a certain time lag (Figure 2.1). The internal bodily sounds are turned into parameters that drive the digital manipulation of the sounds themselves and their spatialised diffusion. Additionally, the sound parameters are visualised through a growing abstract net which is projected onto the walls of the chamber. Mikami (1997) has not reflected on the use of visuals in her own writings on this work, meaning perhaps, that the visuals were not a significant component in the piece from her point of view. She has instead largely discussed the role of the sense of hearing as an interface with the instrument. Given the lack of available information on the visual aspect of the work, I will also focus on the role of sound in the installation to be faithful to the artist's interpretation of the piece.

As Sabu Kohso (1995) notes, the formation of the visitor's perception and understanding of the work corresponds to the formation of the acoustic and visual environment. It is not a simple correspondence though. Throughout the duration of the installation, the development of the visitor's subjectivity and that of the environment are interfaced, they affect each other through sound. The ear acts as a 'perceptual link, or code, between the acoustic sense and the space of the room' (Mikami, 1997). Through the ear one grasps the actuality of her own body as a constitutive part of the environment. This is possible because the body, the instrument and the ear are linked to each other by the bioacoustic matter. The body is a sound source. The bioacoustic vibrations of its organs provide the instrument with sonic material. The instrument then digitises those vibrations, it makes them virtual so that they can be digitally processed. Once the manipulation is complete, the digital sounds are converted back into the analogue domain and diffused in the anechoic chamber. As they are diffused, the ear perceives them as external stimuli. The time lag between the original sounds and those diffused in the room is important, for it creates an offset which confuses the visitor's understanding of those sounds as originating from her own body.

Still, a minimal variation in the heartbeat of the visitor, in the attention level of the listener, or in the reflection of a sound wave in the space is bound to alter the experience in a feedback loop. The construction of corporeal perceptions through the exchange of acoustic energy is the expression of those elements' existence in that moment, in that 'now'. For Kohso and Mikami, the simple fact that a heart is beating and a stethoscope is capturing it, the status of the body being alive and the machine functioning, is an expression of their being. It is this observation that, Kohso (1995) argues, makes one realise that 'we have always been instruments, even before listening to any sound'. In the moment when the sound of one's own heartbeat strikes the hearing as a sound diffused from outside the body, one realises it is the body that has produced it and there is no way of stopping it. One cannot stop the heartbeat, nor can close the ears. It is the 'most fundamental form of self-expression' (Mikami, 1997), it originates from a pre-conscious and necessary beating and it reaches the conscious and inevitable hearing. A perceptual feedback loop is enacted, one that can only exist through the configuration of the human body and the machine by means of sound. The eye cannot see one's own heart beating, and even if it could, the eye could close at any time, interrupting the loop. Listening is the only entry point to the perceptual experience of an altered self.

2.2.2 Playing with Perception

In the work *Just Noticeable Difference* (2010), Chris Salter addresses a theme similar to Mikami's installation. Salter's work explores the way one perceives slight changes in the intensity of tactile, proprioceptive and cross-modal stimulation, and what consequences this has on one's own perception of the body as it exists in space (Salter, 2012).[4] Proprioception is the sense of limbs position and movement effort. I will discuss proprioception in depth later in subsection 3.4.1, for it is a significant element in my work.

JND is a box-like structure, an 'installation-environment' where near darkness, sound, tactile vibration and colour-changing light are combined to explore different perceptual thresholds. Upon entering the box, a visitor is led through a door which opens onto the inner space of the structure. Here the visitor lays down on a custom made floor which is embedded with twelve full-frequency exciters, transducers that transform audio signals into mechanical vibrations of the floor. The movements of the visitor's body are captured by pressure sensors embedded in the floor surface.

[4]The use of haptics, that is, tactile and proprioceptive feedback, in interactive music was pioneered, among others, by Claude Cadoz et al. (1984), at a time when the exploration of real-time digital audio synthesis was in its early phase. In the context of his research into physical gesture and new musical instruments, Cadoz created The Cordis Simulation System. This captured physical gestures via force and position sensors and reacted to the player by providing haptic feedback; subsequently, it used gestural information to synthesise sound via an algorithmic simulation of physical sound producing mechanisms. The research into haptics for interactive musical performance has developed further in electronic musical performance (Bongers, 1994; Gillespie, 1992; O'Modhrain, 2000), with fundamental contributions by Bill Verplank et al. (2002), and concurrently in virtual reality (Srinivasan and Basdogan, 1997) and human-computer interaction (see MacLean (2008) for a review and Lopes et al. (2015) for more recent work).

Differently from Mikami's work, Salter's *JND* is based on a fixed composition. Multimodal stimuli are scripted in advance. The body motion data is used to subtly affect a composition of vibration, sound and light that takes place beneath, above and around the visitor. There is not a feedback loop between the instrument and the visitor, rather the instrument performs a composition, which the visitor can slightly influence. The instrument and the performer are linked through the multimodal stimuli, but remain technically and conceptually separated.

According to Salter (2012), those who participated in the installation in one of its early public presentation have vividly reported specific sensations and feelings, including changes in the perception of their bodily weight, pleasure, fear, disorientation and trepidation. Salter reports that some visitors said to have experienced visual and aural illusions, and sometimes hallucinations, which are likely due to the motion, amplitude and timbre of the vibrational impulses. More important for Salter were the accounts of different proprioceptive experiences that some participants reported, like an increase of the body volume in space and the sensation that the body was floating in space. The subtle acoustic and light frequency stimulations performed by the architectural system of *JND* excite the mechanoreceptors of the visitors' bodies. These are the sensory nerve ending that produce responses to internal or external physical stimulation and light stimulation. The stimulation of the mechanoreceptors heightens the perceptual link between the body and the system itself. Whereas the reactions of the audience are likely conditioned by the small size of the space and the complete darkness inside of it, they are useful in understanding vibration and light as a means capable of significantly affecting the perception of one self and the space. Beyond what one listens and sees, sound and light become, in Salter's work, affective vectors, in that they directly affect the visitor's perception of their own bodies and the space surrounding them.

Whereas Salter's work has some similarities with Mikami's work in terms of their shared interest in how technology affects human perception, there is a difference between them which is worthwhile to emphasise. In Mikami's installation, the stimuli produced by the instrument are directly influenced by the bodily sounds of the visitor in a feedback loop. This enables an exchange of affect, meaning that both instrument and performer influence each other's capacities by means of the vibrational force of sound that they exchange. Differently from Mikami's work, the kind of affect produced by *JND* is not relational, but rather it is a kind of controlled affect. In *JND* there is not an exchange between the performer and the instrument, but rather the instrument influences the visitor's perception without being significantly affected itself.

2.3 Biofeedback in Performance

2.3.1 The Sound of the Electric Body

Biofeedback is a medical technique defined as a process that enables the active regulation of one's physiology. The process consists of representing a patient's physiological mechanisms in an audible form (sonification) or visible form (visualisation), so that the patient becomes aware of the body physiology and can attempt at actively regulating it.[5] Biofeedback was developed around the late 1960s[6] in the context of cybernetics. This is a science that, cutting across different disciplines, investigates a diverse range of topics concerned with the behaviour of human and non-human beings and technologies (Wiener, 1948). Most notably, the major research areas of cybernetics are causality and automation manifested in technological developments, and the role of self-reference in epistemology, that is, the study of what knowledge is, how it is acquired and the extent to which knowledge of a certain subject matter can be acquired. I will come back to cybernetics in more detail in the next chapter, when discussing the cyborg.

Initially, biofeedback techniques were implemented by a group of neuroscientists and physiologists as a means to study the human body as a cybernetic system (Miller, 1967; Kamiya, 1969; Peper and Mulholland, 1969). Guided by an interest in testing the possibility to achieve a stable, self-regulated physiological state, biofeedback scientists focused on the study of brainwaves, recorded by means of electroencephalography or EEG, and the activation of alpha waves by trained patients.[7] As elaborated by Bran-

[5]Today there exists a wide range of biofeedback systems that can be purchased by consumers and practitioners alike. I rather not to provide links to commercial products here, but refer the reader to consult the exhaustive information offered by the website of The Association for Applied Psychophysiology and Biofeedback, Inc. at http://www.aapb.org.

[6]The Biofeedback Research Society was formed between 1969-1970, and its first meeting was held at the Surfrider Inn in Santa Monica (Moss, 1998).

[7]Alpha waves are brainwaves at a specific frequency that are generally associated with a meditative

den W. Joseph (2011) this research was largely developed in the United States thanks to a policy of funding, which, throughout the Cold War, explored the realisation of tools for 'mind control' (Delgado, 1969). Within this scientific and cultural context, artists and researchers reappropriated biofeedback techniques to envision new musical applications (Joseph, 2011, 14).

The American composer Alvin Lucier was among the first artists to use biofeedback equipment in a live performance. His *Music for Solo Performer* (1965) was a concert for a large percussion battery activated by the composer's brainwaves, electrical signals produced by the brain. Lucier recounted (Lucier, 1976, 60) how the idea for the piece came in 1964 from a conversation with Demond Dewan, a researcher for the Air Force Cambridge Research Laboratory in Bedford, Massachusetts. Dewan was investigating brainwaves in relation to aircraft pilots' dizziness, blackouts and epileptic fits. He was an amateur organist and shared his equipment and ideas with Lucier to explore the musical capabilities of biofeedback. Lucier began working on a musical composition at the Electronic Music Studio of Brandeis University, Boston, Massachusetts. Lucier (1976, 61) was moved by the fact that a human being, by sitting motionless and merely changing states of visual attention, could modulate large amount of equipment with what he thought of as a 'power from a spiritual realm'. Thus, rather than only recording the brainwaves and modulating them with tape devices, he developed a musical strategy that used the EEG electrical signal as 'an active force' that physically resonated cymbals, gongs, bass drums and timpani.

During the première of the piece on May 5th 1965 at the Rose Art Museum (Brandeis University),[8] he sat motionless on a chair in the centre of the stage, his head covered with electrodes. He was surrounded by a battery of percussions, each coupled with a loudspeaker. The biofeedback system captured his brainwaves and, using a frequency-based threshold switch, it detected and amplified his alpha waves (Lucier, 1976, 61). The waves were then diffused through the loudspeakers to the percussion's skin and caused the percussion to resonate. In addition, alpha waves were used as a modulation signal to drive a tape recorder where pre-recorded alpha waves were stored, pitch-transposed and played back (Lucier, 1976). By varying the duration of

or sleeping state.

[8]It is interesting to note that American composer John Cage encouraged and supported Lucier during the composition and the première of the piece.

the alpha waves and using different layout for the placement of the loudspeakers and the resonant objects, Lucier was able to produce a variety of sound forms. Resonating with Mikami's work discussed earlier, in Lucier's performance sounds emerged from the interplay of physiological signals, mechanical triggers, and resonant surfaces, while conserving the 'natural physical quality' that characterised the EEG signal. Differently from Mikami's installation, here the interplay of those components occurred through the material connection among them. The performance enacted a material process of cause and effect between brainwaves, amplification circuits, mechanical hammers and percussions, thus creating a material relationship between the performer's body and the instrument.[9]

Influenced by cybernetics and experimental psychology, another well known American composer, David Rosenboom, began experimenting with biofeedback techniques in the late 1960s. Rosenboom was interested in using the rhythm of alpha waves to both produce music and explore music perception. Specifically, he experimented with altering the states of consciousness associated with music performance (Rosenboom, 1990, 10). His first piece, a participative performance entitled *Ecology of the Skin* (1970), amplified the brainwaves and heart signals of a group of up to ten participants and used those signals to modulate the processing of keyboard sounds played by distinct performers (Figure 2.2). The participants could modulate the audio system by producing alpha waves (Rosenboom, 1976, 15). The alpha waves were monitored using a miniaturised alpha detector, created by Rosenboom, and fed to a small computer logic system (Digital Equipment Corporation K-Series Module). This counted the amount of time that each participant spent per minute producing alpha waves and produced a control voltage which corresponded to the value of the count each minute. The control voltage was used to modulate the sounds produced by the synthesisers. The participants thus could not directly control the modulation of sound, but rather, they could attempt to provoke fluctuations of their brainwaves and heart signals to influence the composition.

The experience consisted of ten separate sound textures, where each was modulated by the alpha wave reading of a single participant, and a diffused monochromatic

[9]Lucier had imagined to extend his musical system to create whole environments including televisions, radios and lights, but he left the research on biofeedback to work on echo location and resonant characteristics of rooms, a research that eventually resulted in his most well known piece *I am sitting in a room* (1969).

Figure 2.2: David Rosenboom setting up participants in the performance/installation event, *Ecology of the Skin*, at Automation House, New York City, 1970.

blue light, a colour chosen by Rosenboom for its capacity to stimulate phosphenes. Twenty stations equipped with electrodes for electronic stimulation were also available in the space. By physically interfacing brainwaves and other bioelectric signals with analogue sound devices, the process of actively modulating one's own physiological states constituted a means of mediation between the participant's bodies and the instrument. The experience was emergent from the encounter of bioelectric signals, sound technology, and human bodies. In his early writing, Rosenboom considered biofeedback not only an aesthetic medium, but more importantly, a means to 'elevate' the human condition. In his seminal book *Biofeedback and the Arts, Results of Early Experiments*, he has argued that the body is an entity split between the lower materiality of the physical body and the higher mind (Rosenboom, 1976, 3). At the time, his view was that, on one hand, there is the physical body and its physio-electrical signals which can be measured and assessed with scientific rigour; on the other, there is the intangible mind that an individual can access and enhance through biofeedback in order to move beyond the limited condition of 'homo faciens' - man the producer - and become a 'homo sapiens' - man the thinker (*ibid.*). This kind of reflections on biofeedback as a means of elevation of the human condition do not appear in his more recent works,[10] however it is interesting to note the vigour of his thought at the time as it is a reflection of the particular cultural context in which he worked.

The correlation between biofeedback, music and psychology of mind control outlined at the onset of this section, is more evident and ambiguous in the work of another American researcher and musician, Manford Eaton. In his 'bio-music' experiential music systems (Eaton, 1971), participants were administered controlled sensory bombardments including sound, light and electromuscular stimulation. His work was informed by the postwar research on physiological and psychological experiments with sensory deprivation, hallucinogenic drugs, hypnosis and electrical brain stimulation that had been of great interest to the CIA in the previous decade (Joseph, 2011, 13). Eaton's early interest in musical biofeedback slowly grew into a research on subjective musical experience as a negative issue to overcome. In his article, aptly entitled *Induce and Control: Bio-Music is Here Today*, he explained that the subjectivity of listening, the capacity of each human being to respond differently to music, is an obstacle to the transmission of ideas from one person to the other (Eaton,

[10] See for instance (Rosenboom, 1990)

1973). Thus, his bio-music systems were implemented to force all listeners to have the same response to his musical compositions by stimulating their bodies electronically through biofeedback.[11]

Eaton explored the possibility to control the psycho-physiological states of a subject through different technologies (Eaton, 1973). A simple system included strobe lights and white noise generators controlled by the subjects' heart rate while undergoing light electrical shocks. A more complex system involved the subject laying on a medical bed, wearing arm cuffs and eye cups to stop recognisable external stimuli, a helmet with earphones which played white noise at a very high volume and an overhead strobe light. Eaton would occasionally talk to the subject from an adjacent room using a microphone while observing the experiment from behind a one-way mirror. The subject was 'saturated' with 'maximal' audio and visual stimuli with the goal to provoke controlled feelings of ecstasy and anxiety as intermissions between one musical piece and another. Sensory bombardment is used as a means to cleanse the perception channels before musical input is fed to the earphones.[12]

The experimentations with biofeedback in music performance by Lucier, Rosenboom and Eaton bring forth an important argument for the present work. Namely, that interfacing physiological signals with technological systems allows for musical experiences where the performer's body is not in control, but rather is engaged with the system at a visceral level. It is a level of engagement where the line between conscious and unconscious thought, between flesh and circuits is blurred and novel modalities of expression occur. They also show how thin is the line between the use of physiological technology for artistic experience and sensory enforcement.

[11]The parallel with the controlled emotional responses produced by the 'Synthetic Music' concerts of 'sexaphones' and 'scent orchestras' portrayed by Aldous Huxley (1955) in his vivid dystopian novel *Brave New World* is so striking to make one ponder whether Eaton's took inspiration from Huxley's fictional world for his experiments.

[12]Today, about forty years after, the use of extremely high sound levels, in combination with light and electrical stimulation is largely used in contemporary warfare (Joseph, 2011). Highly specialised torture techniques involve maximal music levels used in conjunction with isolation and deprivation of recognisable stimuli to induce the prisoners' bodies into states of disorientation and loss. The ultimate goal being to gain control over both strategic information and the freedom of subjectivities. The resemblance of techniques and scope between Eaton's sensory bombardments and contemporary torture techniques can be striking. Yet, it should not take by surprise given the shared research interest of biofeedback studies and Cold War CIA programs explained above. It is important to outline that Eaton has consistently discussed his work exclusively in terms of artistic research.

2.3.2 The Reorganised Body

Whereas biofeedback music was dedicated to the modulation of human aesthetic and cognitive experience, biotechnological performance art extended the scope of biofeedback techniques to impact the human body. Performance artists used disruptive methods to alter the body biophysical processes, and thus put in evidence the potential of the human body to be reorganised into new modes of embodiment. An example in

Figure 2.3: *Sitting/Swaying*, event for rock suspension by Stelarc, Tamura Gallery, Tokyo 1980.

this sense is found in the body suspension performances that Stelarc performed during the 1970s (Figure 2.3). Stelarc recounted the genesis of the project in an interview by Linz (1992). The earliest suspensions were accompanied by tape music, but he felt that the medium was not integrated enough in the performance. He was aware of the biofeedback research developed in the U.S. and spreading worldwide, and so decided to use biofeedback methods to capture signals from his suspended body and diffuse them in the room in the form of sound. During a performance in 1972 at the Pinacotheca gallery in Melbourne, Australia, Stelarc's body was suspended from the ceiling using ropes and metal hooks that pierced his skin in a carefully designed layout. His body hanging in mid air was counter-balanced by a ring of rocks, his skin and flesh displaced by gravity, as they were malleable objects. A few 1.5-2cm needle electrodes inserted in his flesh captured electrical signals from the muscles, while brainwave and heart rate signals were amplified and diffused in the form of sound (Linz, 1992).

In Stelarc's suspensions with needle electrodes, the way how the technology was used allowed the emergent processes of his body to become evident as they were, a display of what it takes to defy gravity. The epidermal and physiological tension of the bodily tissues was evident through the stretching of the skin, the small amount of blood emerging from the wounds, the still rocks hanging in mid air and the body signals amplified and diffused in the room. The constant physical tension that the body was experiencing became its expression. To an external observer Stelarc's suspension event was a 'gravitational landscape' (Atzori and Woolford, 1998), a sculptural and sonic landscape where gravity was used unusually. To the suspended performer, the physical body was an active site of reflexive experience. As suggested by the frenetic sounds that from the performer's body were diffused in the room, the suspended body was not still. In order to defy gravity and resist its destruction, the body had to adapt its internal processes to the tension of the hooks by shifting across force states. The body was not in one state nor the other, but rather constantly undulating in a 'suspended animation' (Massumi, 2002).

The awareness that a body which is apparently still is always bearing an inner mobility enables us to see movement as more than a translation in space; in this view, movement is also a corporeal and physiological process that makes the body shift across states. It is through the configuration of the fish hooks, the skin, the needle electrodes and the amplified signals of the performer's body that the movement within the body becomes something perceivable. This viewpoint on the inner mobility of the human body provides an interesting contrast with Eaton's work, described in the previous section. Whereas Eaton's bio-music systems are based on the premise that, by immobilising and isolating the visitor external stimuli, one can enforce certain kinds of emotions and feelings, in Stelarc's suspension the immobility of the body is used to immerse completely the performer in the experience and to highlight the immanent activity of the body's physiological, perceptual and cognitive functions.

Swiss dancer and performance artist Yann Marussich also explores the notion of movement as the inner activity of the body. In 2007 at Galerie Guy Bärstchi in Geneva, Switzerland, he presented *Bleu Remix*, a performance that explored the idea of choreography as a 'pre-movement that is written down in the body' (Marussich, 2008). Ahead of the performance, Marussich had medical staff inject methylene blue in his body,[13] and then he sat still in a glass box before the audience for one hour. During the performance, Marussich did not move. Rather, using thermal regulation and a carefully prepared timing, he enacted a 'motionless choreography of methylene blue' (Hauser, 2008). Because of the increasing high temperature in the glass box, the performer's body initiated a process of internal thermoregulation. This process, called acclimatisation, decreases the body temperature through evaporative cooling at the skin surface.

Normally, this results in a transparent liquid mix of water, minerals and urea emerging from the skin, but because the performer had methylene blue circulating in his body, the bodily transparent fluid was mixed with the coloured substance, which resulted in his body sweating a blue liquid. The bodily effort of the performer in resisting the lack of air and the increasing temperature inside the box was made visible. The reorganisation of his body by means of artificially-induced biochemical reactions made his bodily effort clearly evident (Hauser, 2008) through the secretion of the blue methylene. What concerned Marussich was not how to express psychological states or externalise cognitive processes, but rather to reflect on the notion of presence (Hauser, 2008), the feeling of being present in a world outside of one's own body (Riva, 2008). The reorganisation of his body biochemical condition allowed to externalise before an audience the 'continuous inner state' (Marussich, 2008) of his body, thus emphasising the complementarity of evident stillness and inner mobility in the perception of presence.

Stelarc's and Marussich's performances offer a viewpoint that lies at the core of the current investigation. It is both an aesthetic and technical perspective where sound, machinic and physiological technologies yield the capacity to reorganise the human body by disrupting its natural processes. This is a further element in support of the

[13]Methylene blue is a chemical compound used mostly in the pharmaceutics industry, which presents a dark blue colour. It is prepared by treating dimethyl-4-phenylenediamine with hydrogen sulfide dissolved in hydrochloric acid, followed by oxidation with ferric chloride.

notion that the coupling of human and technological bodies at the physiological level can extend, hinder or alter the conditions of human embodiment and thus enable alternative modalities of expression.

2.4 Playing Beyond Control

2.4.1 Visceral Interaction

In the mid 1980s, two researchers working with physiological signals at Stanford University, Benjamin Knapp and Hugh Lusted, created the Biomuse (Knapp and Lusted, 1988). The Biomuse was a gestural device that, using medical grade wet-gel electrodes attached to the skin, captured electrical discharges from the neural activity and limb muscle tension of the performer. The body signals were then transmitted to a digital signal processing (DSP) chip that output user-programmable MIDI events as a continuous data stream (Tanaka, 2012). This allowed a performer to operate a MIDI instrument not necessarily with evident physical gestures, but also by articulating muscular tension using almost imperceptible movements. Similarly to the theremin, and in contrast with most MIDI instruments of the time, the Biomuse had to be played without physical contact with an object. Differently from the theremin, the Biomuse did not itself produced a sound feedback, for the bioelectrical signals had to be converted into MIDI messages and then mapped onto a different sound generator.

Atau Tanaka, a Japanese American composer and performer working at CCRMA at the time,[14] was commissioned to create the first musical piece for the Biomuse, entitled *Kagami*, which premiered in 1992 (Keislar et al., 1993). His work with the Biomuse is relevant to this thesis for it offers a way of understanding musical interaction with an electronic instrument as a corporeal practice, or better, using Tanaka's terminology (Tanaka, 2011, 5), as a visceral interaction. The sensor proximity to the performer's body, the access to physiological processes that the sensors provide, and the information on the intention of movement rather then the actual translation in space are all aspects that point to the visceral modality of interaction enabled by the instrument (Tanaka, 2011). At the time, Tanaka interfaced the MIDI messages coming from the Biomuse with a frequency modulation (FM) synthesis embedded

[14] Center for Computer Research in Music and Acoustics, see https://ccrma.stanford.edu/

in the commercial synthesiser Yamaha DX7 (Tanaka, 2012). Discrete trigger events and continuous control data generated according to the muscular tension of his limbs were mapped to specific parameters of the DX7 to achieve a more nuanced control of DX7 sound synthesis parameters (Tanaka, 2012). Later with the arrival of portable computers and graphical programming software like Max/MSP,[15] Tanaka has used the Biomuse for the manipulation of digital sound sources, such as wavetable oscillators and samples. The sound sources were processed using a wide range of synthesis techniques, such as frequency shifting, harmonisers and resonant filters, which were then channelled into waveshaping and amplitude modulation before being output as new sound forms (Tanaka, 2012).

In contrast with most of the new instruments of the time, which emulated traditional instrument playing, the Biomuse, according to Tanaka (1993b, 125), encouraged the creation of an idiosyncratic gesture vocabulary. This was possible because the interaction with the Biomuse happened through the modulation of muscular tension, rather than through gestures borrowed from traditional musical instruments, and because the production of sound occurred in a separate piece of hardware, rather than being directly linked to the physical gesture. For Tanaka (1993b), when performing with the Biomuse, physical effort becomes a function of musical expressivity. What this means, is that the expressive features of a musical piece played with the Biomuse depend directly on the intensity levels of the performer's muscular tension. Another interesting aspect to outline is that due to the unstable nature of the biosignals and to the fact that no muscle articulation can be repeated exactly in the same way, the Biomuse reveals 'certain imperfections, certain glitches' that, for Tanaka (1993a), are integral part of the musical experience afforded by the Biomuse. For example, the same type of forearm extension always produces slightly different muscle biosignals across multiple iterations. In addition, the biosignal reading is affected by the position of the electrodes on the performer's body and may vary as soon as the electrodes are slightly displaced. As a result, the performer may execute a gesture with the intent to modulate a sound in a particular way, but the changes in the biosignal reading may result in a modulation that is subtly different from the one originally intended by the performer. Here, the physical, or better, the visceral engagement of the performer's body and his adaptiveness to the possible 'glitches' of the instrument is paramount to

[15] http://cycling74.com

both the musical delivery and the transparency of the interaction between the player and instrument.

Perhaps, what best exemplifies this understanding of the relation between physical effort and musical expressivity is the work of the trio Sensorband of which Tanaka was part (Bongers and Sensorband, 1998). The trio included Dutch composer Edwin

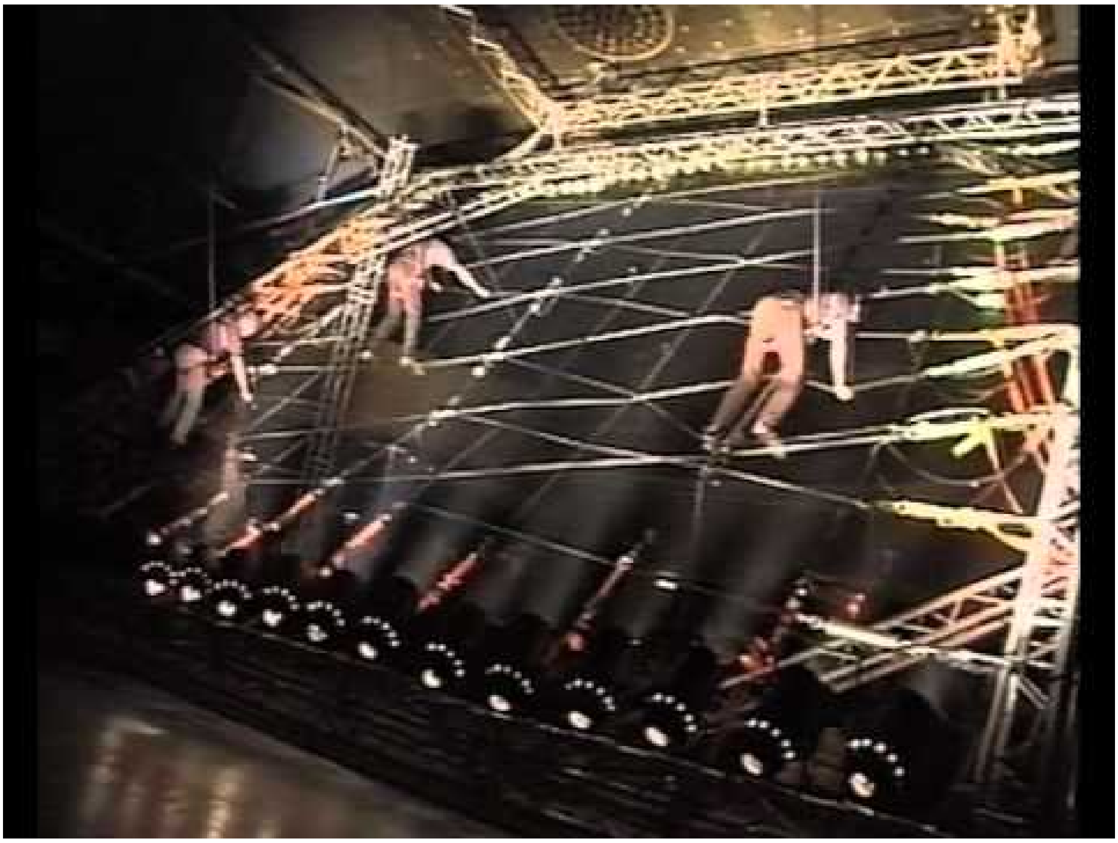


Figure 2.4: Sensorband performing with the SoundNET at DEAF Festival, Rotterdam 1996.

van der Heide playing the MIDI-Conductor,[16] Polish composer Zbigniev Karkowsky performing on a motion- and position-sensing instrument embedded with an array of infrared sensors, and Tanaka on the Biomuse. Working regularly at STEIM in Amsterdam, the trio found inspiration in The Web, an instrument created by seminal Dutch composer and performer Michel Waisvisz (Krefeld, 1990). This was a 1m wide net embedded with tension sensors whose information was mapped into sound synthesis parameters. With the help of Bert Bongers, Sensorband created a large-scale

[16]This was a modified version of The Hands built by Bert Bongers

version of The Web called SoundNET (Bongers and Sensorband, 1998). This was a monumental interactive instrument in the form of a net measuring 122 square meters. The net was made of 16-mm-thick climbing ropes whose tension and oscillation was measured by an embedded array of tension sensors (Figure 2.4). Using large springs connected to a linear potentiometer the sensors registered the displacement of the ropes and sent a variable resistance control signal to an analogue to digital converter (ADC) (Tanaka, 2000, 393). The data collected was digitised and translated into MIDI messages that modulated the processing of pre-recorded environmental sounds. In order to perform the instrument, the players had to climb the net and strenuously pull the ropes. The instrument's monumental dimensions made it ideal to be played by multiple performers, but it also required intense physical effort to play it, as each performer had to climb the ropes across an area of over a hundred square meters. In this sense, Tanaka has described the SoundNET as an instrument that inverts the emphasis on sensing and processing technologies that is common in interactive music performance. The imposing dimensions of the SoundNET, and more importantly, the exhausting series of physical actions that each player had to perform in order to play it, show the performer-instrument interaction as if it was a confrontation. The common understandings of musical intention and control are purposely put into question by the design of the instrument and the performance strategy. Visceral interaction moves beyond the notion of control by redefining musical intention as the result of the biophysical interdependence of a player and an electronic instrument.

2.4.2 Too Many Notes

The African-American computer music pioneer George Lewis has created a musical system called Voyager (Lewis, 2000). The system, whose first version was programmed at STEIM between 1986 and 1988, listens to the music played by a human player and produces an intricate set of musical responses that imitate, directly oppose or ignore the player's interpretation (Lewis, 2000, 34-35). Lewis' interest in creating this kind of electronic instrument originated from the fact the he was, and currently still is, a renown trombone improviser. The system is composed of sixty-four single-voice MIDI-controlled algorithms, that Lewis has called 'players', which operate asynchronously in response to the player's musical phrases . Each of the 'players' can operate at the same time without necessarily being metrically synced with the others. This produces groupings of 'sonic behaviours' that create diverse layers of multi-rhythms. Up to two human improvisers can perform with the system, using MIDI-enabled keyboards or acoustic instruments equipped with pitch following devices, algorithms that identify the pitch of an incoming note and translate it into MIDI data.

During performance, the Voyager recombines the algorithmic players in separate groups every 5-7 s, and then each group chooses a varied array of operational parameters, including a set of pitches, microtonal variations and tempo, which characterises the sonic output of each group. The players' group can also decide whether to be influenced by one or two improvisers, or to be completely independent from them. This implies that the system can produce music even when there is no improvisers playing along with it. This generative behaviour of the system means that when there is a human performer, she has to take into account the autonomous musical choices of the system. This is an important point in terms of the concern of this thesis. For a human performer, playing with Voyager means to let go of any hierarchy of 'human leader/computer follower'. The lack of buttons, pedals or physical cue to influence the system make the communication between instrument and player occur in the domain of sound. It is a 'subject-subject' relationship, as Lewis (2000, 34) has called it. The lack of physical contact with the electronic instrument however, does not mean that corporeal performance is absent. On the contrary, the human improviser interacts with Voyager by playing playing a traditional instrument; as a result, the physical nuances afforded by the traditional instrument are captured by the electronic instrument and translated into variables that modulate its musical algorithms.

Similar approaches to the design of computer music instruments can be found in the seminal work of Joel Chadabe (1980) and Robert Rowe (1993), who have created systems that listened and responded to the player in different ways. However, the reason why I focus on Lewis' work here lies in its unique conceptual and political basis. Lewis approaches the performer-instrument relationship as one where each has an equal stake in the musical outcome. His approach rests upon his strong awareness of the cultural and political value underpinning electronic instrument design, computer music, and art practices in general. His view has been clearly summed up in his statement that 'a formal aesthetic can articulate political and social meaning'. He has adamantly stressed that a computer music system, far from being 'objective' or 'universal', is embedded with the specific ideas of those who created it (Lewis, 1995). Assumptions on the nature of human-machine interaction are imbued into the system, for Lewis, an argument that resonates with the larger research of the the social construction of technology (Bijker et al., 1987; Klein, 2002). Whereas today's computer music systems, and the various communities that develop them, have evolved in ways that offer much deeper customisation than what was available at the time when Lewis had stated this position, the fact remains that a piece of musical technology is imbued with cultural assumptions, as Thor Magnusson (2009) and Owen Green (2011) have argued more recently.

For Lewis, to create and perform with the Voyager is to respond firmly to the conformity of standards in human-computer interaction with effective and creative alternatives (Lewis, 1995). It means to 'de-instrumentalize' the computer (Lewis, 2000, 36). With its lack of hierarchy between performer and instrument, Voyager embodies Lewis' intent to bring forth, through music and computers, an awareness of the cultural and political role of electronic instruments in musical practice. An awareness that rests on two points. First, that the function of an electronic musical instrument is not necessarily to aid human performers in the control of musical parameters, but it can also, and perhaps more interestingly, act independently from human performers. Second, that any kind of system design yields a cultural and political value, whether or not the artist acknowledges it or exploits it.

2.5 Body and Sound Prostheses

2.5.1 Machine Prosthesis for a Performer's Body

According to Stelarc, the human being cannot be characterised by our bodies or physical presence. In his view, the external form of the body is 'obsolete'. Stelarc's statement on the body obsolescence, as he has explained in an interview with Ford (2011), is not intended to negate the fact that humans need a physical body, nor it is intended to support the belief that the mind can exist without its fleshly embodiment. Rather, the obsolescence he talks about addresses the particular body that evolution has transformed human beings into, and more specifically, addresses the potential of that body to be remodelled. For Stelarc the body is an envelope of a dynamic entity that emerges from an open-ended process transformation together with technology. In an interview with the author (Donnarumma, 2012a), Stelarc has talked about human condition as a 'fluid unfolding' where institutions, political structures, culture and technology are seen as our 'external organs'. From this standpoint, he has produced different performances using mechatronic machines, as in *Exoskeleton* (1999) and *Muscle Machine* (2003), virtual avatars, *Movatar* (1999), and various robotic and biotechnological prosthesis, like the *Third Hand* (1980) and the *Ear on Arm* (2006). A common themes in his work is the idea of the human body as an object for possible redesign, that is, the modification of the body's physical capacities through the use of prosthetic devices.[17]

In the performance *Exoskeleton*, Stelarc embedded his own body inside a 'jerky and powerful 600-kg machine' (Stelarc, 2002) that enacted on stage what he has defined as a hybridised human-user interface. Powered by an external air compressor and eighteen pneumatic actuators, the machine walked forward, backwards and sideways. The machine choreography, as Stelarc (2002, 73) has called it, was controlled by the physical gestures and orientation of Stelarc's body which were tracked using wearable magnetic sensors. Stelarc's arms movements were translated to the machine's legs motion. The sounds of the air compressor, the clicks of the switches operated by the performer and the impact of the pneumatic legs on the floor were acoustically amplified so that the performer would compose the sounds by controlling the machine movements. Live video feeds captured by several cameras provided macros of both Stelarc's body and the machine parts that were projected onto large screens. The human and the machine appeared visually juxtaposed. The work augmented the human body to redesign its physical and locomotive characteristics through the use of machinic prostheses. In this sense, the prosthesis in Stelarc's work has been understood as a signal of the 'original incompleteness [...] of the self', a condition of unboundedness that 'violates the logic of totality', intended here as an invulnerable unity, that rests at the heart of Western understanding of human subjectivity (Zylinska, 2002).

[17]During the same interview with the author mentioned above (Donnarumma, 2012a), Stelarc has explained that his interest in the ways the body can be sculpted, modelled or redesigned comes from his background as a sculptor.

The tension between technological control, entertainment and bodily modification is at the core of the technologically mediated ritual/performances created by the Catalan performer Marcel.lí Antúnez Roca, one of the founders of the well-known performance art group La Fura dels Baus.[18] Together with music technology researcher Sergi Jordà, since the 1990s Antúnez has integrated his interest in biology, technology and culture with mechanical and digital machines in a series of solo works, including *Epizoo* (1994), *Aphasia* (1998), *Transpermia* (2003) and *Protomembrana* (2006). In the performance, or 'tele-torture' as the artist has defined it, *Epi-*

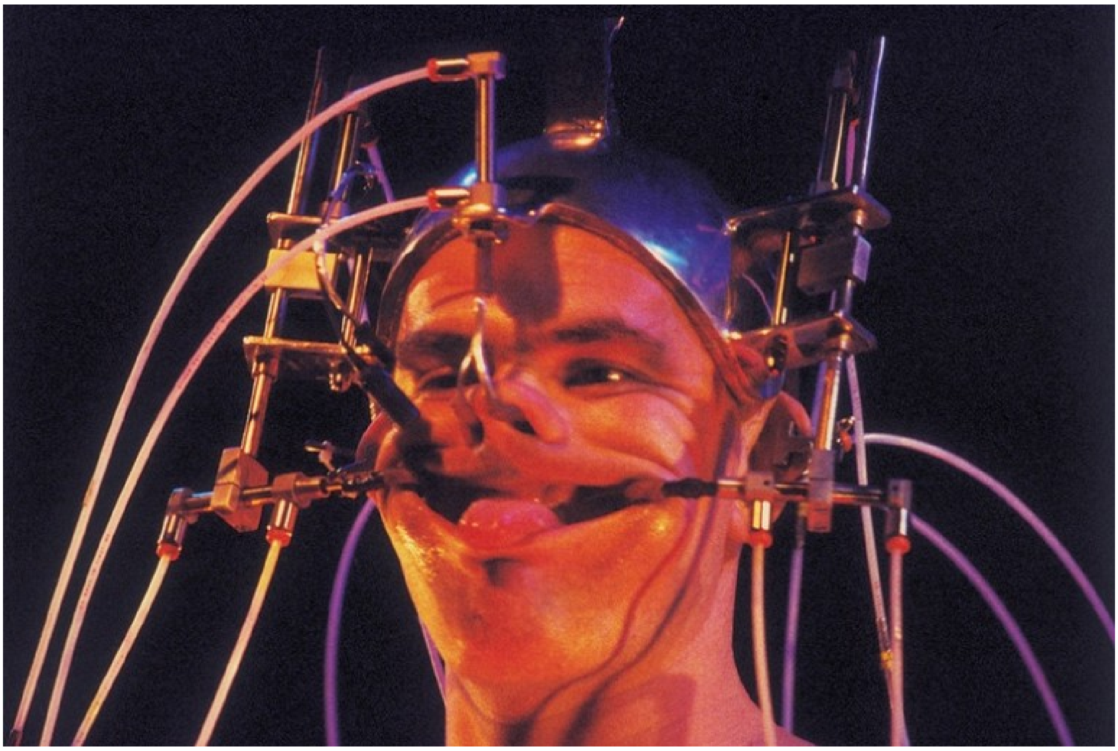


Figure 2.5: Marcel.lí Antúnez Roca performing *Epizoo*, 1994.

zoo, Antúnez wears a custom exoskeleton, created by Roland Olbeter (Jordà, 2005), mounted with sound, light, robotic and pneumatic devices attached to different part of his body (Figure 2.5). The devices are activated by the audience through a remote control panel triggering sounds, videos and lights, and causing Antúnez's muscle to extend, contract and twitch unnaturally (Salter, 2010, 250). His body is subjected to

[18]La Fura dels Baus was created in Catalonia, Spain immediately after the end of Franco's dictatorship in the late 1970s.

spasmodic and repetitive deformation. Antúnez's *Epizoo* re-contextualises body art in the field of technological mediation by making his body 'a sacrificial repository' of telematic torture orchestrated by the audience (Lozano-Hemmer, 1996). By offering to the audience the capacity to directly manipulate his body in an intimate and clearly violent way, the performance outlines the subtle boundaries that separate virtual entertainment from actual torture, and control of technology from technological control.[19]

The symbolic and physical standardisation of the female body according to consumerist and capitalistic canons of beauty is the subject matter of the ritual performances by French body artist Orlan. Coming from the second wave of feminist performance of the 1970s, in the 1990s Orlan began a series of technologically mediated performances entitled *The Reincarnation of Saint Orlan* (Orlan, 1996). During these performances she laid on a surgical operation table and directed medical staff who performed actual cosmetic surgery on her body. However, rather than having her bodily features 'corrected', she purposely misused standard cosmetic surgery procedures to modify her body in a ritual of 'self-directed violence' (Faber, 2002, 85). During the seventh, eight and ninth surgeries, the most radical of the series, she had cheek implants added to her forehead, and the largest breast implant possible for her anatomy implanted in her body (Faber, 2002, 86). The whole events were videotaped and broadcast, and during the seventh surgery the viewers were also able to ask her questions.

Orlan performed nine cosmetic surgeries, each characterised by a given theme that was rendered through a deliberately grotesque mix of philosophical readings, Christian symbols, and choreographed actions of a medical staff wearing garments designed by well-known fashion designers (Faber, 2002, 85). For Orlan, the plastic surgery performances are a form of self-portraiture that she refers to as 'Carnal Art' (Orlan, 1997). In this sense, the portrait for Orlan is intended not as a representation of the body, but rather as its actual reconstruction. Through the manipulation of her flesh and the integration of prosthetic implants (Botting and Wilson, 2002) she aimed for the actualisation of what she has called a 'mutant body' (Orlan, 1996). Orlan does not stand against aesthetic surgery, but rather against the standards of female beauty that underpin it. She uses technological prostheses towards the 'defiguration

[19]This is taken from a private conversation between the author and Sergi Jordà in March 2014.

and refiguration' of her body (Gray, 2002, 186), that is, the aesthetic deconstruction and reconstruction of the physical features that are used to define beauty in Western culture. In so doing, she intends to assert one's right to choose one own's form of embodiment through the new modalities enabled by prosthetic and medical technology (Gray, 2002, 186).

The accounts of these body art performances affords for a conception of technology as an active means of alteration of one's embodiment. Technology here is more than a means of mediation, it becomes constitutive of the artist's embodiment. Stelarc's, Antúnez's and Orlan's works raise the questions of how the boundaries of the human body have to be defined in the light of its liminality with electronic instruments, and perhaps more importantly, what kind of potentials such relation between human and machine realises. In their works, the notion of control ceases to be a means to preserve normative strategies and becomes a means to actively subvert them. In the specific context of the present research this view implies a founding argument. By altering the material instantiation of the body, technological instruments allow for unconforming modalities of embodiment and thus nurture critical modes of expression.

2.5.2 Touching Sound with Prosthetic Hands

The opportunity to nurture alternative and critical embodiments through the use of prosthetic technologies does not exist only in body art practice, but also in electronic musical performance. In this case, the physical mediation of a human performer and a prosthetic musical instrument can be used to inform the way sound and the performer's body are conceived and performed. An example in this sense is the work of Michel Waisvisz between 1984 and 2008. Working with portable customised computers and gestural controller, his practice contributed to posit a performer's physicality to the performance with electronic musical instrument. With the advent of personal computing during the mid 1980s, computers became smaller. In addition, the MIDI protocol, released in 1984 (Loy, 1985) standardised two key operations: acquiring information on human physical gesture using switches, knobs, and pedals; communicating that information among separate hardware through wired connections. In the same year, Waisvisz, together with a team of engineers and software developers working at STEIM in Amsterdam,[20] created a new musical instrument that leveraged wearable sensor technology and MIDI capability for the physical performance of eletronic music, it was called The Hands (Waisvisz, 2006b). It was one of the first electronic musical instrument to use a range of different sensors to capture different aspects of a performer's motion.

Figure 2.6: Michel Waisvisz performing with The Hands, Amsterdam. STEIM Archive.

The instrument consisted of two hand-held wooden frames embedded with tilt, pressure and infrasound sensors along with a small keyboard that captured information from Waisvisz's hand gestures (Figure 2.6). The data was than sent through a hardwired connection to a re-programmable small custom microcomputer called SensorLab, worn by Waisvisz on his back.[21] The SensorLab converted the sensor data into MIDI commands that triggered and modulated sounds on a Yamaha DX7 MIDI

[20]Studio for Electro-Instrumental Music. See http://steim.org The team included Johan den Biggelaar, Wim Rijnsburger, Hans Venmans, Peter Cost, Tom Demeijer, Bert Bongers and Frank Balde

[21]See http://steim.org/support/sensor.html

synthesiser (Waisvisz, 2006b). Coming at a time where, despite the availability of early personal computers, electronic music was still largely produced and performed in the few institutional studios who could afford large, complex and costly computers, The Hands represented, for Waisvisz, a means to 'touch' sound with his own hands (Waisvisz, 2006b). This links back to my claim on the political value of the modalities whereby technology is conceived of, and used, by artists (subsection 1.2.3). The work of Waisvisz reappropriated early sensor- and computer-based technology to create a custom electronic musical instrument that, as a result, was not bound to the technical limitations and high costs indicated by computer manufacturers. Beyond the technical and economic advantages it provided at the time, the implementation of custom microcomputers and sensors by Waisvisz and his team embodies a particular kind of explorative approach to the conception and development of technology for musical performance; an approach where the development of custom technologies is guided by the need to realise uncharted modalities of physical performance with electronic instruments.

In Waisvisz's performances with The Hands, the physicality of the interaction with the technological system is pivotal. The Hands do not modify the physical capacities of the human body, but rather extend the player's musical skill through the metaphor of 'touch'. In his own words, what was needed was an instrument that would enable a player to 'operate, navigate, compose, mould and play sound in a sensible, refined and even sensual and groovy way' (Waisvisz, 2006b). Because the sensors used by Waisvisz captured different kinds of data from his movements, the mediation of his body with the machine took place at a physical level. The ability to touch sound allowed the immediate expression of a musical idea in a similar way to traditional instruments (Waisvisz et al., 1998). Not only did Waisvisz initiate a new model of performance, one where the electronic musical instrument and the performer's physicality are linked to create a sonic world, ultimately, he brought computational machines closer to the performer's body and established a paradigm of interaction between the two that demonstrated new ways of thinking about live electronic music and sound production.

Whereas in the works of Stelarc, Antúnez and Orlan the technology moved into the body altering the artist's embodiment, in Waisvisz's work the body moved into the technology animating the instrument with the physical expression of the performer. Waisvisz's thought is grounded in an understanding of musical performance, and sound itself, as essentially physical expressions of human embodiment, and as such bound to be instinctive, not repeatable in the exact same way and prone to miscalculation. In his own words, 'we should abolish the illusion of "control" [...] get inspired by change, miscalculation, invested instinct, insightful anticipation, surprise and failure' (Waisvisz, 2006a). What Waisvisz means is that, similarly to traditional instruments, the electronic instrument and the human body shall literally touch each other to allow musical expression to move past the symbolic interaction provided by electronic systems and embrace corporeal modalities of interaction. Waisvisz proposes a paradigm of technologically mediated musical performance where the playfulness and quality of a musical experience does not depend only on the control the performer has over the instrument, but relies and emphasises an open-ended interaction between the player and the instrument. An interaction where a player is able to creatively and intuitively engage with the instrument beyond the concern of the symbolic layer dividing gesture and sound production. This research will draw upon and extend Waisvisz's proposal to create works where the performer's body and the electronic instrument are mutually engaged. The aim will be to embrace risk, surprise and shared control as performance elements that enrich musical expressivity, rather than undermine it.

2.6 Summary

The works I discussed in this chapter interlace across shared conceptual ideas of what a human body and an instrument can do or be used to do. In so doing, they constitute an artistic perspective that is sensible towards the corporeal bound between a performer and an instrument. What this research takes from those works as a whole is that, when engaging in embodied artistic practices with technology, the modalities of the corporeal relationship between performer and electronic instrument are crucial. The ways in which that corporeal relationship unfolds define, at a material level, the expressive capabilities of both the performer's body and the instrument. It is a relationship where the two participate in the emergence of new corporealities, and through this process, artistic expression gradually comes forth.

In particular, a subset of the works I reviewed provides specific insights for my own work, and at the same time, highlights gaps that this research will fill. From the work of Mikami, Salter and Lucier, this thesis draws together the guiding principles to deploy in original artworks the material effectiveness of sound to create corporeal bounds between performer and instrument. Mikami, Salter and Lucier investigated how the vibrational force of sound can link the perception of human bodies to the environment surrounding them. They have done so however adopting an approach where either the performer's body or the electronic instrument has an active role in the process. In Mikami's work the human body produces sounds which are manipulated and played back by the instrument. The instrument itself does not directly inform or influence the performer's body, it is rather designed to take a distance from it. In Salter's work the opposite happens. The instrument produces audiovisual stimuli that influence the performer's body, and the latter can do very little to actively take part in the process. In Lucier's piece, the player's body feeds signals to the instrument, which in turn, outputs sounds by hitting a set of percussion instruments. As in Mikami's work, the instrument does not give anything back to the player, and listening is the only feedback channel. This research will explore the mutual physical influence of performer and instrument through sound as a means to displace a subject-object view of the performer-instrument relationship.

The focus of the thesis on the physicality of interaction between performer and instrument is taken from Tanaka and Waisvisz. Their work provides me with the insight on how to create instruments that use body sensors to magnify physical and physiological aspects of gestural expressivity. Their works have showed that by embedding the instrument with the capacity to sense the player's physical effort, a performance can move beyond the preoccupation of how to control given instrument's parameters and lead towards more immediate, intuitive musical expression. In this way, musical expression is emergent from an holistic experience where the player and the instrument feel like one body, a technological body. Their approach is useful to my work as it suggests that embracing unexpected musical results as integral part of electronic musical performance can enrich musical expression. This resonates with Lewis' work with Voyager, an instrument that listens to the music played by a human performer and responds by imitating it, opposing it or discarding completely. Lewis's work is important to my enquiry because it shows the importance of sharing the control of the musical outcome between the performer and the instrument to make room for intuitive interaction and emerging sonic behaviours. This thesis will combine insights from Waisvisz, Tanaka and Lewis' works to explore musical performance as an embodied practice based on physical effort, visceral interaction and shared control. Using the methods and technology offered by the current physiological technologies (Fairclough, 2009), this thesis will offer a toolset to observe in detail the link of physiology and physical expression, beyond the use of raw physiological signals. The intent is to provide an electronic instrument with accurate information on the expressive aspects of a player's physical performance and let the instrument use this information to produce unexpected musical responses.

Finally, this research will investigate further the idea, found in Stelarc's and Marussich's body art performances, that an electronic instrument can be designed to physically alter the material organisation of the performer's body. By disrupting physical and physiological processes of their own bodies they have made those processes available to the public as vectors of artistic expression. In so doing, their works expose the performer's presence as an expressive act in itself. In Stelarc's *Suspensions*, the physical tension experienced by his body comes forth through the increasing stretch of the skin. The body looks still, but it is in fact rapidly reorganising itself so that the skin can hold the weight of the entire body. The body's stillness belies the rapid adaptation it is going through to handle the change of gravitational force. In Marussich's performance, where he sits still while bodily biochemical reactions becomes slowly visible to the audience in the form of blue sweat, the reorganisation of the body happens programmatically. The timing of methylene blue injection, the body's positioning inside the glass box and the temperature increase are finely programmed in advance. For Marussich, this programmatic reorganisation of the body is a choreography. A motionless choreography that amplifies the performer's corporeality. Their works delineate another gap that this work will fill. In much of body art practice using technology, if sound is used, it is deployed as a peripheral element, thus overlooking its material force to affect human bodies, instruments and spaces. In this work, I will tackle this issue by creating body performances where sound is the key element, and its material force is key to configure the performer's body and the instrument.

Chapter 3

Key Theories

3.1 Introduction

In the previous chapter, I reviewed a series of performances and instruments which offered a rich view of corporeality in musical and body art performance. In concluding that chapter, I defined the insights I take from Mikami, Salter, Tanaka, Lewis, Waisvisz, Lucier, Stelarc and Marussich and the gaps that my research aims to fill. These can be summarised in three main points: to explore the mutual influence between instrument and performer; to use physiological technologies to detail the link of physiology and expression and share the control over a piece between player and instrument; to use the material force of sound as a key element in body art performance with electronic instrument. Whereas my work is aligned with the approach of those artists, I see an underlying conceptual concern with their works; a concern that I wish to develop further by taking some substantially different steps in building the theoretical framework of my practice.

In the works cited above there is a stronger focus on the performer's body than there is on the instrument, it is a subject-object relationship. In the case of Tanaka, Waisvisz, and Lucier, the performer's body is augmented with an electronic instrument. In the case of Mikami and Salter, even though the works induce perceptual changes in the performers' bodies, performer and instrument do not have the same stake in the performance outcome. Stelarc and Marussich firmly centre the conceptual, technical, and artistic approach of their interventions on the performer's body. With this research I investigate a balanced relationship of performer and instrument, their arrangement into one technological body. I am interested in the corporeality and expressivity that arises from the technological body. In this chapter I will address the first of the research questions I indicated in the introduction: which analytical resources can be extended to address the corporeality of the technological body in sound performance.

In this chapter, I will propose a particular analytical framework which allows to shift the way we understand the relationship of human beings and technology and, by extension, the relationship of performer and electronic instrument in musical performance. The shift will require moving away from a conception based on a subject-object dichotomy to one based on a constructive mutual influence.

The analytical framework I will propose results from an urging need to expand my artistic vision by delving into the concepts which underpinned my artistic work in the past five years.[1] The particular notions I will collect and discuss in this chapter have formed my understanding of the relations between body, sound and technology; this understanding has, in turn, shaped the conceptualisation and realisation of the two artistic works I created during this research. Put differently, the artistic works would have not emerged had I not immersed myself in the theoretical analysis of the following literature. Here lies one of the transdisciplinary aspects of this enquiry: analytical resources, artistic vision and scientific findings have equally contributed to the research, and their combination and mutual influence is embodied in two final artworks.

The framework proposed here is limited to, and constrained by, the particular scope of this research and my artistic practice. It is not meant to represent an absolute or universal view on corporeality and embodiment and it will therefore omit those resources which do not directly contribute to the concerns highlighted thus far. The framework is therefore offered to the reader with the intent to provide a particular path through the vast literature on the human body and its relation to technology, so as to learn how this specific body of literature can inform technologically mediated sound performance. Importantly, the framework is underpinned by the science of sound, bioacoustics and vibration; it weaves a thread across particular notions which, when examined through the concept of sound as a vibrational force, will be instrumental in constructing and discussing my thesis (and, it is hoped, will be of use to other artists and researchers). While throughout this manuscript I will focus on the specific issues at hand, I will also ensure to point out the salient passages of the text which open up onto issues exceeding the current framework, and I will provide the needed references. This will help the reader re-purpose some of the ideas being proposed here in different research fields.

First, I will discuss the notion of human unfinishedness, as it emerges from the accounts of individuation and trans-individuation by Simondon (1992), Stiegler (2011b)

[1]Being a doctoral candidate in a computing department, I was not required to bring together such an extensive analytical framework as the one that follows. I chose to do so early on in my doctoral studies and this has largely affected my creative process by inspiring new artistic concepts, creating challenging issues in terms of how to conduct the research, and, ultimately, allowing me to develop my skill in working across art, theory and technology.

and Venn (2010), to introduce an idea of the player's body as an incomplete entity that, together with the instrument, evolves through iterative phases without reaching a fixed state. This process, I will argue, emerges through thresholds (Blackman, 2014; Massumi, 2002) which produce sound and body art performance as a form of rhythmic embodiment. I will give some examples drawing on the experience of raving (Pini, 2001) and dancehall (Henriques, 2010). As a result, the player's body becomes a stratified entity whose basic expression is its shifting form of embodiment (Deleuze and Guattari, 1987).

This will help us understand more recent theories on the intimate relationships that bond technologies and human and non-human beings as well as their relevance to technologically-mediated artistic performance. This notion, referred to as posthuman condition by Haraway (1991), Hayles (1999) and Braidotti (2013), to name only the resources I will draw on, is useful in investigating the modalities whereby the properties of technologies (musical instruments) and human beings (performers) influence one another and become manifested through embodied practices. To examine this form of technological embodiment more in depth I will look at the cyborg (Clynes and Kline, 1960) and its cultural and political implications (Haraway, 1985). Some discourses on the cyborg however produce technological embodiment as a material body, occluding the phenomenal and psychological dimensions of this form of embodiment. In order to provide a balance between materiality, immateriality and lived experience I will look at the experience of living a prosthesis and the hybrid forms of feeling and having a body it yields (Sobchack, 2010).

Then, I will analyse the principles and criteria of the mutual influence of human and machine, in sound and body art performance and elsewhere. I will discuss further phenomenological insights on the human use of instruments. I will look at traditional phenomenological approaches (Merleau-Ponty, 1978; Gallagher, 2001), and then elaborate on some problems intrinsic to this kind of approach, noting how it discards differences of gender, race, age and differently abled bodies (Young, 1980; Shildrick, 2002). This will allow us to link back to the importance of thresholds, training and attunement in technically-mediated embodied practices, which I will examine in the context of jazz improvisation (Sudnow, 1978; Berliner, 1994) and experimental psychology (Blackman, 2012; Solomons and Stein, 1896). Finally, I will elaborate further these views by discussing the interdependency of cognition, perception and bodily experience in the way we know and make the world (Maturana and Varela, 1980; Varela et al., 1991). This view however presents some problems, for it renders the human body as a self-enclosed and self-sustaining entity. This problem will be discussed by focusing on the more recent views on the mediation of human bodies and technologies at the biological and physiological level (Ansell-Pearson, 1999); and how this particular kind of mediation alters, hinders or extends the capacity of a body to affect another (Clough, 2008).

3.2 Human Unfinishedness

3.2.1 Individuation and Technical Milieu

As seen in the introduction, traditional readings of musical performance assume that the performer's body is self-enclosed. This forces us to conceive the musical instrument as an object, which relates to performer's body in a more or less mediated degree. As a result, musical expression is tied almost exclusively to the cognitive, physical and programmatic abilities of the performer. I want to propose a different view which rejects these assumptions. In this subsection, I will begin by arguing that, during a performance, the performer's body is not self-enclosed, but permeable, open to be affected by the musical instrument and the context of their interaction. To do so, I will draw on process philosophy, and in particular the work by French philosopher Gilbert Simondon (1992) on the notion of individuation.[2] The question I will begin with is how the interaction with the instrument, the environment and other beings influences the performance of a player, and vice versa. With the term 'performance' I refer not only to musical performance, but also to the physical, cognitive and psychological performance that is integral to the act of playing music on a stage.

[2]The permeability or openness of the individual is a broad theme which has been - and still is - examined by theorists across philosophy (Simondon, 1992; Ettinger, 1995), cultural studies (Blackman, 2012), feminist studies (Grosz, 1994; Butler, 1993), phenomenology (Merleau-Ponty, 1978; Young, 2005; Sobchack, 2004), and in further research areas by many other scholars. My choice to ground the present research in Simondon's analytical framework and not in other relevant ones - such as Actor-Network-Theory heralded by Bruno Latour (2005) - is twofold: it shows the process of becoming as an iterative process unfolding gradually, but non-linearly through thresholds conditions; it provides notions that are precise and yet flexible enough to be re-purposed in the particular context of this research, which is an artistic practice-based project at its core.

For Simondon, individuation is the biological, psychological, and social process whereby an individual acquires specific physical, psychological and behavioural features. He argues that the individual (the performer) is constituted by contingent potentialities which can be realised through others.[3] To clarify this argument, Simondon gives the example of the physical individuation of crystals, the process known as crystallisation (Simondon, 1992, 302-305). He considers a supersaturated solution, a solution whose concentration is beyond a saturation point. In Simondon's terms,

Figure 3.1: A Bismuth crystal at 100x magnification. This crystal has long been considered the chemical element with the highest atomic mass.

a supersaturated solution is characterised by a *metastable equilibrium*. Metastable, in his idiom, stands for a primal condition of matter, an unstable equilibrium which is possible thanks to manifold levels of energy in tension amongst each other which, once organised, produce an individual. The solution then yields a range of energy and density levels which, when organised, bring into being individual crystals (Figure 3.1). The point is that the crystals are not actually present in the solution, but

[3]According to Simondon (1992, 302), individuation is a feature common to both human beings and physical phenomena.

their potential is. In other words, the potential for individual crystals to emerge from the solution constitutes the solution itself.

Transposing his idea of individuation to the domain of the living beings, Simondon states that the same model characterises human individuation, although it bears an important difference. Unlike the physical individuation of crystals which is 'definitive' (Simondon, 1992, 304), human individuation is not exhausted in one iteration; rather, it is a process of permanent individuation, what he calls *becoming*.[4] Musical performance, I argue, is a mode of becoming during which the player brings forth latent potentials. Paraphrasing Simondon, becoming does not only bring the player into being, it also defines the way she organises and acts; through the process of becoming the performer re-structures herself. Hence the player 'does not represent the totality of being' because it is 'merely the result of a phase in the being's development' (Simondon, 1992, 300). The process of individuation is a partial and relative resolution, continually operating through the latent potentials held by the performer in what Simondon calls the pre-individual. The completion of one cycle of individuation does not exhaust all the potentials of the pre-individual; rather, a potential is always present and feeds subsequent processes of individuation.

While I regard Simondon's theory of individuation extremely important to the present research, his theoretical apparatus presents issues that need to be confronted. Simondon's theory is intended as a general framework and thus it opens up issues that are not fully attended to in his work. In a recent article, theorist Couze Venn (2010) elaborates thoroughly on these issues which, at a general level, concern Simondon's overlooking of the role of historicity and temporality in the process of individuation. Venn groups these problems in terms of three themes: the affective and emotional dimension of individuation, the relationality of all living beings, and the importance of the context wherein particular individuations unfold. Concerning the first theme, Venn notes that by theorising becoming in terms of information and signification, Simondon's theory lessen the role of the 'affectivo-emotional' (Venn, 2010, 148) rela-

[4]'Becoming' is a standard philosophical term, originating in Heraclitus' doctrine, differently explored by Western philosophers including Georg Wilhelm Friedrich Hegel (1969), Karl Marx (1964), Henri Bergson (1911), Alfred N. Whitehead (1929), later used in the work of, most notably, Simondon himself, Deleuze and Guattari (1987), and more recently developed further by the current of New Materialism (Van der Tuin and Dolphijn, 2012, 28).

tions with others.[5] Drawing on painter and feminist theorist Bracha Ettinger (1995), Venn argues that becoming is a process of co-constitution which involves others (human, non-human beings, and technology) and unfolds through experience (lived affect). Thus, he calls for a grounding of the notions of information and signification in the lived experience of the individual with others; what he calls the 'non-conscious and proprioceptive communication that takes place through touch, smell, the gaze, movement, sound, taste occurring directly between bodies' (Venn, 2010, 156).

Secondly, drawing on Haraway's work, Venn stresses the need to make explicit how human individuation is inscribed within 'nested networks' that include all living species. Re-articulating Simondon's work through this conception - referred to as the relationality of the living, or the capacity of all living beings to establish relationships with each other - actually reinforces Simondon's theory by showing all actors, including humans, as being 'neither wholes nor parts' (Haraway, 2003, 8), but co-existing and co-constituting each other's becoming. Finally, Venn argues for the importance to recognise that the specificity and contingency of bodies, and the affect they share, is sealed within particular milieux. Individuation is *situated*, or defined and limited by its context. This, for Venn, is shown by the inability to re-live affective experiences outside of the specific milieu where they first emerged. Milieux, Venn continues, do not only constitute individuals and their worlds, they also specify the constraints limiting what actions can be done and what is not allowed. 'Belonging, becoming and acting lock into each other' (Venn, 2010, 158). Through the above arguments, I started to displace the notion of the performer's body as self-enclosed and self-sustaining and provided some initial arguments to understand it as rather permeable, always in a process of becoming. This allows us to turn now to the role of technical instruments with a new viewpoint.

In a later work, Simondon expands his theoretical framework by arguing that individuation does not happen only at the level of the single individual. It also takes place at a social and a technical level. At a social level, individuals establish relations among themselves so as to form a collective entity. At a technical level, individuals and technical objects establish relations which bring forth the latent capacities of

[5]This is illustrated by considering how trauma conditions the subject formation. The ensemble of elements including memory, psychic disturbance, technical framing, non-conscious body-to-body interactions - what can be called an affective economy - shows the limitation of Simondon's framework of thought.

each and, in so doing, they constitute each other. To give more details about this argument, and specifically about the problem of technical individuation, it is useful to look at the work of Bernard Stiegler (2011b). Largely influenced by Simondon, Stiegler argues that technical individuation takes place through the formation of a *technical milieu*. The term 'technical' for Stiegler is synonym with a constellation of technologies, technical skills and technological models. In electronic music performance these are: the stage, the speakers, the musical instrument, the computer and the sensors, as well as the programming and performative skills of the player and the interaction models enacted during a performance. The term 'milieu' is intended by Stiegler to mean both what is around the individual (the environment) and what is between individuals (the medium). In the context of a musical performance, these are the public event, the venue, the audience, as well as the cultural context and the media through which the performance is experienced. The notion of the technical milieu is key to my research, for it renders technological systems as both constituted by and constituent of human becoming. This expands on Simondon's work by emphasising the involvement of multiple subjectivities, technical systems and contexts in the process of becoming. Through the lens of the technical milieu, technological systems such as computational musical instruments are 'artificial organs' (Stiegler, 2011a), in the sense that they are situated in, integrated with and constitutive of the player's becoming.

Whereas Stiegler's notion of technical individuation addresses the issue of context, or milieu - which, through Venn's analysis, I indicated as being one of the weaknesses of Simondon's theory - it still elides the problems of relationality and affectivity in human becoming, in music performance and elsewhere. In the next subsection, I will provide more analytical tools to understand relationality and affectivity in musical performance, and I will dedicated particular attention to those issues in subsection 3.3.2, through the work of Donna Haraway on the cyborg, and in subsection 3.4.2, via the work of Lisa Blackman on the phenomenon of automaticity.

3.2.2 Thresholds and the Rhythm of Becoming

In this subsection I will add more details to my view of musical performance as a mode of becoming shared by performer and instrument. I will do so by discussing how the relationality of technical instruments and human bodies unfolds through material, cognitive, perceptual and psychological *thresholds*.

Following Simondon, Canadian theorist Brian Massumi posits the potentials of a body as the source of the process of individuation. The term potential is used literally, as a latent quality or ability of a (living or non-living) body which may or may be not developed; for instance, the potential to see an image through a trompe l'oeil, or the potential to reinterpret a known musical scale without actually wanting to (see subsection 3.4.1). According to Massumi (1995, 95), a body's potentials are independent and discontinuous until they move beyond a threshold and become actualised. When this happens, the body acquires new modes of operation. The notion of threshold is crucial to my research and I will discuss it throughout this thesis. Massumi explains his idea of the threshold by recalling an optical illusion. Most optical illusions require the viewer to stare at an image for a short time before the effect actually 'appears'. The image does not change but the excess of the visual input makes one's vision surpass a given threshold. As a result, the image is perceived as a new one despite being the same. Interviewed by Boever et al. (2009), Massumi claims that, in a similar way, the human body's potentials - the latent abilities and qualities of a human body - are developed only when they exceed a given threshold through technical objects.

Objecting to this view which encloses threshold phenomena within the domain of perception and neurophysiology, body theorist Lisa Blackman (2014) notes that thresholds are exceeded most fundamentally through training, habit, discipline and choreography, as it happens during the training of a particular bodily practice. Blackman gives the example of experiments with automatic writing in subliminal psychology (see subsection 3.4.2), and I would add to this physically active meditation like Sufi swirling, sacred healing rituals such as Ayahuasca ceremonies, but also experimental music performances such as Rosenboom's biofeedback music experiments or Stelarc's suspension performances (discussed in the previous chapter). The motivation of my interest in threshold phenomena, and how they can be enacted in technologically mediated musical performance, is summarised by Blackman (2014, 1) when she states that threshold experiences 'disturb, disrupt and unsettle distinctions between the self and the other, inside and out, natural and cultural, real and unreal, material and immaterial'. Thresholds show the importance of balancing the body's materiality with its *immateriality*, the body's potential for psychic and psychological attunement (Blackman, 2012, 2014). Crucially, thresholds are dynamic. Because a human body is related to the world, to other beings and technical objects surrounding it, thresholds are dynamically shifting. Thus, because potentials operate across dynamic thresholds, even when an individual goes through several phases of individuation it never replicates itself in the same form. This process is, in my view, a system of nested modes of becoming based on repetition and rhythm. The notion of repetition I use here does not refer to an ideal of identical representation, but, via Deleuze and Guattari (1987), to a capacity of generative potential. Linking back to the vibrational force of sound, which forms the backbone of this research project, I want to clarify this idea of repetition by drawing an analogy between individuation and vibration. In the same way as sound waves will always be different according to the medium, or media, they are diffused through and listened in, individuation cycles will always be different according to the milieu, or milieux, they are enacted by and experienced in. As Henriques (2010, 78), via Lefebvre, succinctly puts it: 'With repetition giving birth to difference, [...] for both frequencies and feelings, being itself is always becoming and becoming is always becoming different'. Hence becoming can be understood as a vibrational rhythm: a recursive cycle of phases, turbulences and pressures whose milieu is both, at once, the source of continuous variations and what remains after them.

In this situated process of becoming, living beings and technical objects rhythmically alter and extend the thresholds which an individual may exceed. What deserves emphasis here is that the conception of human and technical individuation as enmeshed, situated processes implies that technical objects and living beings are relational: they relate to each other in an a process of mutual formation. Thus the relation of technical objects and individuals can be generative, in the sense that it can generate new modalities of becoming, but also disruptive, in that it can hinder, alter or radically modify their process of becoming. This argument offers a way of thinking about human-instrument relationship, in music and elsewhere, which does not imply only positive outcomes, but embraces the idea that error and failure are integral to the rhythm of becoming. This argument will be used throughout this thesis to characterise my notion of the configuration between performer and electronic instrument.

To clarify the relevance of the notions of threshold and technical milieu to this research project, and in particular to sound, I want to transpose the discursive argument weaved thus far into a graspable lived experience. The experience of a rave (or a musical performance or a dancehall session) provides for a practical example of this notion of becoming and establishes a direct link to the kind of aesthetic research on sound which this project pursues. As I briefly described in subsection 1.1.1, 'raving' and listening to the sound and vibrations diffused by a complex and monumental set of speakers (sound technologies) is all but a solitary experience. Listening is already in itself 'a connective relationship, or attunement,' (Henriques, 2010, 76) where the attention of the listener is directed towards the sound-producing actor. But in the particular milieu of the rave, this connectivity of listening is magnified and materialised by the intense amplification power of the sound system, the deep and vast acoustic resonances of the warehouse, the emphatic effects of emotional peaks and drug-induced 'high', and the forceful intimacy shared among the 'ravers' (which tends to be joyful, but it can in extreme cases descend into aggressive feelings). These elements - technical objects, sound, people and context - contribute to produce a collective feeling of recursive entrainment which last throughout the night and, quite likely, follows ravers into their everyday routine. It is a mode of being, or better, of becoming.

Drawing on Henriques (2010), it can be said that the recursive entrainment which is produced at a rave (or at a dancehall, or a musical performance) is a rhythmic mode of becoming. The performative assemblage which is constituted by the building, the technical instruments, the sound and the bodies of the ravers enables corporeal ways of knowing. It does so by surpassing auditive, material and psychological thresholds. This rhythmic mode of becoming emerges from repetitions (of light and musical patterns), oscillations (of dancing bodies and emotional 'highs' and 'lows') and vibrations (of sounds and feelings shared across people). Through repetition and vibrational movements a state of entrainment is produced, a 'peak' state, quoting cultural theorist Maria Pini (2001). This is a particular kind of affective experience which shows how affect escapes the discursive; it has to be 'embodied, felt and experienced', as Henriques (2010, 82) puts it.

This however does mean that affect is irrational; affective experiences, such as those emerging through the rhythmic becoming of the rave, are produced through specific performance techniques of 'crews and crowds' specialised in making meaning through practice (*ibid.*). As with any other rhythm, training and self-discipline are required to perform this particular rhythm of becoming.[6] In her study of club culture and female subjectivity, Pini (2001) stresses this point.[7] At a rave, the ability to reach a peak state of entrainment - in other words, to surpass corporeal and psychological thresholds and escape the rational subject - is not automatically earned upon entering the venue; it is *worked through*, produced through a series of operations involving the management and regulation of energy, pain and drugs, as well as the avoidance of 'bad vibes' and 'wrong' gazes by other ravers. It is a rhythmic choreography which ravers train through repetition. Rave after rave they *learn to be affected* (Despret, 2004).

This is what I explore through my artistic practise: how technical milieux (venues, computers, sensors, sound, rhythms, feelings, sensations, programming and performing skills) can enable performers and audiences to surpass certain material, perceptual, psychological and cognitive thresholds and thus learn to be affected. The two performances which I have created during this research were conceived with this in mind.

3.2.3 Expression as Articulation of Forces

If, as I argued so far, musical performance is a mode of becoming where player, instrument and context form a performative assemblage, where does musical expression reside? Does it come from the instrument, the performer's body, the music or any combination of these? Defining musical expression, and where it does actually come from, is a thorny and pressing issue in studies of musical performance and new instrument design. As I mentioned in the introduction, the problem is often thought to be solved by entering into a discussion of musical qualities (composition, timbre, spatiality) or technical affordances (degrees of control, immediacy of action, latency). But these are, in my view, partial elements of a much more complex answer. This kind of discussion is most often biased by an assumption that musical expression depends fully on volition. Imagine a professional pianist who, in order to fully abide to his intentions during a performance, coldly count time bars while looking for the exact position of the next key to press. Of course, this would not be an expressive performance. There is much more than intention to musical expression. Understanding

[6] See also Henriques (2011) on the training of the dancehall 'crews'.

[7] For a broader view on the cultural study of rave and clubbing see also the feminist engagement of Hillegonda Rietveld (1998) and the anthropological study by Phil Jackson (2003).

that performer and technical milieu co-constitute each other during a performance, by establishing relations and surpassing thresholds, gives us a fresh viewpoint on the issue. In this subsection I will offer initial arguments to claim that expression is not exclusively tied to volition. To do so, I will discuss the work of French philosophers Gilles Deleuze and Félix Guattari, who have extended Simondon's theory of individuation by combining resources from geology and genetics, among other things.

Deleuze and Guattari (1987, 50) argued that all things, living and non-living, human and non-human, can be seen as consisting of strata. They borrowed the term

Figure 3.2: A rock formation located around the Grand Canyon, USA. The stratified layers of matter are clearly visible as differently colored lines.

strata from geology, where it is used to indicate rock formations organised in a series of levels (Figure 3.2). Their use of the term implied that all things, living and non-living, are arrangements of layered elements. The most primordial layer is, for them, matter; unformed and disorganised matter that constitutes the base of things. They argued that when matter is organised into strata and forms a distinctive body, it expresses itself through rhythm. In other words, in their view, expression is the way in which disorganised matter is articulated, through repetition, into a distinctive embodied entity.[8] This meaning of expression is not tied to physical action or volition, but to the capacity of embodiment to be generative of novelty and adaptive to context. Importantly, for Deleuze and Guattari (1987, 313), the context, or milieu, is 'vibratory, [...] a block of space-time constituted by periodic repetition'. The embodiment of strata does not reach a definitive state, but shifts across a series of intermediate states (Deleuze and Guattari, 1987, 51), across repetitions which yield differences. This resonates with Simondon's idea of the embodiment of an individual as a temporary output of an ongoing process of individuation.

Deleuze and Guattari's exemplify this argument by looking at rock formations. A rock formation originates from raw matter which, due to both its internal composition and the action of external natural forces, organises itself into an arrangement of several layers. According to Deleuze and Guattari's argument, the way matter organises itself into layers *is* the expression of the rock formation. In a similar way, I argue, the way the player's body, the instrument, the sound, the venue, and the audience establish relations among them is *already* a musical expression. Any player, instrument, listener or venue taken by itself does not have the same capacity of expression which emerges from their organisation into a milieu, the milieu of musical performance. This resonates with the conception of the co-constitution of human beings and technical milieu discussed in the previous section and expands it further. It shows how expression can be understood as the representation of shifting modes of embodiment.

Furthermore, similarly to a rock formation, which is subjected to constant change and cannot be said to enter a definitive embodiment, the milieu of musical performance is subjected to continuous changes (psychological, cultural, political or architectural) and, as it is readily recognised, cannot be repeated in the exact same way across different iterations. This is, after all, the uniqueness of musical performance. I will come back to this issue in the discussion of the thesis findings (section 7.5) where I will apply this particular notion of musical expression to the analysis of the works discussed in the previous chapter, as well as to my own performances.

[8] Using this definition, they stated that not only humans and animals and insects are capable of expression, but also rocks and plants and anything that is 'stratified', in the sense their logic proposed. Their reading of expression resonates with Leibniz's conception of expression as representation (Leibniz, 1969). Incidentally, Deleuze has analysed Leibniz's philosophy in (Deleuze, 1992).

Deleuze (1981) further expanded his analysis of expression in a work devoted to the aesthetic and techniques of the controversial English painter Francis Bacon.[9] He analysed how expression in Bacon's work emerged from the artist's particular painting technique. Bacon used to draw human body parts, such as faces, eyes, mouths, and limbs, and then scrub the initial drawing with large brush gestures. This resulted in his distinctive arresting portraits that recall human figures, but distort them in such a way that they acquire alternative, almost animal, traits. Deleuze termed the quasi-human characters in Bacon's painting as 'Figures'. The Figure is, according to Deleuze, not the body of the character, but the material the body is made of. Thus, for Deleuze, when Bacon scrubbed his drawing, he did not create new bodies, but rather manipulated the material those bodies were made of. The manipulation of the Figure created by the physical act of scrubbing across the canvas represented, for Deleuze, a manipulation of the expressive features of the painting itself. Thus, Deleuze argued, the expression of Bacon's painting resided in the way the force of his gestures manipulated the Figure on the canvas. The force of Bacon's gesture on the canvas can be perceived by observing the scrubbing and distortion of the drawing. This perception of forces is what Deleuze (1981, 33) called a *sensation*. By observing the amorphous Figure, and following with the eye the direction and rhythm of the brush across the canvas, one feels a sensation of those forces. Sensation thus is the atom of expression, in Deleuze's terms.

There are two points to be extracted from Deleuze and Guattari's analysis of expression and sensation. First, I read their definition of expression as not tied to willed volition, but to the materiality of embodiment as a process rather than a condition. This will be useful later to extend the understanding of expression in musical performance, which is commonly understood as tied to the intentional action of a performer. Second, Deleuze's notion of sensation helps us understand the link between material forces, rhythm and expression; it shows how the force, rhythm and movement of a gesture, as it manipulates the painting, is an expression that can be only felt, not perceived. As such, sensation brings forth a particular form of expression that differs from, and yet coexists with, the perceivable expressive features of the finalised artwork. Later, in subsection 7.4.2, I will apply Deleuze's notion of sensation to analyse one of my performances, *Corpus Nil*, where the performer's body is phys-

[9]The work of Francis Bacon is a strong influence in my artistic practise.

ically manipulated into amorphous shapes by the rhythms of choreographic gestures and composed sounds. I will discuss how the muscular force of the performer and the vibrational force produced by the instrument influence the physical, psychic, and perceptual manipulation of the performer's body on stage, and how this negotiation of forces brings forth the expressive features of the piece.

3.3 The Posthuman

3.3.1 The Technological Body in Embodied Practices

The discussion so far helped us define musical performance as a form of becoming. I have defined becoming as a rhythmic movement of stratification operating across thresholds; a process where human and technological actors are enmeshed; that is, they are in contact by fitting each other. In regard to the relationship of human and technical instruments, in musical performance, rave and elsewhere, I have discussed the importance of training, jointly performed by human and technological actors, in producing states of entrainment. In this section I want to eviscerate the details of how the enmeshing of human bodies and technological instruments play out in embodied practices. To that end, I will turn to the posthumanist discourse, which offers important resources in this respect.

Posthumanism analyses the modalities and stakes of the intimate relations of the human and the non-human, the living and the non-living, the organic and the technical. The posthumanist understanding of the human being intends to move past the humanist view which sees individuals as 'distinct beings' (Pepperell, 2003). Whereas humanism sees the human subject as independent from and antagonists of the non-human - which includes machine and computational technology, animals and the environment - the posthuman sees the subject as relational (Braidotti, 2013) and thus 'integrated into, and embodied within an extended technological world' (Pepperell, 2003). Starting from this conception of the relation between human and machine, different theories of the posthuman have been developed. The seminal work of Donna Haraway (1991) looked at how the boundaries of what we used to define human have become increasingly blurred. In her view, a posthuman discourse produces unclear distinctions amongst human, machine and animals that can be used to foster a new understanding of gender and species. I will discuss her view in detail in the next section which deals with the notion of the cyborg. Here, in order to specify how the posthuman condition plays out in embodied practices, I will elaborate on the theories of the American literary critic Katherine N. Hayles and Italian-Australian feminist philosopher Rosi Braidotti.[10]

In the book *How We Became Post-Human: Virtual Bodies in Cybernetics, Literature, and Informatics* (Hayles, 1999), Hayles defines the 'posthuman' as a condition where human beings and machines develop together through their mutual interaction. Hayles's reading of the posthuman starts from the premise that the meaning of embodiment is twofold: on one hand, embodiment signifies the material instantiation of an organism in a context; on the other, it signifies the information pattern that an organism yields (Hayles, 1999, 2). She argues that a human being and a piece of code are both embodied because they are both situated. Their existence is meaningful in a specific context (be it a city or a computer), and they both yield and share information patterns. For Hayles, human beings and machines share information patterns through their interaction, and in so doing, they constitute each other's modalities of embodiment. Hayles thus defines the posthuman subject as an amalgam of different components, a material-informational body that is unbound because it develops through 'continuous construction and reconstruction' of diverse material instantiations and information patterns (Hayles, 1999, 3). Hayles's posthuman therefore, 'configures human being so that it can be seamlessly articulated with intelligent machines' (Hayles, 1999, 3).

Whereas I consider Hayles's take on the posthuman an important basis of my research, I read the seamlessness of human-technology configurations as an arguable point.[11] What makes it difficult to comprehend their configuration as a relationship without seams is that both human beings and technologies are prone to errors and

[10] Whereas this thesis does not draws on his proposal, it is worthwhile to acknowledge the work of Ollivier Dyens, who argued that through the entanglement of human biology, information and machines the boundaries between organic and inorganic become interlaced in ways that make the human subject disembodied in a cultural system that integrate biology, art and artifacts (Dyens, 2001). Similarly, although not relevant to the posthuman discussion, it is also worth noting the work of Mark B. N. Hansen, who looked at phenomenological issues in virtual reality. Hansen has argued against the idea of human disembodiment through technologies to affirm the human extended embodiment through mixed realities, that include both the real and cyberspace (Hansen, 2006).

[11] As a reference, the reader may find interesting the analysis of the debate on seamful and seamless design in ubiquitous computing by Chalmers and MacColl (2003).

miscalculations. As stressed by Waisvisz (2006b), error and miscalculation should not be discarded or overlooked, for they are a constitutive part of the relationship of humans and technology, especially in technologically mediated music performance. I argue that error, miscalculation and glitches are seams which join the capacities of human beings and technologies without necessarily undermining their configuration, but making it more varied. To acknowledge that human-machine amalgams may not be seamlessness has two implications: it means that their capacity to produce new corporealities may be compromised, hindered or blocked; and it implies that, by incorporating and resolving errors and glitches, those new corporealities can avoid stagnation and become resilient. They can become more resistant to normative standards, or compliance, to use Lewis's idiom (Lewis, 2000). Thus, Hayles's statement that the posthuman individual extends her embodied awareness through the coupling and coexistence with machines (Hayles, 1999, 291) acquires a more nuanced nature when read through the acknowledgement of error and miscalculation.

A specific element of Hayles's thought that is useful here is her analysis of the problem of *technical incorporation*, or how incorporated practices are mediated through technology (Hayles, 1999, 204-205). Incorporated practices are, after Connerton (1989), socially influenced bodily practices rooted into bodily automatism and psychological processes. They are physical modes of expression that do not generally rely on conscious thought because driven by sensorimotor programs which are often autonomous from it (Gallagher, 2001), like one's hand gesture accompanying a speech, or one's posture while sitting (this topic will be discussed in detail later in subsection 3.4.1). Hayles's analysis of the role of technology in changing incorporated practices is important to my work for it shows a link between human physiology, instrument's capacities and expressivity; a link that is central to my idea of performer-instrument configuration. Hayles argues that the use of new technologies alters incorporated practices by affecting 'how people use their bodies and experience space and time' (Hayles, 1999, 205). For her, technology has the capacity to intervene upon human corporeality by altering the physiological basis of the human sensorimotor system. In so doing, Hayles observes, the operational capacities of a technology are interwoven in the fabric of one's habitual sensorimotor programs. What I take from Hayles's view is that, by linking hardware and software with human physiology, technologically mediated embodied practices yield a particular kind of expressivity.

With this I do not mean to overvalue the materiality of the body and dismiss its lived and psychic experience, whose importance I have emphasised earlier when discussing thresholds experiences, such as entrainment. Rather, I want to recognise and characterise the capacity of technical instruments to affect both the body's materiality as well as its psyche. Hayles's analysis of technical incorporation is not developed in depth and thus occludes the lived and psychological experience of incorporation. However, the relation between the objective body (material and physiological), the lived body (perceptual and phenomenal) and the immaterial body (psychological and relational) in technologically-mediated musical performance, and embodied practices in general, is crucial to my inquiry. I will attend fully to this problematic later by looking at the work of Vivian Sobchack and Lisa Blackman, respectively in subsection 3.3.3 and subsection 3.4.2. Before concluding this subsection I want to argue for the urgency to acknowledge the political stakes that are inherent to the technological body in embodied practices, especially in musical performance.

Braidotti has dedicated much of her work (Braidotti, 1994) (Braidotti, 2002) to the understanding of human subjectivity and how difference of gender can be understood beyond the negative meaning that comes with its opposition with sameness. In her book *The Posthuman* (Braidotti, 2013), she uses that approach to advance her posthuman theory of the subject. Her take on the posthuman rests on the premise that we live in a global economy where nanotechnology, biotechnology, information technology, and cognitive sciences are converging into new capitalistic strategies. She cogently notes that advanced capitalism aims to accumulate profits by investing in scientific and economical 'commodification of all that lives' (Braidotti, 2013, 59). This includes genomic research on human beings, plants, and animals, and biotechnological intervention, but also the trade of information database by multinational corporations such as Facebook.

As a result of the convergence of capitalist strategies and life-mining technologies into embodied practices, the human being for Braidotti is 'technologically-mediated to an unprecedented degree' which erases the tight boundaries that humanism set around 'Man' as a unitary being (Braidotti, 2013, 57). For Braidotti, the posthuman condition exposes the need to creatively and critically conceive of human subjectivity as the expression of processes of becoming that embrace human and non-human life, living matter and non-living. From this viewpoint, Braidotti's posthuman theory of the subject aims to grasp the new capacities of the biotechnologically-mediated bodies through what Braidotti (2013, 56) calls 'vitalist materialism'. This approach draws upon the views of philosophers Spinoza (1677a) and Bergson (1911), via Deleuze and Guattari (1987), to describe the posthuman as a subject that arises from the self-organisation of life itself. Where the meaning of 'life' refers to all living matter, not only human beings but non-anthropomorphic living forms as well.[12]

Hayles's and Braidotti's discourses rely on the understanding that the boundaries between human beings and other animals, living and non-living beings, subjects and objects have to be radically challenged. What can be distilled from their arguments to inform this research is that because human subjectivity is a process rather than a condition, a matter of relations rather than isolation, human beings extend both their awareness of the world and relational capacity through the coupling with technological bodies. From this viewpoint, the idea of human will as a means of control over technological means is merely a deceptive screen behind which the nature of human beings manifests itself 'through chaotic dynamics and emergent structures' (Hayles, 1999, 288). My focus on physiology and technical instruments is motivated by a strong interest in how the materiality of the body influences bodily practices; however, this does not mean I want to reduce the body to an essentially physiological or material entity. Rather, this project aims to acknowledge and analyse the body as an assemblage of the physiological, the phenomenal, the psychological and the cognitive.

3.3.2 The Cyborg: Merging Incomplete Bodies with Technology

Many of the artistic performances discussed in the previous chapter - including the works by Marce.li Antunez, Stelarc and Orlan - were, especially in the 1990's, referred to with a set of terms including 'cyberarts', 'cyborg', 'cyberspace', 'cyberpunk' and so on.[13] Still today, the terminology is far from gone in popular culture as well as in

[12]Braidotti has described her understanding of Life with the notion of *zoe*. This refers the Greek distinction between *zoe* and *bios* where, according to Giorgio Agamben's reading in (Agamben, 1995), the former indicates the basic fact of living, which is common to all living forms, and the latter refers to the way of living that defines an individual or a group.

[13]See Featherstone and Burrows (1995) for a collection of essays focused on this vocabulary and its cultural implications.

the artistic community.[14] The notion of the cyborg is commonly taken to represent quirky, audacious and often abject physical integrations of technology and the human body, but its signification in body studies is more profound. In this subsection I will trace the origin of the cyborg and discuss its cultural implications.

Ever since human beings began creating artefacts, and well before the arrival of machinic technologies, artefacts and technical objects have been used as extensions of human capacities, an argument that I have discussed earlier looking at Ortega y Gasset (1941) and Leroi-Gourhan (1945). Nonetheless, the posthuman discourse contends that machine and technology have enabled actual examples where living and non-living beings, humans and machines blend into each other, blurring out their ontological separation. The idea of the cyborg, a cybernetic organism part human and part machine, is one such example. The notion of cyborg was originally developed by American scientists Manfred Clynes and Nathan S. Kline (Clynes and Kline, 1960) in the frame of cybernetic studies (Wiener, 1948). Cybernetics is a science field that studies communication and automatic control systems in both machines and living things. The legacy of cybernetics is highly significant in the development of culture and society as we know it. Here, I focus on the notions of feedback and the cyborg which are directly related to my work.

The idea of feedback was originally elaborated during the late 1940's and 1950's in the foundational era of cybernetics. American scientist Norbert Wiener, along with John von Neumann, Claude Shannon and Warren McCulloch, were among the first to publicly discuss the notion of feedback at the Macy conferences, the forum where cybernetic studies were founded and discussed at the time (Hayles, 1999, 7). Wiener, a professor of Mathematics at the Massachusetts Institute of Technology, was inspired by his research on automatic control systems to improve the efficiency of anti-aircraft gun. Wiener's ideas of feedback holds that a homeostatic system - be it a guided missile or a human being - controls itself by monitoring the results of its own operations (Wiener, 1948). The efficiency of a system relies for Wiener on two core aspects of the feedback process: how much information the system gathers to describe the results of its operation, and how fast it selects those information. The more information the system gathers and selects in the shortest time possible, the

[14] Due to my focus on the relations of body and technology in the arts I am often invited to participate in events such as 'Sonic Cyborg' at Vassar College in New York state, see http://bit.ly/2a08Iav.

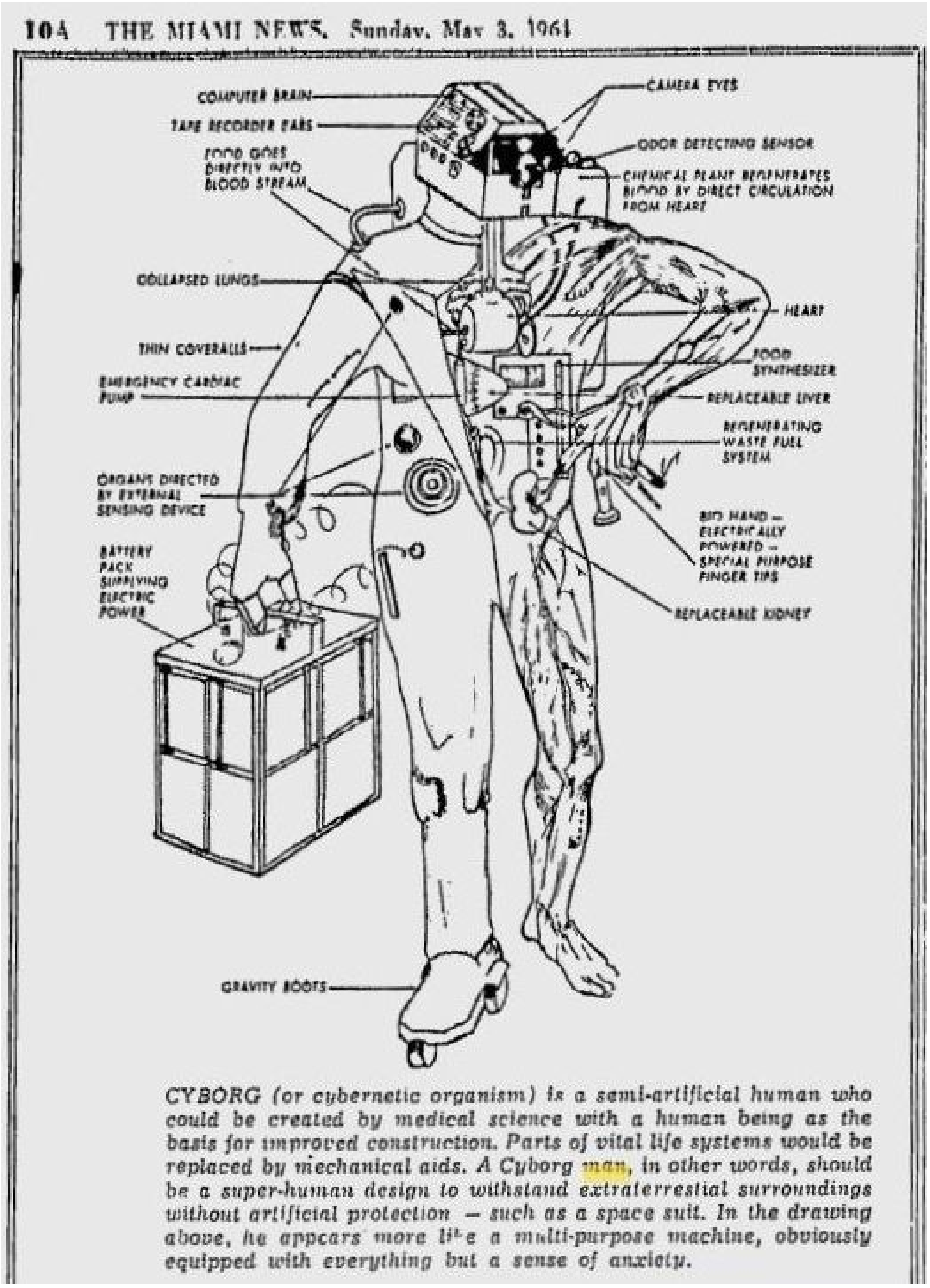


Figure 3.3: An illustration portraying a cyborg appeared in the Miami News newspaper, May 1964.

more efficient the system's homeostatic regulation. It follows that, in Weiner's view, if the system would have to interpret the overall structure of the different pieces of information, its efficiency would be undermined (Hayles, 1999, 54).

In 1960, Clynes and Kline picked up Weiner's idea of feedback and coined the term 'cyborg' to illustrate a 'self-regulating man-machine systems'. In a (largely speculative) paper on space travel entitled *Cyborg and Space* (Clynes and Kline, 1960) they discussed how to extend the human homeostatic system so that it would adapt more easily to hostile environments while retaining its human biological features. They described the cyborg as a living organism whose homeostatic process is enhanced through the use of machines that are physically embedded in its body. Specifically, they considered the benefits of embedding the body of an astronaut with hardware designed to maintain the body's biological processes in a stable condition when travelling in space.[15] Clynes and Kline's vision has strongly influenced science fiction, enough so to ensure the cyborg an established place in today's Western and Eastern literature and film.[16] During the last decades however cyborgs have become actual, living instances. Through the advance of the research in prosthetics, artificial life, synthetic organism and genetically modified animals, living bodies and machines have been physically blended and genetically merged into cyborgs. From this viewpoint, several cultural and critical theorists (Haraway, 1991; Gray et al., 1995; Hayles, 1999; Braidotti, 2013) developed accounts of the cyborg that move beyond and constrast the idea of an enhanced homeostatic organism. They look at the cyborg as a means to outline and discuss new perspectives on human agency and relationality. Their views disrupt, if in different ways, the classical humanist standpoint where the individuality of the human being is paramount to its nature. Rather, they argue for the understanding of human nature as the relational capacity to merge with others, including living and non-living being, natural or technological others.

[15]As a case study, they reported on a first cyborg experiment where a rat's tail was embedded with an osmotic pump which injected in the animal's body some (undefined) chemical substances to maintain the rat's organism in a stable condition without it noticing.

[16]Writers like Philip K. Dick and Isaac Asimov, and film directors, such as Fritz Lang, Ridley Scott, Paul Verhoeven, James Cameron and more recently Spike Jonze, have created manifold wo/man-machines. The gynoid impostor *Maria*, the sensitive 'replicant' *Rachel*, the justice hero *RoboCop*, the killing cyborgs *Terminator*) and more recently new forms of intelligent virtual life, like the caring and love-dispensing algorithm *Samantha*. Japanese anime have a long tradition of cyborg-inspired works, including cult movies such as *Ghost in The Shell*, which is still being hired since 1995, *Akira*, *Battle Angel Aelita*, and the more experimental series *Technolyze* and *Ergo Proxy*.

In the seminal *A Cyborg Manifesto: Science, Technology, and Socialist Feminism in the Late Twentieth Century*,[17] Donna Haraway (1991) analysed contemporary science fiction - populated by creatures that are at the same time human and animal or human and machine, and modern medicine - where prosthetics and genomics establish new intimate and biological bonds between man and machine (Haraway, 1991, 3). In her view, the cyborg blurs the humanist models of a unitary gender, species, and human nature by placing humans, living beings, and machines on the same ontological ground. For Haraway, the cyborg opens up the boundaries of the human body by giving alternative, non-anthropocentric meanings to the notions of 'communication, infection, gender, genre, species, intercourse, information, and semiology' (Haraway, 1995, xiv). Haraway conceives of living and non-living beings - human, animals, plants and computational technologies - as unbounded entities, or 'cross-species' characterised by a 'confusion of boundaries' (Haraway, 1991, 5). It follows that human nature, for Haraway, does not stop at the boundary of the skin; in her view, human and non-human bodies are being melded continuously, they are 'taken apart and put together' (Haraway, 2003, 8) in the practical realisation of cultural and artistic models.[18]

The discourse on cyborgs and cyborg technologies provides a significant argument to this research. In our society, cultural models are created through the configuration of human and technological bodies into living instances which extend, in positive and negative respects, the limits of their parts. The way in which the notion of the cyborg in popular culture has contributed to normalise tired stereotypes such as the highly eroticised cyborg woman (Balsamo, 1996) or typify different kinds of human embodiments as 'monstrous' (Shildrick, 2002) are clear examples of this argument. The modalities whereby human beings and technologies are arranged together are not politically neutral; on the contrary, the criteria against which human embodiments are assessed by institutions and organisations are conditioned by the way human-technology relationship are staged in literature and film as well as in musical performance, I argue.

[17]This was originally published in (Haraway, 1985).

[18]In regard to relationality among species, see also a phenomenological analysis of human-horse incorporation by Ann Game (2001).

I shall clarify the importance of this argument to the present project. The way technological musical instruments are incorporated in particular ways and by particular kinds of bodies have cultural and political implications. This is because the design and performance paradigms which underpin a technological musical instrument foster specific cultural models; they are bound to. The present research project aims to stress, analytically and practically, the political and cultural responsibility of artists working with bodies and technologies; a responsibility which researchers, performers and designers have to carefully consider in their practice for it can enables them to disrupt, hinder or reinforce the normative standards defining human embodiment. In the case of my own work, I take this responsibility seriously and attempt to develop performative strategies and corporeal technologies which destabilise normative assumptions. I will further elaborate on this point in relation to my own artistic practice throughout chapter 5, chapter 6, and chapter 7.

3.3.3 Bodily Integrity or Living a Prosthesis

So far in this chapter I have emphasised how technical incorporation - or the role of technical instruments in mediating incorporated practices - produces new modes of experiencing embodiment. In the current posthuman landscape characterised by ubiquitous, 'smart' and prosthetic devices the 'sense of connection to our tools is heightened' (Haraway, 1991, 75) to the point where humans and machines produce each other through intimate modalities of relation. Gray, Mentors and Figueroa-Sarriera push this argument as far as to argue that '[t]here is no one kind of cyborg' (Gray et al., 1995, 2), but rather varied cyborg technologies and theories evolving differentially according to the context of use and analysis. They assert that it is technically possible to identify cyborgs everywhere in our society (*ibid.*): from the patient who receives a vaccine to treat a virus infection in her body, to the military pilot who controls a guided missile using speech and location sensors. This, they stress, shows that the cyborg is not only about human bodies, rather it indicates the 'full range of intimate organic-machinic relations', from genetically-engineered animals to biocomputers and artificial intelligence (AI) software (*ibid.*).

While I agree with the call to recognise that cyborgs are not only fantastic man-machine assemblages, but can be found in more mundane contexts, I do not fully support this kind of discourse, for it tends to produce the cyborg, or the technological body, as a strictly material body. This produces a condition where we are forced to talk about the technological body as a coupling of a 'real' body and a 'prosthetic' body, which enhances our capacity to know and make the world. From here, we are easily led to construct metaphors of the musical instrument as a prosthetic extension of the player, as I discussed in the introduction. I oppose this kind of analysis for it forces us to step back onto a subject-object understanding of human-instrument relationship, a tired dichotomy which this project aims to dissolve. A fundamental problem with this kind of discourse is that it prompts analyses of the cyborg and the prosthesis based on what come across as purely material and quantifiable relations, physiological processes and mechanical mechanisms. The lived experience of incorporating a technological instrument is however neither clearly material nor precisely quantifiable. In this subsection, I want to expand the analysis of the material physiological body by looking at what physiology alone cannot explain: the perceptual, expressive lived body. After all, in musical performance we do not attend to material and physiological bodies but to expressive, energetic and lived bodies.

In the previous subsections I have used the notion of technical incorporation to examine how embodied practices are experienced differently through technology. But the notion of incorporation also points at a different issue, that is, *bodily integrity*. In cultural studies, bodily integrity refers to the way human bodies experience and deal with changes in their condition through methods of incorporation, assuming thus that bodies are neither fixed nor stable (see Blackman (2012)). How to conceive the body as a whole in the face of its corporeal coupling with technical instruments? How do other factors such as personal lived experience, temporality and situatedness problematise bodily integrity? These are the questions I want to examine in this subsection.

Thus, I will turn to what exceeds and complements the posthuman notions discussed above: a reflection on the relation between the objective body (material and physiological) and the lived body (perceptive expressive) and how this relation affects bodily integrity. This problematic is crucial to the current project. In my artistic work I use physiological computing techniques to create sonic interactions between the performer's body and the instrument. The way I conceptualise and design those interactions is directly derived from the analytical framework I am elaborating in this chapter. Therefore, my use of physiological computing techniques does not aim to externalise physiological states, but rather to enable the lived bodies involved in a performance (the performer and the listeners) to learn to be affected, to enter a rhythmic entrainment, to vibrate with the sensation of the human, vibrational and technological forces at play.

An apt way of problematising the relation between objective and lived body in relation to a prosthesis is provided by American feminist scholar Vivian Sobchack (2010). In her auto-ethnographic analysis of the phenomenology of the 'phantom limb' she produces an understanding of bodily integrity as an ambiguous and mutable experience of the lived body, which opposes the positivist representations of life sciences where human embodiment is fixed and autonomous.[19] In 1993, as a result of a recurrent soft-tissue cancer in her thigh, Sobchack's left leg was amputated high above the knee and replaced, in due time, with a prosthetic leg. She recounts and analyses how her experience of getting accustomed to the sense of her phantom limb, and the subsequent incorporation of the prosthetic leg, heightened her consciousness of the 'dynamism and mutability' of her lived body.

Sobchack describes the renewing of her bodily integrity as a gradual process. First, she incorporated the phantom limb in an ambiguous way; the phantom limb was, at once, absent and present. She could feel it, but not perceive it; recognise it without seeing it. Then, after she used and familiarised with the prosthetic leg, the phantom limb 'both figuratively and functionally elongated and grew into the hollow of [the] prosthetic socket' (Sobchack, 2010, 63). What Sobchack means is that she did not feel the phantom limb as an objective entity or the prosthesis as a functional attachment; rather the phantom limb *animated* the prosthesis. The feeling of the phantom limb became embodied in the prosthesis and eventually disappeared. But the way the phantom was incorporated was ambiguous: she did not feel the phantom as 'an objective and bounded thing' which her body had assimilated; nor she felt her subjec-

[19]The problem of bodily integrity is the subject of a vast area of study including feminist ontology, gender studies, body theory, phenomenology and medical ethics. Here I focus on Sobchack's particular contribution for it relates directly to my analysis of the relation between corporeality and technical instruments. For a comprehensive collection of articles examining the problem of bodily integrity from a variety of different viewpoints see the related special issue of the journal *Body & Society* (Blackman, 2010) and a recent article by Shildrick (2013) where she examines incorporation in the context of organs transplantation from a body to another and microchimerism, the circulation of cells between a mother and her child.

tive experience had ceased perceiving the phantom. Rather, drawing on Weiss (1999), Sobchack explains that the incorporation process had opened her bodily experience to another form of bodily integrity, another sense of herself as a whole, what Weiss (1999, 37) calls morphological imagination. Drawing on this experience, Sobchack (2010, 53) argues that the objective criteria used to determine a hierarchy and division between the phantom leg, the prosthetic leg and the real leg - such as material presence, visibility and functionality - are highly questionable, for they occlude the lived experience of incorporation. In contrast with many scholarly analyses of the 'prosthetic', Sobchack cogently notes that for many of the people using prostheses in their daily life, the prosthesis makes the phenomenal body more ambiguous and dynamic; for one's experience of bodily integrity is dependent on the way one engages with others and the contexts of the engagement. The prosthesis is both, at once, absent and present, and this experience changes according to contexts and situations. Linking back to the ambivalent potential of human-instrument assemblages I emphasised in section 3.3, Shildrick (2013, 278) stresses that a 'prosthesis may both extend functional agency *and* radically destabilize specifically human agency as such' (emphasis by the original author). The way a prosthesis - or an incorporated technology - is subjectively experienced is a complex, ambivalent matter which cannot be resolved by simply assessing the presence, visibility, and functionality of a prosthesis.

Sobchack's phenomenological approach is important to this research because it allows us to analyse the intimate relation of a technical instrument and a human body through the lens of the lived, expressive body. This helps us balance out the physiological and the lived, the material and the phenomenal, the technical and the corporeal and embrace them as part of a broader and more ramified notion of the body. It helps us recognise how technical incorporation is a complex and multi-layered process where physiological, phenomenal and psychic processes unfold through each other through habit and repetition. As Shildrick (2013, 273) succinctly puts it: '[T]o rely on a prosthesis is not a matter of a self using an exterior and impartial technology, but of incorporation, of becoming embodied as hybrid'. Technical incorporation ambiguously blurs the boundaries between the subject and the object giving rise to experiences and problematics which are not reducible to the material or the immaterial, the individual and the instruments, but must be accounted for as indeterminate and complex transformations.

3.4 Embodiment and Biomediation

3.4.1 The Human's Use of Instruments

In the next two subsections I will delve deeper into the issue of bodily integrity in relation to technical instruments, and in particular in the ambiguous tension between material and immaterial, subjective and objective which we discussed above with the work of Sobchack. I will provide an account of the human's use of instruments using resources from phenomenology (Merleau-Ponty, 1978; Gallagher, 2001) and body theory (Blackman, 2012). These resources, as we will see, are not always compatible. Traditional phenomenological accounts - such as the classic work of Merleau-Ponty and those extending his arguments calling upon neuroscience - often neglect the affective, psychic and gendered dimensions of the lived body. This rightly makes body theory accounts often cautious towards those traditional resources. Here I will lay out particular views drawing on both approaches. The aim is to grasp what one can speak back to the other. Following a phenomenological introduction to the role of proprioception and body schemata in the human's use of instruments, I will critically extend this set of arguments looking at phenomena of automatism in jazz performance (Berliner, 1994) and subliminal psychology (Blackman, 2012). This will bring forth aspects of the human's use of instrument which exceed traditional phenomenology and are a source of inspiration for my artistic work.

Merleau-Ponty explained that at the basis of human's use of instruments lies the mechanism of proprioception. Proprioception is a mechanism that allows the body to determine the position of neighbouring parts of the body and the strength of effort exerted to perform a physical gesture. In more detail, Schmidt and Lee (1988, 153-158) described that this is made possible by the integration of information from a broad range of sensory receptors located in the muscles, joints, and the inner ear.[20] One way to grasp the mechanism of proprioception is to compare it with two other modes of self-perception: exteroception and interoception. Exteroception organises tactile sensitivity to external objects, whereas interoception organises the sensitivity to the movement of the body's internal organs.

[20]Technically, a sensory receptor is the ending of a sensory nerve. It transduces internal or external stimuli in an electrical impulses for the central nervous system. The muscle sensory receptors are called muscle spindles, and they sense the changes in the muscle length, for instance.

Merleau-Ponty (1978, 111) described that 'there is not a perception followed by a movement, for both form a system which varies as a whole'. Perception and movement function together, constituting a delicate balance between intention and performance and between the movement as intended and how it actually occurs.[21] Merleau-Ponty pointed to the fact that proprioception and the related closed-loop motor control mechanisms are both conscious and pre-conscious. An example of a conscious proprioceptive mechanism is the case where one touches the tip of the nose with the eyes closed. In this case, one does not learn the position of the nose through sight, but it is the sense of proprioception that provides this information. On the other hand, pre-conscious proprioception is demonstrated by the righting reflex. This is a reflex, or an involuntary reaction, that the human body produces to correct the body orientation when falling or tripping. For instance, when one falls asleep while sitting on a train, the head repeatedly tends to fall on one side and the body moves the neck muscles autonomously to position the head in a correct position. The fact that proprioception is both conscious and pre-conscious is important here because it shows that 'the body and consciousness are not mutually limiting, they can only be parallel', as Merleau-Ponty (1978, 124) argued. It is a question of understanding the lived body as a site where physiology, perception, cognition and action interact continuously with each other. For Fuller (2005, 63), it is from their 'sustained interactions' that one's expression emerges. This implies that physiology, perception, cognition and action are not hierarchically organised, rather, they operate by affecting each other.

To further understand the superposition of conscious and pre-conscious factors determining human movement and use of instrument, it is worthwhile looking at Shaun Gallagher's work on body schemata (Gallagher, 1986). Body schemata are motor control programs that govern posture, movement, and the use of instruments. Body schemata, Gallagher (2001, 150) explains, are pre-conscious in that they operate below 'the level of self-referential intentionality'. When moving or maintaining a posture, the human body automatically performs a body schema and so allows one

[21]For a radical take on this problematic see the work of phenomenologist Maxine Sheets-Johnston (1999) on the primacy of movement, where she argues that, in short, feeling is the embodiment of movement and that it is movement to yield one's subjectivity. I do not make use of her work here as I want to focus the discussion on movement in relation to the use of instruments, as opposed to an analysis of movement in itself, which would require a different kind of analytical framework than the one I set up in this thesis.

to move without consciously focusing on the state of the body and the position of limbs. One does not need to be consciously aware of the position of the feet while running up a familiar staircase. A body schema, according to Gallagher (2001, 150), should not be confused with a reflex. Whereas a reflex is an automatism which one can hardly influence, a body schema enables movements that 'can be precisely shaped by the intentional experience or goal-directed behaviour of the subject'. When one reaches for a glass of water with the intention to drink from it, as Gallagher (2001, 151) illustrates, the hand 'shapes itself' in an a way that allows one to accurately grab the glass; one does not shape the hand posture in advance. Body schemata thus are not a cognitive operation, yet they can contribute to, or undermine, intentional activities.

Although I regard the work of Merleau-Ponty and Gallagher key to the understanding of the superposition of conscious and pre-conscious bodily performance, it is important to address at least two problems with their approach to phenomenological experience (and much of current phenomenology drawing from neuroscience). One is the assumption that the body is 'gender-neutral, ageless and universalised' (Shildrick, 2002, 50). Whereas Merleau-Ponty's phenomenology applies to human experience in general it also elides the particular modes of being in the world of specific bodies, as feminist philosophers Young (1980) and Shildrick (2002) note. These include female, transgender, intersex and differently abled bodies, as well as those bodies considered 'monstrous' in particular societies because of their differences and vulnerabilities. As philosopher Gail Weiss (1999, 4) notes, via Young and Butler, human bodies are 'marked' by racial, sexual, age, ethnic, class, moral, and technological differences that must be taken into consideration to understand the difference and richness of distinct modes of embodiment.

The second problem is the lack of consideration for the situatedness of the lived body. In her analysis of the particular phenomenological experience of the female person, Young (1980) cogently reminds us that the lived body is defined by its *situation*, that is, 'the historical, cultural, social, and economic limits of her situation'. Starting with this premise, Young aligns the meaning of 'feminine' with the particular situation where the phenomenal female body is formed and experienced. In so doing, she rejects the notion of a biological, physical, or essential femininity which was used to characterise women's bodies in 1960s phenomenological psychology as well as in popular culture.

The reason why this feminist critique of traditional phenomenology is important to my research is that, through the artistic performances I have created, I explore the alterity of the technological body: the capacity of a body enmeshed with a technical instrument to be 'other' than the normative assumptions governing Western society. Admittedly, my own body, which I use extensively in my performances as a means of research, experimentation and expression, may seem fairly 'normal', or should I say, normalised. I am a tall, thin white man and I identify my gender as that of a man. I do not have a prosthesis, nor I dream of forcefully embedding cyborg technologies inside my body. On the other hand, I have altered my body by tattooing about fifty per cent of it, I wear digital hearing aids every day due to my hearing loss (I will detail this experience later in section 4.2), and I have an androgynous body, of which I am fully aware, fond and respectful. By growing up, and initially struggling with, this kind of body, I became increasingly interested in how, on stage, technology can be used to make the body more or less fluidly become 'other', something different from what it is everyday. What interests me thus is a radical experimentation with normative values, with the way they are culturally embodied and and the way technology-mediated artistic practice can displace them.

3.4.2 Automatism and Threshold Conditions

In this subsection, I will elaborate on what exceeds the phenomenological discourse on body schemata by discussing experiences of body-instrument automatism in jazz improvisation (Berliner, 1994) and experimental psychology (Blackman, 2012). In the examples I will discuss, the body and the instrument are experienced as acting independently from the conscious will of the subject. This will problematise the human-instrument relationship in musical performance by bringing to the fore the potential of both the body and the instrument to act as if they were independent from one's own intention. This discussion will allow us to mobilise the tension between physiology and psychology, training and suggestion, self-discipline and unconsciousness, human actor and technical instrument. The two artworks I created during this research enact that tension through particular configurations of human bodies and technological instruments. Thus, the arguments I will present next are crucial to the development of the two artistic works.

Merleau-Ponty (1978, 143) exemplified the working of body schemata observing the case of a blind man's stick. The stick is not an external object to the man who carries it. Rather, the stick is to the blind man a physical extension of touch. This happens because the stick becomes an additional source of information on the position of the limbs, and thus, with continuous training, it is integrated in the body schemata; it is converted into a sensitive part of the body that complements the proprioceptive sense.

To add more to his view, Merleau-Ponty looked at instrumental players, specifically at organists. When rehearsing for a performance with an organ that a player has not used before, the organist, according to Merleau-Ponty (1978, 145-146), does not commit to memory the objective position of pedals, pulls and stops. Rather, she incorporates the way in which given articulations of pedals, pulls and stops let her achieve given musical or emotional values. Her gestures draw 'affective vectors' (Merleau-Ponty, 1978, 146) mediating the expressiveness of the organ through her body. The organist does not perform in an objective space but in an affective one. Body schemata constitute 'knowledge in the hands', as Merleau-Ponty (1978, 144) called it. This is a particularly relevant insight for my research. In musical performance, body schemata drive the way the performer physically interacts with the instrument in accord to the musical or emotional significance that given parts of the instrument allow for.

This aspect of body schemata, or the degree of autonomy the body holds in musical performance, has been largely discussed in the study of jazz improvisation. In his classic work on learning jazz improvisation, David Sudnow (1978) used phenomenological insights to describe how his hands learned to improvise through a progressively more intimate relationship with the piano; a know-how earned through an understanding of the autonomy of the body in learning and performing embodied practices. In his ethnographic study of jazz improvisation, Paul F. Berliner (1994) used first-person interviews to show how improvisers have to be well aware of the autonomy of their bodies. They have to learn that intentional control and unintentional actions of the body contribute in equal part to a successful performance. For instance, Berliner (1994, 190) described how, early on in their training, jazz students learn that 'the body engages itself directly in the composition of new phrases'. The fingers may 'give' musical ideas to a pianist by creating variations on a previously trained phrase for physical relief, for example. In short, the automatisms of the body schemata can provide new musical ideas.

Importantly, as many of the improvisers interviewed by Berliner (1994, 208) described, this level of automatism is achieved through the repeated training of phrases that require to reach a certain threshold of intense physical effort. An autonomous variation on a formerly mastered finger pattern often happens in combination with a 'limit' situation, a threshold condition. For instance, increasing effort and fatigue due to a long ostinato prompt the body schemata to autonomously optimise the performer's physical interaction with the instrument. As a consequence, a player may find herself unintentionally playing a given phrase in a different way. One may understand this mechanism as producing an incorrect interpretation or an error; in a sense, it is a kind of glitch that happens because, in order to optimise movements due to fatigue or discomfort, the body shifts between different schemata to negotiate a novel bodily condition. On the other hand, I prefer to emphasise that these glitches in the body schemata are the source of new musical ideas, as Berliner's interviewees admitted on several occasions. Ideas that would have not emerged otherwise.

This example serves to understand the relationship of human beings and instruments as a process of balance and unbalance, a metastable equilibrium in Simondon's terms, between the conscious and the pre-conscious, the material and the immaterial, the cognitive and the perceptual, the error and the insight. With this phenomenological account of jazz improvisation I want to suggests that variations on musical performance arise from the pre-conscious performance of body schemata as well as intentional variations. This is possible because the body configures itself with the instrument to fit each other for the sake of the performance. The instrument has an active role in this process because it is according to its specific material and sonic qualities that the body learns new body schemata and thus shifts across different modalities of embodiment. Importantly, this discussion also shows how errors can provide novel musical ideas, which links back to and extends further the idea discussed earlier that errors are not only integral to human-instrument configurations, they are also the source of mechanisms that help evade routine and develop more varied experiences.

Although my discussion thus far concentrated on the physiological and phenomenological mechanisms of the human's use of instrument, I do not want to delimit or reduce the body to its physiology and physicality, as stressed earlier. What I want to emphasise is the direct and unstable interaction between physiology, cognition, subjectivity and technical instrument. This kind of interaction in musical performance has the potential to engender both error and creative expression in ways which confound the boundaries between intention and action, consciousness and pre-consciousness, material and immaterial body. As a result, what emerges as a crucial creative potential is the threshold itself, the fine line that joins conscious the pre-conscious, intention and action. This resonates with Massumi's idea that threshold phenomena actualise latent abilities and qualities of a human body (see my earlier discussion in subsection 3.2.2). Indeed, we have seen that jazz improvisers often experience their own body as an entity on its own, so much so that when they reach threshold conditions due to fatigue or strain their bodies may autonomously perform latent musical ideas. Fatigue, strain and repetition create the threshold condition whereby the body exceeds its own conscious operations and enters a new field of action, where the distance between conscious and preconscious seems to disappear and leave space for new modes of expression. This however is a partial understanding of threshold phenomena.

As Lisa Blackman (2014) perceptively notes, the rendering of threshold phenomena that we see in Massumi's work (and much of the current studies of affect) suffers from being alienated from its originary context.[22] Within current affect research, the roles of particular subjectivities, technical instruments and contexts is often dismissed in favour of (new) materialist views on physiology and perception. But, originally, threshold phenomena were examined through a deep and personal involvement of the experimenter, which included thorough training, discipline and a specific kind of technical framing. Blackman (2012) traces the origin of the study of threshold

[22]It is important to note how Blackman's motivation to analyse threshold phenomena differs from my own. The driving force of Blackman's interest in threshold phenomena and their genealogy is the problem of subjectivity or personality. She sees threshold phenomena as the means to displace and confuse the boundaries between past and present, self and other, material and immaterial, psychological and social. My own interest in threshold phenomena is slightly shifted from the problem of personality and intends to address how threshold phenomena take place in human-instrument configurations; specifically how they can yield new forms of corporeality and affective experience during the interaction of a human player and a computational musical instrument.

phenomena back to the early psychological research into, what she terms, immaterial phenomena: practices and processes such as mediumship, hypnotic suggestion, telepathy and hallucinatory phenomena that problematise a sterile cut between the physiological and the psychological body; phenomena which force us to attend to the role of subjectivity in the experience of threshold conditions. Particularly relevant to this thesis are the experiments on induced automatism by researchers Leon Solomons and Gertrude Stein, which Blackman (2014, 2012) has discussed on different occasions. Solomons and Stein (1896), two students at William James's psychological laboratory at Harvard,[23] investigated hysteria as an expression of *automaticity*; that is 'the feeling of being moved or directed by [...] an extra-personal force or entity' (Blackman, 2014, 3). Among several automatism experiments, Solomon and Stein recreated in their laboratory the experience of automatic writing, a practice studied in psychic research to communicate with spirits. Automatic writing is performed using a particular instrument, a writing planchette, which consists of a glass plate rolling on metal balls and embedded with a pencil. As Blackman (2012) describes, the experimenter engages in an activity that holds her attention, such as reading a novel, and if she becomes enough immersed in the novel, the arm attached to the pencil may move without the subject being aware of it. However, as soon as the subject becomes aware of the movement this is experienced as 'extra-personal', as something other than the subject. This is not an immediate process but a performative one. As Solomons and Stein (1896) described, to be able to perform automatic writing they conducted an intense training, experiencing particular threshold of sound, labour and attention through choreography and self-discipline.

It is not difficult to draw a parallel between Solomon and Stein's experience of automatic writing and the jazz students' experiences of automatic musical variations discussed earlier. Both practices are characterised and enabled by intense training, heightened attention and a feeling of 'becoming unconscious' (Solomons and Stein, 1896, 499), which many musicians, myself included, would have no difficulty in identifying with. Importantly, both practices rely on an intimate relation between a particular technical instrument (a planchette or a trumpet) and a performative subject (a medium or a musician).

[23]William James was a seminal American philosopher and psychologist, acknowledged as a leader of the philosophical movement of pragmatism and of the psychological movement of functionalism.

These examples point right at the core of this research project: the creative potential of experimenting with a technological body that is *at once* material, lived and immaterial. On one hand, it is possible to provide specific phenomenological and physiological explanations for the kinaesthetic experience of automatism, as I did earlier in the case of jazz improvisers. On the other, the immaterial and performative nature of those experiences - the way in which they emerge through training in threshold conditions and draw on subjective forms of psychic attunement - exceeds phenomenological and physiological explanations. It calls for an understanding of human-instrument relationships as personal, mutable, contextualised, technically specified and explicable only through their performance. This kind of performativity of threshold conditions is what I have explored and experienced in the two artworks that emerged from the current research. I will detail the artworks and their realisation in chapter 5 and chapter 6.

3.4.3 Biomediating Human and Technological Bodies

In the previous two subsections I examined the relation between the use of technological instruments, threshold conditions and affective experiences by laying out arguments from phenomenology, body studies, music and experimental psychology. While each of those resources has a particular viewpoint and theoretical framing which makes them not entirely compatible with each other, my aim was to understand what they could speak back to each other. In so doing, I refined the view of the technological body as a complex ecology of material, lived and immaterial components. In this section - the last one before I describe and discuss my own analytical tool, the notion of configuration - I want to look more in depth at the mediation of the body, the technical instrument and the milieu in embodied practices; how the co-constitution of human beings and technical milieux (see section 3.2) enables the making and knowing of the world. To do so I will discuss the notions of autopoiesis and enactivism, which form the grounding for the theory of the embodied mind; a vast scientific framework based on the idea that cognition depends on the kinds of experience afforded by a particular body, which is itself embedded in a specific biological, psychological and cultural context (Varela et al., 1991). Some problems with this theory will be confronted by calling upon resources from the discourse of biomediation. The discourse of biomediation is crucial to this research, for it analyses in detail the two kinds of media which are at the core of the practical part of the current research, and which I used in the two final artworks: biomedia (Thacker, 2004), the technologies acting upon or drawing from biological data, in my case, physiological computing technologies; and new media, the digital technologies which help construct human embodied experiences, in my case, interactive audio and data analysis software. This analysis will allow us to understand how human-machine co-constitution takes place in embodied practices, and what kind of affective experiences it yields.

The term autopoiesis, from the Greek *αυτο* (auto-) meaning 'self', and *ποηδίς* (poiesis) meaning 'creation', 'production', was coined by Chilean biologist Humberto Maturana to describe cellular life in 1972 (Maturana and Varela, 1980, xvii), and then further elaborated together with his colleague Francisco Varela in the book *Autopoiesis and Cognition: The Realization of the Living* (Maturana and Varela, 1980). Inspired by the cybernetic insights on homeostatic systems, they defined autopoiesis as the mechanism enabling the self-production and self-conservation of a cell. They argued that a cell is an organised group of molecules constrained within a chemical semi-permeable boundary and embedded in a medium, which is its environment. The boundary keeps intact the structure of the cell and yet allows chemical substances to enter the cell from the medium. Inside the cell, a network of metabolic reactions brings about large molecular transformations that continuously change the cell organisation. Because, as Maturana and Varela emphasised, any living system is a molecular system the notion of autopoiesis can be generalised to embrace all living systems. Thus, in their opinion, autopoiesis enables all living systems to produce themselves through a situated relation of co-dependence with their own environment.

Maturana and Varela further extended the notion of autopoiesis by applying it to the problem of cognition. They used the relational capacity of the living system with its medium to explain the mechanism of perception. In their view, the environment produces a range of stimuli and the living being selects which stimuli to be sensitive to so that it can maintain its autopoietic process. These ideas were further developed by Varela under the influence of Husserl, Heidegger, Merleau-Ponty's phenomenology and his study of Buddhism and Taoism (Froese, 2011). Varela thought that the theory of autopoiesis should have been extended by analysing human experience. To this end, he integrated autopoiesis with Merleau-Ponty's phenomenological insights on the nature of subjective and inter-subjective perception.

In the book *The Embodied Mind: Cognitive Science and Human Experience* (Varela et al., 1991), Varela, Rosch and Thompson argued that human beings know the world in the way they do because of the specific structure of their bodies. If their bodies were different then their perception and knowledge of the world would differ as well. The proposition of Varela and his colleagues, known as *enactivism* (*ibid.*), claims that there is no separation between the cognitive operation and the biological structure of a human being. It argues that the mind is embodied because human consciousness depends on, and cannot exist outside of, one's own bodily experience. The theory of the embodied mind thus asserts that human beings know and make the world by integrating their biological structure and cognitive capacity. This puts an emphasis on the mutual dependence of the mind and the body in the production of knowledge through embodied practices and physical action.

While the embodied mind thesis is certainly useful in sidestepping the tired dichotomy separating the mind from the body, it does little to move past the idea of the human being as a self-enclosed and self-sustaining entity. This assumption, inherited by the notion of autopoiesis, makes it difficult to escape the idea of the human body as a universal subject in interaction with others, and risks thus to fall back on another dichotomy, that of the subject-object relationship between human beings and others, especially technical instruments. As American sociologist and philosopher Patricia Clough (2008) points out in *The Affective Turn: Political Economy, Biomedia and Bodies*, the problem with the autopoietic discourse is its understanding of the living being as a self-enclosed organism. This raises two issues: on one hand, as argued by Hayles (1999), the notion that an organism functions only to produce itself is contradictory to evolution, which takes place through speciation;[24] on the other hand, as Keith Ansell-Pearson (1999, 170) notes, by stating that only living organism are capable of self-organisation and self-production, autopoiesis overlooks the 'dynamical and processual character of machinic evolution'. For Ansell-Pearson (1999), machinic evolution involves both living and non-living beings. It is a process that links the self-organisational structures of living and non-living organisms in ways that cross the ontological limits of each. Ansell-Pearson elaborates his critique by calling upon

[24]The evolutionary process by which new biological species arise.

the work of Margulis (1967) on *endosymbiosis*. This is a modality of cellular evolution that involves cell nuclei and foreign cellular components such as mitochondria. The latter are captured in the body of the cell, yet they conserve their own autonomous reproductive process and thus can reproduce through contact among different species (Figure 3.4). Ansell-Pearson uses the idea of endosymbiosis to cogently argue that organisms are capable to be more or less open according to different scales of operation. In this light, and resonating with Haraway, Hayles, and Braidotti's work discussed earlier, the organism for Ansell-Pearson (1999, 154) should be redefined as a system which produces itself with varying degrees of openness, performing what he has described as a 'play between nonorganic and stratified life'.

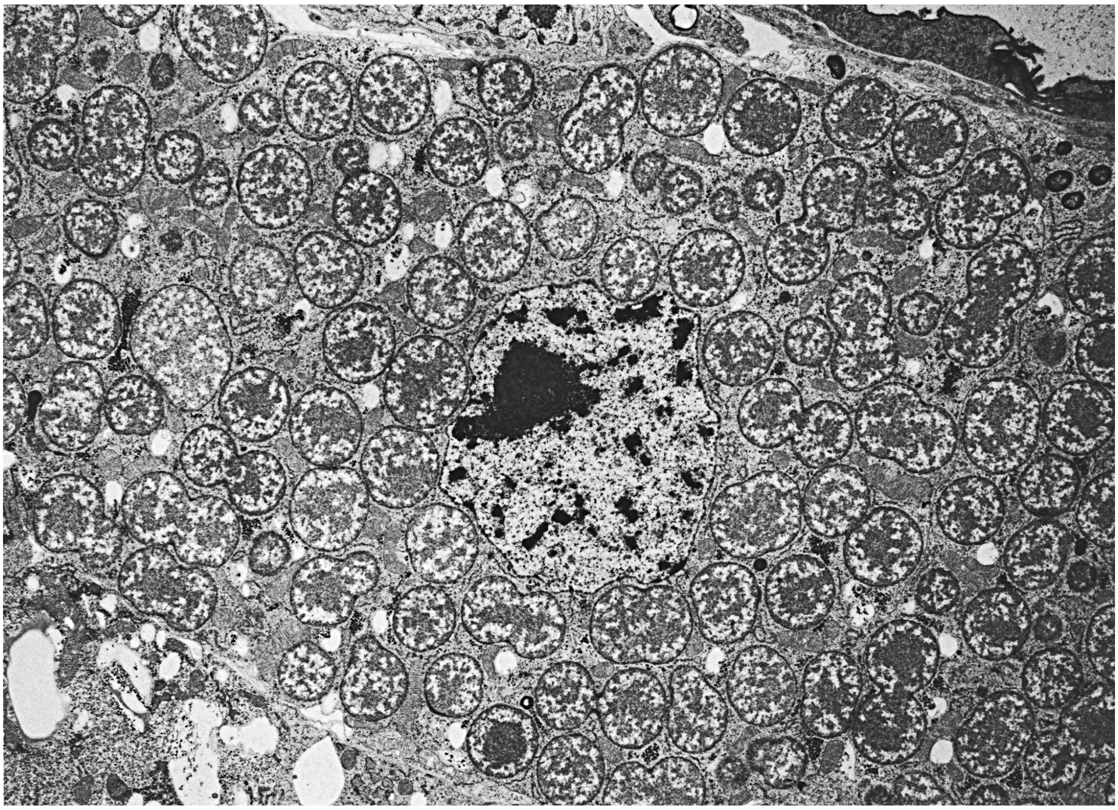


Figure 3.4: A *Buchnera aphidicola* in a host cell. The Buchnera is a primary endosymbiont of the aphid. In the picture the central object is the host nucleus and the Buchnera cells are round and packed into the cytoplasm.

Drawing on accounts of the evolutionary interplay of living being and non-living, Clough argues that the capacity to be self-organisational is 'immanent to bodily matter and matter generally' (Clough, 2008, 1). This allows both to maintain their autonomy while co-depending on each other in the production of themselves. Clough, similarly to Braidotti and Ansell-Pearson, calls upon Spinoza (1677b) to refer to this capacity as affect, or the relational capacity of a body to affect another and therefore to augment or diminish a body's capacity to act (*ibid.*). In her analysis, affect is that which links ontologically bodily matter and non-living matter, which drives their co-constitution. Clough (2008, 2) situates her analysis of affect in the current landscape of technological media. She defines two technological media: biomedia, as defined by Eugene Thacker (2004); and new media, drawing on Hansen (2004).

Biomedia are understood by Clough as the technologies enabling the mass production of genetic material and acting upon, or drawing from, biological data. The term new media refers, for Clough, to the active role of digital technologies in constructing human embodied experiences through an intensification of human autonomic processes. The interaction of bodily matter and non-living matter with biomedia and new media is what Clough defines as *biomediation*. In her words, biomediation is characterised by the capacity of biomedia and new media to 'attach to and expand the informational substrate of bodily matter and matter generally' (Clough, 2008, 2). Put differently, biomedia and new media hinder or extend the ontological and perceptual capacity of the human body, while maintaining it as a biological entity (Clough, 2008, 2).[25]

The above account of biomediation complements the analysis of the co-constitution of human and machines I have elaborated in this chapter. The idea of biomediation shows that the properties of an individual and those of a technology do not only grow interwoven, as I contended earlier; through biomedia and new media, I argue, human and machine properties *intensify* the affective capacity of the same body they co-constitute. The term 'intensify' is useful here for it has a double reading: the first

[25]Biomediation can also extend biology itself. According to Thacker, biomediation allows to use biology beyond its own limits while maintaining its biological features (Thacker, 2004, 14-15). Thacker makes two examples; one is biocomputing, where DNA molecules are used to perform computation in test tubes, and the other is bioinformatics, where DNA is treated as information, and thus digitised, categorised and archived into databases (Thacker, 2004, 4). In both examples the process of biomediation produces a view of biology such that it is not ontologically separate from the technical medium, but rather it *is* the technical medium. In other words, the biological features of a human body are used as a means of technological computation. This finalises the merging of biological and inorganic bodies into one self-organisational entity (Thacker, 2003) and thus mobilises biology as both the source and the medium of technological operations (Thacker, 2004, 201).

means to make something more intense, and the second, used in photography, means to increase the opacity of something. Therefore, to say that biomedia and new media intensify a body's potential to affect does not only mean that said potential is made more intense, but also that it is made more opaque, less transparent, in other words, more difficult to detect. Therefore, in my view, biomediation is the medium through which an individual and a technology co-constitute each other and form a body possessing a particular kind of affect; one that is at the same time intensified and obscured by the same body it emerges from.

This process whereby a biomediated body develops such a particular kind of affect can be understood more fully by recalling Hayles's idea of technical incorporation (Hayles, 1999, 205), which I have discussed earlier in section 3.3. For Hayles, technology alters human bodily automatism at the level of the sensorimotor system; the operational capacities of a technology become, in her view, interlaced with human physiology. The alteration of bodily automatism through the use of technology is therefore a process that unfolds with a high degree of granularity, pervading both human and technological bodies at the level of their informational substrata. However, I argue that the affective potential of those bodies is made more intense and more opaque for it is cultivated at the level of human physiology *and* released through embodied practices, thus negotiating a complex relationship between the psychological, the lived, the physiological and the technical. This resonates with Sobchack's conception of incorporation, where she emphasises the role of training, discipline and the 'lived' experience in negotiating an economy of desire between person, technological extension (a prosthesis), others and context.

3.5 Summary

In this chapter, I discussed the analytical framework of this research, which I used to provide a view on sound and body art performance that dissolves the dichotomy human-subject versus instrument-object. A selection of analytical perspectives on the formation and nature of the human body and its relation to technical systems (including machinic, computational and biological technologies) was drawn from philosophy and cultural studies. I discussed interlaced notions including human unfinishedness, thresholds and rhythmic becoming, and analysed the phenomenological basis of the use of instruments in the context of posthumanism and studies of affect and biomedia. This framework provides an understanding of technological embodiment, in artistic performance and elsewhere, as an entanglement of the material and the immaterial, the psychological and the psychic, the sensory and cognitive, the human and the technical. Key to this understanding were a set of concepts - technical milieu, training, psychic attunement, rhythm and repetition - which I have analysed in the context of technologically-mediated embodied practices, such as music performance, raving and dancehall.

Now I want to ask a question to which, given the analytical framework presented in this chapter, the reader may already have the answer: In our physical interaction with technology, are the capacities of our bodies the object or the subject of the action? My point here is that rather than understanding human beings as subjects whose control over their own bodies is influenced by technology, it is worthwhile to consider another viewpoint; one where human beings and technology mutually affect each other's identities, properties and capacities. I want to suggest that this viewpoint allows us to move beyond the idea where corporeality in sound and body art performance is fixed and determined. It allows us to embrace a notion where corporeality emerges through the material, immaterial and affective interaction of human bodies and technologies. The question then becomes which means can be used to analyse such arrangements in aesthetic and political terms, and how this analysis can be useful to understand the corporeality of the technological body, in electronic musical performance and elsewhere. My proposal is to utilise an analytical device which I refer to as *configuration*. The next chapter is dedicated to presenting and discussing this analytical device, which represents the first contribution of the present research.

Chapter 4

Configuration

4.1 Introduction

Configuration, in my own terms, is a method to map different forms of embodiments. It is a way to examine the relationships between things forming a living body; an ecology, as it were, of the material, lived and immaterial aspects of embodied existence. The concept of configuration is key to my practice-based investigation of the performer-instrument relationship in sound performance. I shall give a basic example to exemplify it. A player's body and an instrument's parts are fitted to each other, meaning that they have particular material relationships; keys have to be pressed, buttons have to be pushed, sensors have to be excited by certain signals, and so on. While sound is created through the performance of those material relationships - pressing a key, pushing a button, contracting a muscle - this performance happens through a metastable equilibrium of programmatic ideas and affective experiences, bodily skills and automatism, rhythms and thresholds. Each of the elements at play - material, programmatic and affective - influences the other throughout the musical performance. It is a mutual relationship among different things, a negotiation. This ecology of things, energies and strategies forming the particular embodiment of the player-instrument is what I call a 'configuration'. Configuration allows for an ecological analysis of the corporeality of the technological body, in sound performance and elsewhere, where there is no subject or object, but relationships, forces and strategies performing through each other.

To better understand my use of the term configuration, we can look at Michel Foucault's use of the term 'dispositif' (Foucault, 1994). Similarly to Foucault's dispositif, configuration is the set of relationships that can be established across an heterogeneous set of elements to obtain a given effect.[1] Differently from a dispositif, which can be used in any kind of context and especially in the study of larger social complexes, configuration is a tool to analyse specific forms of embodiment. Configuration extends Foucault's notion of dispositif by taking into consideration the set of relationships that connect elements at a material level. This focus on the material relationships of things does not at all mean that configuration is blind to corporeal,

[1]The dispositif, or apparatus, has been the subject, or means, of major philosophical works. Whereas an in depth analysis of the different uses of the notion is beyond the scope of this project, the reader can refer to the work of Foucault, cited above, Gilles Deleuze (2007), Vilém Flusser (1983) and Giorgio Agamben (2009).

cultural and political issues of human embodiment. On the contrary, configuration serves to analyse the cultural and political issues of corporeality from the viewpoint of the material relationships that enable them.[2]

The idea of configuration can be used to analyse the relationships of any form of embodiment including human beings, non-human beings and objects.[3] In this research, I focus on human-machine configurations, in music performance and elsewhere. To look at how things are configured does not mean to analyse how they relate to each other or to observe the immediate effects of their relationship. Rather, it means to grasp how the material relationships of human beings and technological instruments enable, influence, block or hinder the relations between the material and the immaterial, the cognitive and the affective, the sensory and the perceptual. Configuration helps analyse how the qualities of human beings and technologies grow interwoven through the biomediation of incorporated practices (Shildrick, 2013; Clough, 2008; Hayles, 1999). Put differently, it is a means to grasp how particular kinds of affect and expression (Blackman, 2012; Deleuze and Guattari, 1987) arise from the cooperation of instruments, algorithms, sensors, vibrations and bodies.

The term configuration is particularly useful because it is a noun and a verb at once. As a noun, it indicates a set of relationships among things fitted to each other. As a verb, it refers to the action of configuring things. A particular kind of musical performance can be examined in terms of how the human and the technological parts are configured: how the technological parts hinder, alter or help create body schemata, how the human parts extend or undermine the functioning of the instruments, and what kind of affective and expressive experiences emerge from their biomediation. At the same time, a particular kind of configuration in musical performance can be created by manipulating the material relationships between the human and the machine parts. The instrument can be designed to positively or negatively influence body schemata or alter human physiology and this will lead to particular affective ex-

[2]This is a further aspect that differentiates configuration from similar notions found in cybernetics.

[3]The hermit crab is an interesting example of a configuration between a non-human being and an object. This animal has a soft body which would be easily attacked by predators. So it uses empty animal shells to protect its body. It salvages empty shells from sand beaches or fights other animals to obtain their shells. Once it enters a new shell, its body adapts to the shell's shape. When the crab's body outgrows the shell, the crab goes on providing itself another shell. Even more interestingly, instead of using animal shells, often these crabs adopt plastic containers that they salvage from human waste.

periences. Conversely, the human parts can be set up with the instrument to induce specific changes in it, from its constitutive structure to its output.

During my practical research, I have used configuration as a means to examine particular aspects of human-machine configurations through two experiments; and then I have configured the bodies of human performers and electronic instruments to create two artworks. I will present this aspects of the research in chapter 5 and chapter 6. In the remainder of this section, I will detail the notion of configuration at a basic level, and then apply it to sound performance. The basic characterisation of configuration is a needed premise in order to fully understand how configuration will be of use to this research, and how it may be used in other projects.

4.2 Living a Configuration, or How to Learn to Listen Again

Following the example of Sobchack's autobiographic analysis of living with a prosthetic leg, I will give an example of a particular human-machine configuration by drawing on my own experience of hearing loss. I will use this experience to describe the configuration of my body with two electronic hearing aids. As mentioned in the introduction, I have a moderate hearing loss - technically called bilateral sensorineural hearing loss.[4] It is a degenerative injury of the inner ear which, in my case, affects both ears to a similar degree. Practically, the quietest sounds I can hear are moderately loud (between 40-70 dB), and therefore I found difficult to keep up conversations with other people unless I wear the hearing aids. In my case, the hearing loss was provoked, most likely, by being exposed to excessively loud sounds, amplified music in particular, for about twenty years without wearing protections (stupid, I know!). Since 2014 I wear two hearing aids, one for each ear. These are electronic, battery-operated devices worn inside the outer ear. They amplify sound to allow for improved communication. They use a microphone to capture sound and a digital amplifier to increase the loudness of a the frequencies I am not normally able to ear.

[4]Sensorineural hearing loss is caused by the progressive swelling and death of cochlear hair cells.

The process of learning and unlearning to listen is of particular importance here, thus I will spend a few words describing how hearing works. The cochlea[5] has tens of thousands of hair cells which amplify sound waves and excite the neurons of the auditory nerve. The hair cells are laid out so that those located at the front of the cochlea encode the higher sound frequencies while those at the back encode the lower frequencies. When a particular hair cell dies the corresponding sound frequency cannot be transmitted to the auditory nerve. Interestingly, when this happen the brain does not explicitly signal a dysfunction, rather, it *unlearns* what things sound like. Put differently, the brain re-learns to listen according to the limited information it receives. Therefore, those, like myself, who suffer from progressive hearing loss do not immediately become aware of their loss, quite the contrary. It took me several years to realise I had an issue with my hearing, because the world around me sounded the same as always; but I was wrong. I *thought* that the world sounded the same, but in fact my body had merely learned to listen with the few information it received.

To emphasise the importance of training and lived experience in human-machine configurations, I will give some details on the way I learned to listen again through the hearing aids. Wearing the aids for the first time was shocking. While any kind of sound felt very loud, I was unable to recognise most of the sounds around me. My body had forgotten how particular things sounded like; and differently from before, I had become aware of it. This affected also my movement, for I was unable to recognise the resonances and reverberations of familiar places. As a result, during the first week, I had difficulties orientating my body in space; I would regularly hit low hanging objects or ceilings I used to be familiar with. Walking on a pavement in the centre of London was a terrible experience: excessively loud car roars, overwhelming engine booms and unbearable high-pitched sirens. For the next two months, especially after a whole day out, I noticed an increasing physical and psychological tiredness likely due to the overload of new sounds that my body was exposed to and my inability to cope with it.

At this point, my body was indeed able to hear more and better, but, crucially, it was not ready for this new experience yet. What followed was a long and often distressing period of training; through discipline and self-monitoring, the body slowly

[5]The cochlea is the spiral cavity of the inner ear containing the organ of Corti, which produces nerve impulses in response to sound vibrations.

learned the sound of the world once again. This was not only a sensory or cognitive process, but a psychological process too. Through intense training, exposure to different spaces (gardens, streets, classrooms, concert venues) and help from my closest friends, the configuration of the aids and my body evolved: from the clumsy feeling of an external object stuck in my outer ear to the *almost* seamless experience of being one with the electronic device. I emphasised the term ‘almost’ because the seamlessness of my configuration with the aids is deceptive: the aids cannot be worn at night and are not water-proof. This means that, at least twice a day, either at night or when I take a shower, I have to take the aids off and come back to a world of muffled, unclear and subtle sounds. In addition, the process of re-learning which I mentioned above also happens the other way around. The more I become used to sound as it is reproduced by the aids, the less I am able to hear and listen without them.

The configuration of my body and the aids, as any other type of configuration, can be characterised at four concurrent levels: material, physiological, phenomenal and psychological. The material arrangement of the aids and my body is the grounding of our configuration. The hearing aid is designed to fit my ear in the best and most functional way; it is miniaturised, sturdy and easy to fit, but it is not perfect. It does not feel immediately comfortable, although it does seem to disappear after several hours. The body parts and the aids circuits are not simply paired, they are materially fitted to each other. It is this particular arrangement that enables my body and the hearing aids to listen. Sonic vibration enters my fleshly outer ear, is captured by the microphone, transduced in electrical signals, amplified by the digital algorithms, transduced in acoustic vibration, transmitted to my bony eardrum and finally excites my auditory nerve.

The material and the physiological aspects of this configuration are enveloped in my phenomenal experience. The corporeal training needed to learn to listen through the aids has given me a new, ambivalent sense of embodiment. Whether I walk, run or sit, I feel I can move more freely because I have a heightened awareness of my surroundings and thus feel more secure (when I am not wearing the aids I do not hear cars unless they are very close to me). However, the awareness that my condition is bound to degenerate prompted me to learn a whole set of new bodily practices to protect my hearing; for instance, I learned to automatically and precisely position my body at a specific distance from loudspeakers, cars as well as other people, or to tap in particular way the aids's microphone to check whether the battery is on when I am on the move.[6]

These aspects (material, physiological and phenomenal) of my configuration with the aids participate in and are influenced by my psyche. My thoughts and feeling concerning my condition are as much ambivalent as my renewed embodiment. On one hand, the presence of the hearing aids in my ears reassures me; I know I am able to engage in conversations with people more often and directly than I used to without the aids. On the other hand, I feel the aids lessen my spontaneity when interacting with people; for instance, I have to make my condition explicit every time I meet a new person, which, although I am now used to, always makes for a socially awkward moment. More importantly, the hearing improvement provided by the aids is limited; they are calibrated to amplify human speech and background noise removal is far from perfect. As a result, I still have troubles while listening to particular kinds of voices and I do not experience music as I used to. While, being a performer passionate about sound, this is deeply unsettling, at the same time I discovered a new dimension of sound and this inspired me to experiment with vibrations in ways that I could not envision before.

4.3 Analytical features

So, what does this delimited auto-ethnographic analysis tell us about configuration? To delineate more general and basic analytical features of the notion of configuration I will abstract some reflections from the experience I just described.

A configuration is a hybrid material arrangement. To say that a human body and an instrument are configured is to say that they are fitted to each other, rather than simply used together. My hearing aids are designed to fit my ears in a particular way that enables the transmission and transduction of sound through my body, the electronics and back to the body again. Hence a configuration differs from a generic relation, a coupling or a pairing. When a body and a technology are configured they

[6]When the battery is out of charge the aid stops working with a very short notice. It actually talks to me, via a pre-recorded male voice, which informs me by saying: 'Battery'. After a few seconds the aid is off. Certainly, some friendliness could be embedded in the device!

form a whole, which can be analysed as such for it possesses its own characteristics and capacities. My body and the hearing aids constitute my embodiment as a whole. It is a hybrid embodiment, but, whether I wear or not the aids, I do not experience a split between the organic and the technical. My body is slightly deaf (without the aids) *and* can hear pretty well (with them). Yet, a configuration should not be understood as one indivisible entity; on the contrary, it is an heterogeneous set of enmeshed parts, where each part has particular capacities and tendencies. My ear has its own physical and sensory idiosyncrasies, the specific model of my hearing aid works through particular algorithms, I, as an individual, have specific psychological and behavioural traits, wishes and desires. Since the body and the electronic instrument are configured, the process they perform (listening) brings about tensions that influence each of them, with varying degrees of intensity and according to context. The hearing aids may suddenly stop working because of a discharged or faulty battery, and, unless I have a spare battery on me, I am left in a world of muffled sounds.

A configuration is performative. When a body and an instrument are configured their relationship unfolds gradually through training and repetition of bodily practices, as in my experience with the hearing aids. To use the aids means to learn how they *re*-produce sound (and how they may fail to). This implies I have to learn how sound reproduced through the aids affect my body, my psyche and my movement. This requires a long period of training and discipline, as I discussed above. Thus, through training the properties of the human and technological parts grow interlaced with one another; the body and the instrument negotiate with each other, rather than playing out hierarchical roles. To exemplify, hearing aids have different amplification presets which can be triggered by using a dial tone; these presets are algorithms parameters which can be changed by the user according to a particular situation (a crowded bar or a concert hall, for instance). Listening through each of the presets requires further and more subtle training; when I am tired and I happen to suddenly find myself in a crowded situation it is impossible to change my listening preset because the sound in the room is excessively loud for the dial tone to be picked up by the hearing aids. As a result, my sensory, phenomenal and psychic body have to negotiate with the algorithms and the operations of the hearing aid. This negotiation can tend towards negative or positive phases and does not reach a fixed condition, but rather shifts across partial resolutions. Thus, thinking in terms of configuration implies to understand that the body and the instrument are a dynamic, unfinished whole. This differentiates a configuration from a cybernetic feedback (Wiener, 1948); a configuration has a tendency to be unstable, partial and unfinished, for the relationships that tie together its parts are the product of continuous negotiations. A cybernetic feedback, in Wiener's early sense, is designed instead to achieve stability and maintain it.

A configuration is both fixed and changeable. Any given configuration is a set of relationships that prompt specific processes, and yet, any configuration is changeable. My body configuration with the aids shows this well: when I use a specific preset of algorithms, my body experiences a particular mode of listening (a crowded venue or a silent library) which is determined by the properties of the electronic device, the space and my body. My embodiment exists as a fixed mode of being and listening in that specific time and place. However, this fixed mode of embodiment is open to change. Through a particular computer software, I am able to create new presets to amplify a different set of frequencies; in so doing my experience of listening changes greatly (as additional training is required). Or, in the case of an extremely loud situation, I can take the aids off and wear hearing protections, thus temporarily suspending my configuration with the instrument and altering drastically my embodiment. The protections decrease the amplitude of the few sounds which I could normally hear and thus my hearing loss is augmented. So, the technological body, as I see it, is a configuration of human and technological parts simultaneously locked in and changeable; parts fastened together at a given moment in time and space while shifting roles across multiple iterations. This implies that the same type of configuration can vary each time it is repeated.[7]

There are manifold scales of human-machine configurations. An individual and an instrument can form, or have, a configuration; a group of individuals and a set of instruments can constitute, or possess, a collective configuration; and, at a higher level of analysis, society and technology can develop, or yield, a configuration on their own. These scales of configuration operate through each other, rather than being self-enclosed. This brings to the fore a politics of configuration. At the level of the

[7]This idea will be convenient later, in chapter 7, when discussing my two artworks: each artwork has one configuration, yet that configuration yields different kinds of experiences.

individual, a micro-politics of human-machine configuration is concerned with the way an individual and a technology develop, alter or hinder each other's embodiment through the material arrangement of their parts. The configuration of a performer and a traditional musical instrument produces the conditions whereby automatism can emerge or existing ones can be disrupted, as my account of the study of jazz improvisation by Berliner (1994) has shown. The configuration of a performer and an electronic musical instrument creates similar conditions with the important difference that an electronic instrument, embedded with the needed technology, can sense, alter or respond to specific physiological aspects of the performer's body; and it can do so in real time or over an extended period of time. The remainder of this enquiry will analyse this micro-politics of configuration; it will explore, through experiments and artistic performances, what kinds of corporeality emerge from different kinds of configuration, and what types of aesthetics those configurations allow.

But the various types of performer-instrument configurations manifested in artistic practice are embedded in a public context, and this implies that the particular kinds of corporeality and aesthetics they bring forth are culturally and politically relevant. As I have contended on different occasions throughout the previous chapters, the modalities whereby human-machine configurations are created and exhibited convey specific viewpoints that are politically relevant. They mirror, recall, reinforce or disrupt societal models guiding both the standards against which human bodies are assessed and the uses of technology to construct social categories, organisations and identities. Whether or not the artist accepts it or makes full use of it, technologically-mediated performance is embedded in a macro-politics of configuration, as I call it. This consists of how the kinds of bodies shown during a performance, the types of technologies deployed, and the way those bodies and technologies are configured convey specific cultural and political views; views on the relation of society and technology and, by extension, on the relation of labour production, social policies and technological research.

In my artistic practice, I choose to acknowledge and exploit this potential of technologically-mediated performance. The aesthetics of the artworks I have created, which I will discuss in the next chapters, arises from the creation of performer-instrument configurations that forcibly shift one's focus of attention onto the grey zone between human bodies and instruments, between sensory enforcement and musical performance, between pleasure and discomfort. Throughout the next chapters, I will elaborate further on my aesthetic use of human-machine configurations in the context of the two artworks I have created during this research.

4.4 Modes of Configuration in Sound Performance

Now that I have described the characteristics of configuration as an analytical tool and its aesthetic and political implications in the context of my enquiry, I will use it to unwrap the statement on the performer-instrument relationship I made earlier in section 1.2. There I said that during a musical performance instrument and performer are configured. But how does their configuration come about? And which are its modalities? Here, I will answer these questions by identifying three interrelated configuration modes in sound performance (Figure 4.1). A configuration mode is a particular condition, a mode of being, that causes a configuration to take place in a particular way.

The first configuration mode I will discuss is vibration, the second will be flow and the third automaticity. I want to focus on these modes because, as I will show, they are essential to musical performance and provide a blueprint, a design template for my own artistic work. This does not mean that these are the only possible modes, for a different analytics may find and motivate distinct ones. Here, I will briefly remind the reader of my use of those terms, which I mentioned in the prior chapters. When I use the term 'vibration' in this work, I refer to the whole range of material, perceptual and affective phenomena that vibrations and rhythm yield (Henriques, 2011; Goodman, 2009). This includes the vibrations that human beings can hear, as in musical notes, and those they cannot hear but only experience physically, perceptually and affectively. Thus, my use of vibration encompasses the whole range of physical, perceptual and affective experiences that vibrations and rhythm produce.

The term 'flow' on the other hand, is used in this work to indicate a specific condition of performer and instrument that emerges during live performance.[8] This condition, as I will detail below, interlaces bodily, perceptual, psychological and cognitive

[8] This should not be confused with the meaning of 'flow' in affect studies, where it indicates the mobility and fluidity of affect, that is the capacity of affective experiences to move across distinct bodies, spaces and histories.

aspects of musical performance simultaneously, and thus can create in the player a state of complete immersion (Nijs et al., 2009). Views on the nature of flow in musical performance tend to overlook the role of the instrument by describing its function as a passive informational channel. Below, I will reformulate the nature of flow in the context of my proposal of configuration by emphasising the instrument's properties as active factors in conditioning flow. The term 'automaticity', as seen earlier, refers

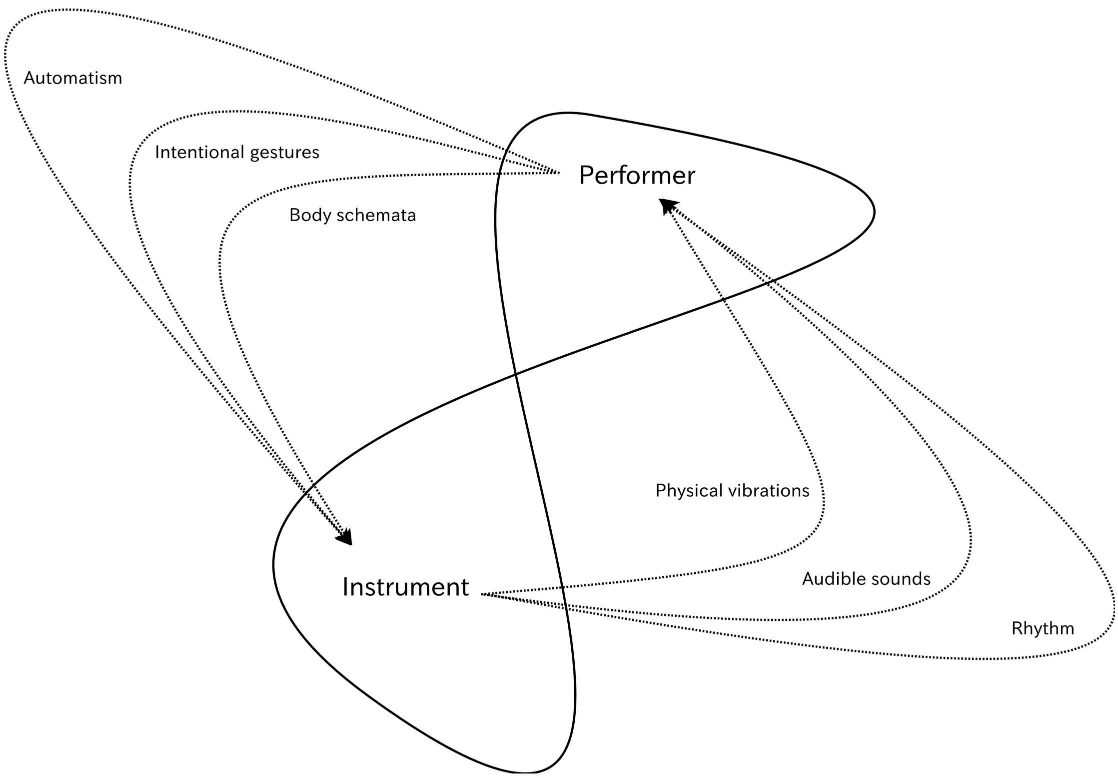


Figure 4.1: Performer-instrument configuration. The performer and the instrument are separated yet they constitute a whole. The arrows indicate the affective forces that the two exchange during performance. The inner layer of those forces consists of body schemata performance and physical vibrations. The first outer layer consists of intentional physical gestures and audible sounds. The third outer layer comprised of rhythm and automatism. These forces are fed back and forth between performer and instrument in a feedback loop, which constitute their mutual attunement.

to bodily automatism that emerge through training, rely on particular technical milieux and manifest themselves as extra-personal, that is, as performed by someone or something other than the subject. Automaticity is tightly related to the notion of threshold: physiological, sensory, and psychological edges beyond which consciousness drops out (Solomons and Stein, 1896). These kinds of threshold conditions are rendered more clearly in those particular embodied practices relying on immaterial processes, or psychic and psychological attunement, such as automatic writing, physically active meditation and musical and sound performance, of course. The first and most basic configuration mode in sound performance is vibration. I will explain this configuration mode by giving a fictional account of a musical performance with a traditional instrument. Hunt (2000) explains how during a musical performance, a performer transfers physical energy into an instrument, which in turn vibrates and releases vibrational energy across its own parts, the performer's body and the bodies of the audience members. Vibration here, I propose, should be understood as a vibrational force (Henriques, 2011), an energy that is released in two forms, inaudible and audible acoustic vibrations, and ultimately produces audible and tangible rhythms. The inaudible vibrations are physically shared across the performer's body and the instrument's parts because they touch each other, they are physically fitted to each other. The audible vibrations on the other hand, are shared through the air and reach the ears of the performer and the spectators, who process them as musical notes. According to a score or cues from other players, this process is repeated iteratively, engaging the performer, the other players, the audience and the instrument in an adaptive loop of physical resonance (Schacher and Stoecklin, 2011).

Vibration is the condition that enables the configuration of instruments and human bodies. This configuration mode is dynamic because vibration is both what causes the configuration to happen, and what results from it. What I mean is that, on one hand, vibration establishes the material and perceptual link between performer and instrument, on the other, it rises from it. In other words, performer and instrument are linked by the vibration they produce; thus they reinforce their own configuration throughout a performance. The context of the performer-instrument configuration is important; according to a venue size, the sound amplification and reverberation, the stage position and the amount of spectators present in the space, vibration is literally absorbed with varying degrees of damping by the materials the venue is built with and the human bodies attending the performance. As a result, the configuration of performer and instrument extends beyond them to engage other materials and bodies.

During this adaptive, reinforcement loop, performer and instrument can enter a state of flow. According to psychologist Mihaly Csikszentmihalyi (1990), flow is a state where an individual experiences a holistic sensation of total involvement and deep immersion in the task at hand. In musical performance, flow is generally understood as an exclusively subjective state experienced by the performer. Nijs et al. (2009) claim that, if the musical challenges match the player's skills, clear goals exist and the instrument provides immediate and defined feedback, then performer and instrument enter a state of flow. This experience of flow is marked, for Nijs, by the performer's subjective understanding that the instrument has become one with her body. Nijs and his colleagues claim that this motivates the understanding of the instrument as an extension of the player's body. I argue that this view overlooks that instruments are active technologies, as Owen Green (2011) stresses, meaning that their material and sonic qualities actively influence human performance. It is a specific technical milieu which enables particular forms of flow (Henriques, 2010).

The extended understanding of flow I am weaving here is not too dissimilar from that of 'peak' or ecstatic states experienced at raves (Pini, 2001) discussed earlier in subsection 3.2.2. Pini's argument however adds a significant element to my analysis of flow. She sees 'peak' experiences as the result of a *careful construction*, as opposed to an unconditional experience which is simply attained upon entering a rave. Thus I argue that flow as a configuration mode is an experience of immersion attained through training and conditioning where differences between self and other, technical and human dissolve. Importantly, I stress the importance to recognise the active role of the instrument in the experience of flow. In music, the instrument gives back to the performer a full range of vibrational phenomena which alter the player's corporeality in different ways.

To acknowledge the corporeal alteration enabled by a particular technical framing means to recognise the extra personal forces at play in musical performance and elsewhere. This leads us to the notion of automaticity, the third configuration mode I want to analyse. Automaticity emphasises the performative feature of human-instrument configurations. It blurs the borders between physiology and psychology, human and technical, self and other. As seen earlier, for Solomons and Stein (1896), the phenomenon of automatism involves becoming unconscious of certain bodily and cognitive operations being performed by one's own body. It happens through repetition, rhythm and effort. When an automatism comes in, consciousness drops out, and other component of intentional action, such as the feeling of effort and the experience of a motor impulse, quickly disappear with it. The dropping out of consciousness is temporary and irregular, and when one becomes aware of an automatism, this is perceived as extra-personal. It is not the jazz improvisers who plays a new musical scale, it is the fingers that 'give it' to the musician (Berliner, 1994). The specificity of a particular technical milieu is crucial to the emergence of automatism. The instrument, the playing techniques, the training, the playing style and sound itself form a technical milieu which defines how automaticity can be experienced. Automaticity is a 'transitional process' emerging and disappearing through 'thresholds of sound, effort, repetition and sensation' (Blackman, 2012, 147). Rather than being an unintentional or uncontrollable phenomenon, which for some musical virtuosity scholar (Ericsson, 2006) should be avoided, automaticity is a complex entanglement of the conscious and the unconscious, the material and the immaterial. In this configuration mode a player does not simply perceive the instrument as one of its body parts, like an attached, external object. The instrument *acts upon* or guides the player's body. It is perceived as an extra-personal force which pulls and pushes the player's body inside and outside of its normal reach.

Arguably, the configuration modes of vibration, flow and automaticity can be found in most sound performance with traditional instruments. But, I argue, they are harder to find in computationally-mediated sound performance. This is because, as I noted in section 2.1, computer- and sensor-based musical instruments are originally engineering constructs made to compute data, and thus tend to lack of the implicit corporeal engagement which traditional instruments provide. It is worthwhile analysing the problem closely, for it represents the motivation behind this research. For the sake of clarity, I will use the term electronic musical instrument to indicate computer- and sensor-based musical instrument, as I did earlier.

Traditional musical performance is characterised by 'instrumental' gestures, which, after Cadoz (2009), are mechanical relationships between a set of processes, which consistently exchange energy. It is a corporeal bond of performer and instrument. When it comes to electronic musical instruments, the situation is different. Gurevich and Cavan Fyans (2011) emphasise that human interaction with electronic instruments often lacks instrumental gestures, as defined by Cadoz (2009), because the energy from the performer's body is transduced into signals which have no physical impact on the instrument. This, for Gurevich and Cavan Fyans, causes the interaction with electronic musical instruments to occur mainly in the symbolic or conceptual domain, rather than in physical or mechanical terms. In the case of a laptop musician, for instance, pushing a button does not input much physical energy in the computer instrument; rather, it acts as a symbolic and functional link between a musical idea and the algorithms that produce sound. As a consequence, musical performance with electronic instruments is rarely conceived in terms of corporeal engagement, and most often in terms of control over a system, as I argued earlier in section 2.1. I want to stress that this focus on control is highly problematic. The problem is that it elides the role and meaning of vibration, flow and automaticity in music making, while promoting a view of technological instruments, and computational technology in general, as passive, functional devices; pieces of circuitry and algorithms inscribed in a cultural logic of normative behaviour and compliant bodies.

My work tackles this issue by using the configuration modes discussed above as a blueprint, a design template for corporeal interactions between an electronic instrument and performer. In the performances I have created, which I will present in chapter 5 and chapter 6, player and instrument are configured through vibration, flow and automaticity. In those performances, the player's musical and physical intentions are heavily influenced, and often constrained, by the instrument. Importantly, those artworks do not attempt to mimic the configuration modes of vibration, flow and automaticity which characterise traditional musical performance. Rather, they use specific features of body technologies and sound technologies to investigate how those configuration modes can exist anew in technologically-mediated musical performance. The development of this approach is the result of an iterative research process which probes the corporeality of the technological body. It does so by weaving a thread around a study of expressivity, empirical users' experiments as well as technical development and confronting these resources with the theory discussed so far. This part of my research process is the subject of the remainder of this thesis. Before concluding though, I want to use the final section of this chapter to discuss some of the limitations of the concept of configuration.

4.5 Limits and Openings

Configuration is not a theory of the world, but a tool to think specific kinds of technological embodiment, which, in this research, I use in the particular context of artistic research. Thus, in this thesis, there are limits to both how the notion of configuration is conceived and what it is used for. Two vast problematics exceeding my use of configuration are the roles of gender and ethics in technological embodiment. While I think that the notion of configuration can be useful in tackling those issues, the present research does not offer the adequate room and analytical framework to confront these issues. That said, I will raise some questions that will provide pointers for future research.

Thus far, I argued that performer and instrument form a technological body and that the tool of configuration helps analyse this form of embodiment; it shows technological embodiment as a metastable equilibrium between the material and the immaterial, the technical and the organic, the perceptual and the cognitive. However, it remains to be considered what is the role played by different genders and different physical and sexual embodiments in the configuration of human bodies and machines. This is important for, as I emphasised on different occasions in this text, there is a tendency to equate discourses on embodiment with argumentation for a universal, ungendered body (Young, 1980; Shildrick, 2002). By crossing out the significant and meaningful differences across genders, ages, and physical abilities, this kind of argumentation creates an homogeneous and flat understanding of what it means to be human. Rather than deepening our conception of the body and its relation to technics, a universal understanding of embodiment simplifies that conception in dangerous ways: it authorises both, at once, the disavowal of other kinds of embodiment and the celebration of a universal form of embodiment, which is in fact inexistent.

Secondly, and equally important given the violent times we are living at the moment of this writing, there is the problem of ethics in technological embodiment. What happens when a human-machine configuration goes wrong? And how are we to analyse a configuration in the context of warfare, torture or any violent behaviour? Or, put more bluntly: How does a child become a soldier? My own analysis in this text touches only slightly upon the issue of ethics in the context of *Nigredo*, a live installation in which I play with the stereotypes of torture technologies to provoke a vivid reactions in the visitors. However, the problem is much more profound and impervious. The question of how a child become a soldier provides for a strong case for an ethic of configuration. This kind of analysis would lead us through the physical, psychological and cultural transformations of the child body; a transformation instigated by others, for we can safely say that no child would nurture a desire to kill at birth, and inscribed in the body, through disciplined training in guerilla tactics, suicide bombing and do-it-yourself weapon making. What this would show is a kind of configuration that perhaps cannot be described, let alone fully understood, without being experienced in the specific milieu it takes place; a milieu which stands in stark contrast with the Western world we are used to and thus requires openness, respect and careful analysis in order to be understood.

Chapter 5

Practice Pt.I: Nigredo

5.1 Introduction

In chapter 2, I discussed a broad range of performances and electronic musical instruments where human embodiment was mediated to different degrees, including biofeedback interfaces, generative music systems, prostheses and gestural controllers. In chapter 3, I examined a set of analytical concepts - human unfinishedness, transindividuation, the human use of instrument, the posthuman, the embodied mind and biomediation - that show how the human body and technology co-constitute new kinds of corporealities. Eventually, I proposed the idea of configuration as an analytical tool to think embodiment, technological embodiment in particular. If we think of technological embodiment as a configuration, in the sense of the term I proposed, it is possible to see how a human and an instrument share more than a subject-object relationship; they are in a complex dialogue which engages the material and the immaterial, the technical and the organic, the perceptual and the sensory in hybrid and unexpected ways.

Thus, the present research extends the body of artistic works seen in chapter 2 by positing two arguments to the creation of technologically mediated sound performance, arguments that I extract from the concepts seen in chapter 3. First, player and instrument are neither in a prosthetic relationship, nor in a primarily cognitive relationship. Rather, they are *configured* in particular ways which enable experiences of threshold conditions, where physiology, perception, cognition, psyche and automaticity co-exist and influence each other. Second, corporeality emerges from the configuration of technology and human bodies. I reject the idea that corporeality is an exclusively human feature in favour of a view where it arises from a dialogue between humans' embodied practices and instruments' operational capacities; a negotiation which is metastable, dynamic and situated in a particular context and historicity.

The notion of configuration, and its entire theoretical grounding, is not only an analytical tool to examine embodiment. It is also a blueprint, a design plan to create technical and artistic work. It allowed me, as an artist and performer, to envision and create artworks where the human body and the technological instrument perform through each other, rather than fall into a tired interaction model focused on intentional control. Practically, I based the design of my hardware-software systems on the idea of configuration. I have used the notion of configuration as a template to implement two systems that displace traditional approaches to sound and musical performance with technology. Two system which afford hybrid human-machine arrangements, performative configurations and dynamic experiences that change across different iterations, while retaining a basic, recognisable aesthetic dimension.

With the collaboration of Dr. Marije Baalman, engineer and artist at STEIM, Studio for Electro-Instrumental Music, and Prof. Atau Tanaka and Dr. Baptiste Caramiaux at Goldsmiths, University of London, I have conducted two experiments. Then, I have used the findings of those experiments to inform the creation of two artistic projects, entitled respectively *Nigredo* and *Corpus Nil*. In the first experiment, which I will present in this chapter, together with Dr. Baalman, we have tested the effect of low frequency vibrations on human perception. In the second experiment, described in the next chapter, together with Prof. Tanaka and Dr. Caramiaux, we have deployed scientific procedures and protocols to test a series of hypotheses on the understanding of gesture expressivity through muscle signals. Through the experiments and the artworks, I have explored how to configure an electronic musical instrument with a human body, in the sense I proposed above, and how this influences corporeality and musical expression. So, if on one hand the idea of configuration functions as a design template for my computational systems and performances, on the other those systems and performances function as a test bed, living site and speculative ground for the idea of configuration (I mentioned this in chapter 1). This practical research allows me to examine the strengths and limits of configuration in guiding the creation of corporeal relationship between an electronic instrument and a performer; and specifically relationships that displace, disrupt and alter normative assumptions on the body and the technology designed for it.

Both this chapter and the next are organised in a similar way. First, I consider the experiment, describing the motivation behind it, presenting the chosen format and protocol and discussing the findings. Next, I focus on the rationale that guided the development of the experiment results into insights for the creation of the artistic project. Finally, I present the artistic project, review the concept and tools used in the creation process and discuss the performative relations of the electronic instrument and the performer's body. I will offer a discussion of this research afterwards, in chapter 7. It is important to note that, in order to make this manuscript graspable by a transdisciplinary readership with different areas of expertise, including body theory scholars, HCI scientists and artists, I chose to maintain a consistent writing style throughout the thesis. To do so, I will present the experiments in a non-traditional way. Scientific experiments are traditionally presented through a systematic structure (hypothesis, method, result, discussion). In the next sections, I will loosely follow that structure to favour a discursive cross-pollination of ideas between the fields of body studies, HCI research and the arts. That said, the interested reader who wishes to repeat the experiments or read through a standard presentation can refer to the full papers attached to section D.1. These are peer-reviewed and formatted according to scientific standard.

5.2 Testing the Effect of Vibrations on the Sensorimotor System

In this first practice chapter, I will consider the research I have conducted on the affective, technical and aesthetic relation of vibration, human bioacoustic and perceptual deprivation in the context of *Nigredo*. This is a performative installation for one visitor at a time, which offers an altered experience of self-perception through sound, low frequency vibration and light. I will present *Nigredo* in section 5.4. Here, I will discuss an experiment I carried out during an artistic residency at STEIM in February 2013. The experiment served to gather an insight on the *experience* of intense vibrational stimuli; this understanding was crucial in the realisation of the final artwork. The experiment was not set up to prove a claim or validate scientific knowledge which has already been demonstrated, but to perform a basic human-machine configuration and examine its affective, experiential and physiological outcomes. Since the experiment was set up with the collaboration of Dr. Baalman, I will use the 'we' rather than the first person.

Our experiment is contextualised in a broader field of research into biofeedback loops ranging from applied science to electronic music and interactive arts. Although our experiment greatly differs from the traditional approaches to biofeedback in that it abuses that technique to pursue an intense, vivid and confrontational experience, the following references help provide a wider view on the more recent experimentations in biofeedback. Prominent scientist and NASA senior researcher Alan Pope has been investigating adaptive biocybernetic feedback loops since the 1990s, first in the context of automated flight and then in gaming therapy (Pope et al., 1995; Pope, 2001). Using EEG (or electroencephalogram) and EMG (or electromyogram),[1] Pope investigates how a user's physiological level of engagement during a task can be used to adapt the operations of a software system, in positive and negative feedback modes. In the field of new musical instrument design, Sebastiàn Mealla explores how the sonification of EEG and ECG (electrocardiogram) from a player can not only influence musical performance and expressiveness but also encourage more engaging forms of collaborative music making across multiple players (Mealla et al., 2011, 2016). An artistic investigation of biofeedback loop across species is offered by the installation *Myconnect* by Slovenian artists Saša Spačal, Dr. Mirjan Švagelj and Anil Pogdornik.[2] Laying down inside a custom-made cocoon, a visitor experiences electrical oscillations produced by a culture of Mycellium fungi in the form of sound, light and tactile stimuli. The heartbeat of the visitor is in turn translated into electrical impulses which excite the fungi, thus establishing a feedback loop of mild stimulations.[3]

At an aesthetic level, an element that inspired the idea for our experiment lay in my interest in including the audience in my work *as performers*. After having played extensively with my own electronic musical instruments, I became interested in how to let the audience experience a physical and intimate relation with an electronic musical system similar to the one I had been experiencing until then in my solo performances. My interest lies in making the bodies of the audience members an integral part of a musical system; to configure them with the instrument, rather than only engage them in a direct way. For the technical aspects of the experiment, we drew upon the link of self-perception and whole-body vibration (WBV) - which I examine next. We wanted to create the basis for a configuration of a performer and an electronic instrument through vibration. The scope of the experiment was to test the implementation of a basic system that would enable an affective feedback between the performer's body and the instrument's sonic qualities. My interest lay in testing how musical expression could emerge from an interaction of a performer and an electronic instrument

[1]These are the same biosignals used respectively by Lucier, Rosenboom and Tanaka, as seen in chapter 2.

[2]This work was recently awarded an honorary mention at the prestigious Ars Electronica festival, in Linz, Austria.

[3]See the related website for further detail at https://projectmyconnect.wordpress.com/.

lacking any intentional gestural interaction. A configuration in which a performer would participate primarily through proprioception and perceptual potentials.

5.2.1 Perceptual Potentials as Latent Bodily Qualities

The notion of perceptual potentials was analysed earlier, in subsection 3.2.1, in the context of the theoretical work of Simondon (1992),Massumi (1995) and Blackman (2012). It is worthwhile expanding it further here for it has a parallel with the scientific understanding of perceptual stimulation through technology. It is by linking the philosophical and scientific formulations of perceptual potentials, acknowledging their differences and contrast, that I set up the artistic experiment that will be described next. Before turning to the technical analysis of the link between perception and vibration, I will therefore contextualise my interest in exploring that link through the lens of perceptual potentials. The term potential is a core notion of Simondon's view on individuation, as seen earlier. Simondon however, has not explicitly defined his notion of potential, and refers to it in two, often interchangeable, ways. One is the commonplace meaning of the term, that is, the possibility of something happening. The other is, from physics, the quantity determining the energy of a mass which may trigger a process. The potential is therefore something latent, an amount of energy that may be released and may have a causal impact, but the potential exists only in its virtuality, for as soon as it is released it stops being a potential and becomes the raw material of another process. It becomes actual, while preserving an immanently changing virtual. This, as we will see soon, resonates with the scientific literature on whole-body vibration (Griffin, M., 1996) and perceptual deprivation (Rasmussen, 1973).

Even more directly related to the scientific literature, is Massumi's take on perceptual potentials (Massumi, 1995, 95), which he describes as rooted in the domains of perception and neurophysiology. For him, a potential is a latent perceptual quality or ability of a (living or non-living) body that may be or may be not developed. He also adds that perceptual potentials, before being released, are independent and discontinuous. This implies that potentials do not own a predetermined scope or field of action, nor are they grouped into fixed functional categories. Potentials can be released in any combination and it is here where their generative, hindering or disrupting charge, their power of change and alteration of human perception lies. However, as seen through the work of Blackman (2012), delimiting potentials and threshold phenomena to perception and neurophysiology, dangerously elides the modes of training and the contexts which allow one to *perform through* threshold phenomena; where to 'perform through' means to experience as well as to make happen. Thus, it can be said that potentials do not simply emerge when particular neurophysiological thresholds are reached; rather, those thresholds are worked through, trained and sought for. Eventually, they are expressed through immaterial processes, actions of psychic and psychological attunement (examples of which we have seen in jazz improvisation and automatic writing in subsection 3.4.2).

Drawing on the above analysis of potentials and thresholds, my take on this topic is concerned with examining how perceptual potential are actualised by the vibrational force of sound *and* what kind of affective, immaterial processes this yields. In this work thus, I use the term perceptual potential to indicate a mode of perception that can be experienced only through a certain amount of stimulation artificially produced by a technological system. In the next section I will turn to the definition of perceptual potential in the scientific literature on whole-body vibration, and its effects on the body's neurophysiological responses.

5.2.2 Whole-Body Vibration and the Sensorimotor System

WBV consists of stimulating a human body by means of low frequency mechanical vibrations. In a laboratory experiment, a participant stands on a small platform that is made to vibrate using acoustic transducers that resonate the platform surface using low frequency vibrations. In this way, the vibration from the platform surface is passed to the body of the participants through direct contact. This method is mostly used to develop approaches to rehabilitation of patients who have experienced significant trauma - like a paralysing stroke - or to enhance the muscular force of athletes. This is because there exists evidence that WBV alters, both in positive and negative ways, physiological responses and muscle functions (Cardinale and Bosco, 2003; Cochrane, 2011). Technically, this happens because, by applying external vibrations to a muscle or a tendon, the contracting cells inside the muscle - the muscle spindles - activate to dampen the tissue displacement. Their continuous activation by means of induced low frequency vibrations - a mechanical form of training - provokes specific adaptive responses, including alteration of both neuromuscular performance (Cardinale and Bosco, 2003) and cardiovascular activity (Rittweger et al., 2000). What is more, it has been observed that WBV alters proprioception, to the point where movement parameters can be incorrectly quantified by the proprioceptive messages (Roll et al., 1989). In the fields of human factors (Griffin, M., 1996) and biomedical military research (Lowry and Bosley, 1962), the use of low frequency vibration has been discussed in terms of its more direct and evident effects on the human body. Similarly to any other body, be it living or non-living, the human body resonates with acoustic vibrations, and by using specific sound frequencies at high amplitudes it is possible to provoke maximum mechanical response (Griffin, M., 1996). In this case, low frequency vibrations are known to produce displacements of the internal organs and the organic structure of the body (Lowry and Bosley, 1962). This creates a range of diverse effects, from simple discomfort to interference in the acquisition of sensory information, decision-making processes and memory (Griffin, M., 1996).

What is important here is that physiological responses, muscle activity, and proprioception can be altered through specific kinds of vibrational stimuli but, unless a certain amount of stimulation is artificially produced, the alteration may not be realised. In other words, there is a threshold in the amount of stimulation needed for the physiological response to be released. And to pass that threshold natural stimuli are not enough, the configuration of a human body and a machine through specific sound frequencies is needed. In the next sections I will describe the experiment where I put into practice both the theory and the scientific literature discussed in this chapter. The experiment will help us analyse what the theory discussed thus far can speak back to the neurophysiology literature, and conversely, what the scientific literature can offer to the theory.

5.2.3 Experiment

For the experiment carried out at STEIM in collaboration with Dr. Baalman, I created a basic instrument, composed of hardware and software, to directly resonate the bones and skull of a group of users using high-powered low frequency exciters (Figure 5.2). These are transducers that transform audio signals into mechanical vibrations of a solid plate. Importantly, the system deployed low frequency vibrations at high amplitudes to purposely produce a maximal resonance within the participants' bodies. The aim was twofold: to test the technical effectiveness of this kind of configuration in creating threshold conditions and to learn how these are experienced by of different kinds of users. First I tested the system on my own body, and then on the bodies of a group of participants.

Figure 5.1: A Visaton BS130 low frequency exciter. The audio signal is transmitted to the exciter via an audio cable. Inside the exciter a driver transduces the audio signal into vibrations of a metal plate. The plate is coupled to a surface so as to resonate it and diffuse sound through the medium of the surface itself, rather than through air, as with traditional loudspeakers.

In a completely dark room I set up a customised chair, in which I embedded three exciters (model Visaton BS130), where each has a diameter of 15.8 cm and thus is capable of vibrating a fairly broad surface area (Figure 5.1). Two exciters were placed in the back seat and one in the seat. In this layout, the exciters directly resonated the bones of the user's body in three points, the skull, the lower spine and the coccyx, the last vertebra of the sacral curve. The choice of using three exciters was dictated by the need to experiment with whole-body vibration. Following some preliminary experimentation on my own body, I noticed that by resonating my sitting body in the three points indicated above, the acoustic vibrations propagate throughout the body before dissipating. On the other hand, a single exciter, or even two, produced a localised feeling of vibration that dissipated soon after its initial impulse.

This kind of layout served me also to explore how a particular acoustic phenomenon, known as standing wave, could be recreated within the human body. In physics, a standing wave is a stationary wave which is produced by the encounter of two waves travelling in opposite directions or by the interference of two or multiple waves reflecting onto each other. The effect of a standing wave is to induce a high resonance into a medium, in this case, a human body, and by means of resonance any object lying on the path of the sound wave is displaced. Interestingly, while the standing wave is produced by an interference, it can be perceived as an entire system of vibration moving in simple harmonic rhythm.

Figure 5.2: A view of the studio at STEIM during the set up of the experiment. The modified chair, embedded with one frequency exciter while the other two were being prepared, can be seen on the right side of the picture.

Using the software Pure Data,[4] I created a set of algorithms which produced patterns of sine waves. Each sine wave was output via an independent audio channel through an external sound card Focusrite Saffire Pro40. The audio signals were then amplified by three Crown XLS 1002 amplifiers and finally transmitted to the exciters, which transduced them into mechanical vibration. The patterns were produced by combining pulses of sine wave tones whose frequency range sits between 5-100 Hz, thus including both infrasounds and audible sounds. Both the frequency range and the vibration patterns were selected in two phases: first, I implemented a set of vibration patterns using the frequencies previously documented in the work of Griffin, M. (1996); then, I experienced the effects of those patterns on my own body for about four days in order to gain a first-hand experience of the possible vibrational effects afforded by this setup. Another reason to limit the upper range to 100 Hz was that beyond this frequency the mechanical effect of the vibration on the exciter itself becomes excessively loud, thus producing sonic artefacts which make it difficult to focus one's attention on the resonance within the body. While experiencing the vibrations on my own body so as to select particular patterns, I annotated the frequencies being used, the location of the body to which the vibration was applied to, and the effects of each frequency combination. Eventually, I chose four vibration patterns to be used in the experiment. These were chosen according to the threshold phenomena they produced (the combinations are illustrated in Table 5.1). The criteria for the selection were: a high level of physical resonance, a clear distinctiveness of the effect, and the capacity to convey a sense of displacement of the internal organs.

The group of participants consisted of thirteen persons, seven males and five females.[5] Most of them had previously participated in separate interactive artworks, two users were practising artists themselves, and no one in the group had prior experience with whole-body vibration. Each participant was first instructed on how to sit correctly on the chair and then informed of an interview that was to follow the experiment. Then, the participant was invited to sit in the dark room alone in order to experience a sequence of vibration patterns for a duration of eight minutes. Each person experienced the same vibration patterns described in Table 5.1, and each

[4]See http://puredata.info

[5]Here, and in the experiment described in the next chapter, the purpose of indicating the participants' gender is to provide complete information on the protocol we have followed and enable thus other researchers to reproduce the experiment in the same conditions.

	Skull	**Spine**	**Coccyx**	**Tested Effect**
Pattern 1	45 Hz	37 Hz	48 Hz	Teeth vibration
Pattern 2	8 Hz	67 Hz	97 Hz	Sense of being elevated
Pattern 3	10 Hz	25 Hz	35 Hz	Vertical vibration
Pattern 4	5 Hz	25 Hz	26 Hz	Sense of falling

Table 5.1: The vibration patterns used in the experiment. These were first selected from a variety of patterns indicated in previously published experimental work, and then selected once more after having experienced their effects on my own body. Eventually, this set of patterns was used in the experiment and thus experienced by the participants as well.

time the patterns were played back in the same order. I chose to maintain the same order instead of randomising the patterns because I was interested in testing how that specific temporal composition was experienced by a diverse group of people.

At the end of each session, the participant was accompanied in a separate room and interviewed by an assistant. In agreement with the participants, the interviews were videotaped, transcribed and analysed to match given accounts to a specific sequence of vibration patterns. We used an 'interview guide' approach (Patton, 1990), a qualitative interviewing method where an interviewer guides the conversation using questions defined in advance, but open to rewording. The assistant was instructed to interview the participants following a questionnaire of fifteen questions we had prepared in advance (listed in Appendix C). If needed, the interviewer was free to reword the questions or change their order to fill in logical gaps in the interviews. He was instructed to make the users feel comfortable and not to deviate the conversation from the questions. The questionnaire was prepared so as to gather experiential insights from the users without influencing their replies.

This method was deemed the most appropriate for the task at hand for it balances a systematic collection of information with a fairly conversational situation, which helps the users being more open to share their experiences. The main weakness of this method lies in that, if the interviewer sequences and rewords the questions differently across users, the comparability of the responses may be reduced. We decided to prioritize the diversity of information over their comparability. The scope of the experiment was to understand the subjective experience of each user, rather than gather objective data based on a measured repeatability. Hence the choice of relying on first person accounts, as opposed to data collection.[6]

Whereas our experiment was set up by making use of scientific literature, it does not, intentionally, deploy a scientific methodology (as opposed to the set of experiments that will be discussed later). This experiment should therefore be expected to offer insights on the artistic exploration of scientific techniques, rather than provide scientific claims. This does not mean that I take the scientific literature as a universal and objective truth. On the contrary, aligning myself with the philosopher Isabelle Stengers (2000), I understand this kind of scientific findings as the result of a tension between scientific objectivity and belief; a tension contextualised in particular milieux (the laboratory) and power relations (the funding institutions) and which, nonetheless, remains necessary to science.[7] So, rather than taking the scientific findings on vibration described above as an objective, absolute grounding for our research, we have created an experiment to put them to test, to question them and explore their implications in the context of my artistic and analytic experimentation. Thus, the intent behind the experiment was not to re-prove the existence of documented effects of induced vibration. We intended to examine how this type of experiment, its technical framing and context would *produce* the subjects and their experiences.

Therefore, the set of questions we created was conceived to gather the participants' responses on four aspects of their personal experience: bodily and emotional feeling after the experience; auditive and visual stimuli perceived inside the blackened room; overall experience of the body during the experiment; sonic and vibrational elements characterising the musical and temporal composition of the experiment (Figure 5.3). By analysing the interviews we gathered that all participants reported being significantly affected by the piece at a bodily and emotional level, but, importantly, in varying degrees of intensity and specificity.

[6]The use of first person interviews to gather experiential insights is an approach adopted by several artists whose practice is interlaced with research, including Salter (2012) among the others, whose work I have reviewed in subsection 2.2.1. As I discussed in subsection 2.2.1, Salter used first person interviews to gather insights on the visitors' experience of a finished work, *JND*, and then used those insights to discuss the artwork. Differently from Salter, I conducted the interviews to gather insights on a basic experiment and then used those insights to inform the creation of the final artwork.

[7]Stengers is one of the eminent philosophers who pioneered critical work in science and technology studies (STS), specifically on the nature and use of the scientific method. Her arguments have influenced also another prominent Bruno Latour, see (Latour, 2004).

Figure 5.3: One of the visitors during an interview at STEIM, following his experience of the experiment on vibration and perceptual potential. Here, he is describing the way he experienced the vibrations, emphasising the intensity of the vibrations with his hand gestures.

The two following quotes illustrate the range of reactions, from a light to a profound one:

> *[In the beginning] I was concentrating more on my rhythm of breathing, and then during the experience I felt more stressed at some points, and then more relaxed.*

> *I think it was an intense experience, yea. It really feels like an experience that goes into your conscious sometimes.*

Strikingly, for all the participants the feeling about the experiment was at once positive and strange, relaxed and uneasy. While no one regretted taking part in the experiment - something that, given the intensity of the vibrations, I had imagined could have happened - all of them described the experiment intense and yet worth experiencing.[8] Some of the participants describe their feeling upon exiting the experiment as follows:

[8]Specifically, four persons said they would have repeated it and eight would have preferred not to experience it again.

> *I feel good, more relaxed. It was physically intense but it relaxed me.*

> *Kind of giggly, not violated, I was expecting to be more violated (laugh). I feel very good, a little bit uneasy but relaxed.*

> *I don't really know! (laugh). Mmh, quite calm, in a way, not a traumatising experience, although it's quite strange, yea. I don't know, I don't know, pretty strange I would say.*

It is significant to note the use of the terms 'violated' and 'traumatised'. Even if they were used jokingly, the choice of those terms suggests that, upon entering the experiment, the look of the setup resembling an electric chair, had a lasting impact on the participants' expectations. Admittedly, this was not a purposeful choice, but a constraint dictated by the available means in the studio where I was working at the time. However, these responses convinced me, later on, to explicitly play with the stereotype imagery of death and torture technology in the construction of the final work. I will elaborate further on this in relation to the notion of technical milieu in subsection 5.4.4, when discussing the aesthetics and ethics of *Nigredo*, the final work emerged from this experiment.

As it can be gathered from the responses quoted so far, most users admitted that the experiment had driven them in a state of confusion, which made them unable to precisely describe their emotional or physical feelings, or to remember the details of the experience. Nonetheless, they used terms such as 'shaken','excited' and 'invaded' which have an explicit correlation with physical contact and abruptness, and the latter in particular has primarily a negative connotation. When asked how did they experience their bodies, some of the participants replied:

> *I feel a bit shaken up, a little bit, literally and figuratively (laugh). It was relaxing but definitely intense, like a roller coaster.*

> *I feel very light, very... yes, excited! It was a very exciting feeling. It was sometimes quite intense, but I enjoyed it! (laugh)*

> *I felt invaded and watched, let's say (laugh). I was wired [...] and there was something that you could say it was... was...*

One participant in particular emphasised how difficult it was for her to recall the details of her experience by exclaiming

> *you know, it's so hard to remember now that you ask!*

When asked about the specific effects of vibrations, many used general terms such as 'strange', 'new', or 'weird' to describe the experience of their bodies, but none referred to the effects on the internal organs which I had purposely tested on my body.

> *My body was completely shaking, it was so strange. I felt like I wanted to move, but the whole chair was 'moving'.*

> *It just made my body sort of new, sort of someone's else, but I knew that it was my body, you know there was like this confrontation with yourself, so it's kind of a weird experience but really interesting.*

What comes immediately to the fore when reading the two responses above is the reference to something 'other', the inexplicable sensation of being moved by 'something else', or even to be confronting oneself from an outside viewpoint. This strongly resonates with the experience of automaticity in jazz improvisation and automatic writing I described earlier (see subsection 3.4.2) although, as I will discuss later, it is slightly different from those kinds of automatisms. I will give more details on this relation in the next section, which is reserved to discuss the experiment's results. In a similar tone, many users spontaneously described their experience as something more experimental than artistically meaningful, while acknowledging a heightened awareness of their bodies at the same time.

> *I feel different. Yes, it was a big break in reality, the way I was feeling when I came here and now that I came out, [...] it changed my way of experiencing, what I'm feeling right now, what I'm seeing, what I'm hearing. Yes, it was a big break.*

> *I think the moment I was most aware of my body was when the vibrations got really intense throughout the whole chair, there was a couple of moments like this.*

Although the duration of the session was known to all in advance, most users reported not being able to discern the passing of time. Among them, most thought the composition had lasted two or three times longer than the actual duration. The next quotes emphasise this difficulty in pinpointing specific conditions of the experiment. When explicitly asked to describe how the composition unfolded during the experience, many reported on the impact of the highest frequencies on their skulls, but, as seen above, only a few could detail the effects of specific vibration patterns on other parts of their bodies.

> *When the sound came on the chair it was another level, when the sound became sensorial. Well, that was very strong [...] it was in me, in my own body.*

> *For me the vibration was a bit too tough, but that worked, because there were these different vibrations, soft and strong, you start to feel a bit loose.*

The only participant who recalled the particular moment when his teeth started vibrating, described it as follows:

> *I was very very aware of my body, especially this speaker in the back of my head was making my teeth chatter, that was interesting; I wanted to stop my teeth from chattering but I couldn't.*

Whereas, as seen thus far, different bodily effects were described by each user, three effects were consistently reported by a group of users, loss of equilibrium, blurred vision and the feeling of being touched. Two participants described these effects as a part of a broader context of bodily reactions and affects:

> *And then someone touched my shoulder, I think, I'm not sure! And this was a bit like "ok, ehm" so there was this kind of reaction in my body as well. I don't know really, it's quite strange to describe this through words.*

> *During the last minute, I was starting to really, I lost my sense of... I had the impression first to fall a bit (leans on the desk to mimic a fall), I was sitting but falling, so you feel like falling, but your body is... yes and then you fall...*

> *I was in another..., I was in a cosmos. The vibration start soft like a massage and then it really affects your body, you loose the sense of... I don't know how to explain, but I was out of my body, I was really starting to levitate a bit.*

Of particular importance is the way in which, in the latter quote, the participant speaks of an out-of-body experience. This is a particular mode of experience manifested through the feeling of floating over one's own body and, in particular cases, of perceiving one's own body from outside of it. The term was coined by British physicist and parapsychologist George Tyrrell (1943) - who performed several experiments in telepathy and ghost apparitions - and then used widely across a vast number of studies on near-death experiences, use of dissociative and psychedelic drugs and sensory deprivation. This participant was the only one explicitly recalling an out-of-body experience, which may imply that she was already interested in this kind of phenomenon or had a particular sensitivity towards it. However, some of the previous statements I have reported may also be related to this kind of experience, even if they were not explicitly defined as such; for instance, 'It just made my body [...] sort of someone's else', or 'You start to feel a bit loose' may be examples of this.

5.2.4 Discussion

So, how can our experiment provide an insight into the relation of vibrations and threshold phenomena? And what can it speak back to the scientific literature I discussed above? Rather than discussing the experiment in terms of its efficacy in altering the neurophysiological body, I want to focus on its capacity to produce different kind of ambiguous, uncertain and energetic subjects. This will allows us to extract an insight which can speak back to the scientific experiments described earlier. Operating from the vantage point of artistic research, it is possible to look at what that literature may have elided. I will base this discussion on the interviews we gathered, although, of course, it cannot be excluded a priori that the users' non-preparedness or politeness were factors which influenced their replies.

The scientific experiments forming the literature discussed above were designed to prove the existence of vibrational effects on the human body, as it might be expected by research conducted across the military and human-factor complex. This kind of context of experimentation is a generally positivist field of research where the kind of body being investigated is primarily physiological. The body is examined as an organism which, once stimulated through technical instruments, reacts by producing quantifiable effects. It is, in other words, a body lacking subjectivity, psyche, desire and fear. What our experiment brings to the fore instead is how the use of vibration within a particular technical framing and context of experimentation can produce differential, ambiguous and affectively-heightened bodies. For example, the specific physiological effects of each vibration pattern (teeth vibration, sense of being elevated, vertical vibration and sense of falling, see Table 5.1) seemed to have not been clearly perceived by most participants, or at least, not consciously acknowledged. Rather, to the participants, the feeling of having experienced their bodies as new and unknown was drastically more important than the specific physiological effects - most of which they could not even recall or describe. This does not mean that those physiological effects do not deserve attention. What this shows, in my view, is the importance to grasp the entanglement of physiology, psyche and cognition to the technical mediation of corporeality.

The phenomenal effects described by the participants cannot exist without their physiological grounding. The feeling of being touched can be related to the capacity of low frequency vibrations to excite the muscle receptors and thus alter the proprioceptive sense. The loss of equilibrium is likely caused by the alteration of the proprioceptive sense in combination with the relative displacement of the internal organs. The blurred vision is most likely caused by vibrations applied to the skull, which cause the eyeballs to be slightly displaced according to the frequency rate of the vibration. But the physiological body is 'absent' to the participants: they do not *feel* the excitement of their muscle receptors, they feel the immaterial touch of another (inexistent) person.

Thus, if we want to understand the balance between the physiological, the psychological and the cognitive, what can we say? At the level of the physiological body, it would seem that the alteration of the proprioceptive sense tends to negatively affect the interoceptive sense.[9] This in turn, might reinforce the alteration of one's self-perception, which leads us to the realm of the phenomenal. One perceives the touch of another person, a touch that does not actually happens, it is, simply enough, just felt. Then, of course, in order to be felt this kind of touch has to be imagined, embod-

[9]The perception of the changes in the activity of the internal organs.

ied somehow by the psyche, reified in its immateriality. To perceive the immaterial touch, the loss of equilibrium or the feeling of being outside one's own body as such, one has to be psychically attuned with the context and the technical framing as well as the experience itself. This kind of attunement manifests itself in the participants' enjoyment of the experiment despite the high physical intensity of the vibrational stimuli they were subjected to. While the participants acknowledged this intensity, as their use of terms such as 'invaded' and 'shaken' indicates - no one found the experience to be negative; yet, only some of them would have repeated it. After the experiments, most participants reacted energetically to the experience of threshold phenomena, and yet they were unsure of what to take from it - at least at the moment of the interview. This reminds of Shildrick's statement on the dual nature of a prosthesis: it extends functional agency and radically destabilize human agency as such.

5.3 Turning an Experiment into an Artwork

The experiment discussed above produced an insight which led me to the creation of *Nigredo*, a live installation which I will describe in the next sections. However, as I wrote earlier, the translation of technical and scientific findings in the artistic domain is neither immediate nor simple, but should be taken carefully into consideration. Here, I will describe the analytical process that allowed me to extract findings and ideas from the experiment and use them in the creation of the artwork.

The most basic finding of the experiment was, as detailed above, that adequately amplified low frequency vibrations can effectively alter one's perception of her own body without the need of a laboratory setting. More importantly, I argued that the experiment showed how the technical milieu - the infrasound transducers, the vibrational rhythms, the darkness and the chair - can produce new kind of corporealities. And this, in turn, shows the entanglement of the material and the immaterial, the physiological and the psychological, the organic and the technical. In our experiment, this alteration, or hybrid corporeality, was manifested in the form of a series of physical, perceptual and psychological effects that varied from one visitor to another, such as the feeling of being touched, loss of equilibrium, blurred vision and alteration of the perception of time. This is useful in that it indicates how vibrations can be used to significantly affect a performer's self-perception and that the kind of alteration depends on the subject who experiences it and the context in which it is situated. The highly subjective experience reported by those who participated in the experiment points to the potential of a single human-machine configuration to vary according to the specificities of the human body that takes part in it. In aesthetic terms this means that it is possible to create a single artwork that, by being experienced differently by each visitor, can prompt a broad range of reactions and reflections.

Turning to the core problematic of this research, how to displace a subject-object relationship between performer and instrument, it is possible to provide further reflections. An instrument, like the one we created for the experiment, capable of significantly affecting the human body at the physical, perceptual and psychological level takes control out of the reach of the performer. It could, to some extent, control the performer's body itself. This leads to a problem which conflicts with the idea of configuration. This kind of performer-instrument relationship, where the instrument has a relative control over the performer's body and the performer has no influence on the instrument, would not be a configuration at all. Creating an instrument whose only function is to alter the visitor's self-perception does not sidestep the subject-object relationship of performer and instrument, it simply reverses it. It is a kind of experimental approach which resembles closely the approach of researchers in the field of military science or human-factors and, as such, produces a physiological body, an object of science to be quantified. And this is exactly the conception which the current project aims to displace. At an aesthetic level, as suggested by some participants, an experiment solely focused of producing a sensory alteration is not an artistically expressive experience, perhaps just an interesting technical exercise.

To address this issue, during the realisation of *Nigredo* I further developed the instrument which was used in the experiment. The goal was to find ways in which the vibrations could be mutually shared between instrument and performer's body, rather than simply directed from the former to the latter. I kept the basic setup identical to the one used in the experiment, but importantly, I changed the source of the vibrations. Rather than having the instrument generate synthesised sine waves, I modified the hardware and software to capture bioacoustic vibrations from the performer's body, that is, the sound of muscle contracting, and the rhythm of the blood flowing and the heart beating. Then, in real time, the instrument manipulates the bioacoustic vibrations and feeds them back to the performer's body through the same high-power infrasound transducer used in the experiment. Therefore, differently from the experiment, in *Nigredo* the performer's body produces vibrations which are greatly amplified by the instrument and then fed back to the performer's body in the form of high-power vibrations of the coccyx, spine and skull. To strengthen the perceptual feedback loop between the visitor and the technical system, I added to the instrument a set of interactive lights linked to the performer's breathing rate, and eventually included a mirror facing the performer; this is intended as a means to strengthen the impact of the threshold phenomena by offering to the visitor the possibility to look at herself in the most significant moments of the piece (the details of these additional implementation are described in the next sections).

As a result, in *Nigredo* the instrument and the performer are both actively engaged in a process of mutual information. A process which unfolds through the rhythmic exchange of vibrational force. The performer is able to both listen to and watch herself while the configuration of her body and the instrument reinforces itself in a positive feedback loop. Furthermore, contrary to the experiment, because the vibrations originate from the performer's body, she can actively alter the configuration by contracting her muscles, speaking or trying to change her heartbeat.

5.4 Nigredo: A Private Experience of Altered Self-perception

Nigredo is an eight-minute-long artwork to be experienced by one visitor at a time.[10] The work, presented in the form of a time-based installation (Figure 5.4), is an experiment in alternative modes of musical performance. It stretches, as it were, the very meaning of musical performance by forcing the visitor to take the role of a performer and treating the live musical composition as an organised series of audible sounds and rhythms of acoustic resonances, as the seminal composer Edgar Varese (1966) would call it. In a completely blackened room a visitor sits in front of a mirror. Technically speaking, the visitor is first induced in a state of perceptual deprivation, and then

[10]The project's webpage, including a video, pictures and further information, can be found at http://marcodonnarumma.com/works/nigredo/. Thus far, *Nigredo* has been exhibited in Mexico, Germany and Austria and has been awarded two prizes: the TransitioMX Electronic Arts and Video Award, Mexico City, 2013, and the Cynetart Award for Computer Based Art, Dresden, 2014. See respectively (TransitioMX, 2013) and (Cynetart, 2014).

Figure 5.4: Side view of a visitor sitting inside the installation. The picture portrays the moment in which the vibration started. The visitor can be seen slightly lifting his hands due to the sudden vibration.

subjected to diverse physical, sonic and visual stimulations. These are designed and temporally composed to exploit and reinforce the capacity of whole-body vibration (WBV) to provoke physiological alterations and interferences in the acquisition of sensory information, as described in subsection 5.2.2.

However, the essential aim of the work is to unlock latent qualities of the human body through its configuration with a technological instrument; it aims to produce the visitors' bodies as new hybrid, corporeal entities through the experience of threshold phenomena, where corporeal is intended as, at once, material and immaterial, perceptual and psychological. To do so, *Nigredo* re-appropriates physiological and biomedical methods towards a critical questioning of the relation that links humans and machines. At a high level, it questions the role of machine technologies in the formation of human beings in the era where everything is commodified, including our own bodies. In more detail, the work enables a process of mutual co-dependence of the human body and the machine. It does so by using sounds from the human body as a material acoustic force that, when amplified and manipulated by a machine, resonates bones, internal organs, surfaces and spaces. A process where performer and machine perform through each other by exchanging acoustic energy in a feedback loop. In the next sections, I will discuss how, by delving into the tension between perceptual deprivation and listening, *Nigredo* probes the idea that we do not possess a complete perception of our corporeality, but rather this is emergent from the dynamic configuration of the human body and technology.

5.4.1 Tools

In this work, I have repurposed biofeedback methods, WBV, wearable bioacoustic technology and techniques of perceptual deprivation. As previously described in subsection 2.3.1, biofeedback is a technique that makes internal bodily mechanisms, that would otherwise be imperceptible, become manifest as audio or visual stimuli (Moss, 1998). For this work, and differently from the experiment described above, I capture the sound of the visitor's heart beating and blood flowing using a modified version of the XTH Sense.[11] This sensor is comprised of an armband embedded with a wideband

[11]As noted at the onset of this thesis, the XTH Sense is a biophysical wearable instrument created in 2011 by the author during his Master by Research at Edinburgh University, and which is still being developed today. See http://xth.io.

electret condenser microphone (the model is Kingstate KECG2742PBL-A). This is encased within a silicon mold, which avoids the microphone touching the skin. The silicon mold isolates the microphone from external noise and electrical interferences and amplifies the skin vibration before it reaches the microphone. The design is inspired by the work of Silva and Chau in the design of control systems for prosthetics (Silva and Chau, 2003). The bioacoustic signal is transmitted from the XTH Sense as an analogue sound signal through an audio cable. The signal is then acquired by an external sound card which digitises it at a sampling rate of 44100 Hz and sends it to the performance software. The signal is not amplified. A high-pass filter (HPF) with a fc of 1 Hz is used in order to bypass artefacts created by limb movement (Day, 2002).

WBV, as described earlier, refers to the exposure of a human body to externally-induced mechanical vibrations, often by means of devices that produce infrasound wave, called exciters. For this artwork, I have used three low frequency exciters by Visaton (model BS 130), the same model used in the experiment. An exciter is constructed in a similar way as a traditional speaker but it lacks a membrane. It consists of three components, an oscillating mass, two contact pins to connect it to an amplifier and a mounting plate to hook up the surface to be excited. By applying a sound signal to the contact pins, the oscillating mass begins to shake at the frequency of the signal. The oscillation is transmitted to the mounting plate and from there to the external surface it is coupled to. As a result, the external surface vibrates at the rate of the audio signal. This technology is commonly used to vibrate hard surfaces, like seats in cinema halls. In this work, I use it to vibrate the bones and skull of the visitors.

Bioacoustics is the science of sound production and reception in living creatures. By using resources from neurophysiology and anatomy, bioacoustics investigates how living beings, including humans, produce and detect sounds, and how those sounds traverse different media. In this case, the installation uses low frequency vibrations produced by the internal organs of the visitor's body, including blood flow pulsations, heartbeat and muscle sounds (MMG). The human bioacoustic sounds are used in combination with the exciters to create a physical configuration of the human body with the instrument. Finally, perceptual deprivation (Metzger, 1930), also known as Ganzfeld effect, is a phenomenon similar to the more widely known sensory deprivation. Whereas the latter is provoked by lack or decrease of stimulation, the former is provoked by the exposure to a disorganised, uniform stimulation field, such as constant high-amplitude noise, continuous intense light or a combination of the two.

> Before reading the following sections, the reader is invited to watch a video documenting the work. The video can be found online by clicking here, or alternatively here.

5.4.2 Setting up human parts with machine parts

The current setup of *Nigredo* involves placing a very small booth measuring 1.20 m X 1.20 m X 2.40 m in the centre of a sound-proofed room measuring about 11 m X 4 m X 9 m (Figure 5.5). Inside the booth are a custom made chair and the machinery that will be attached to the visitor's body, while outside the booth, but inside the sound-proofed room, are the sound system, composed of two subwoofers and four loudspeakers, a mixing desk, two analogue amplifiers, an eight-channel external soundcard and a computer. The visitor experiences the work inside the booth while being unaware of the space surrounding it. The booth walls are empty frames made of planed fir, a lightweight and flame-retardant wood commonly used for roof construction. Each frame is covered with molton, a black fabric used in theatre scenography, in order to simulate four walls and ensure complete darkness inside the booth. This also allows for the sound diffused from the external sound system to reach the visitor's body inside the booth. Since the sound amplitude in the mid-high frequency range is decreased by the fabric, those frequencies are additionally amplified. The booth is fixed to both the floor and the ceiling of the surrounding room in order to stabilise it and make it safe for the visitor in case of a panic attack or other emergency. The chair has three exciters embedded that make direct contact with the skin and hair over the visitor's skull and vertebral column. The exciters directly resonate the bones of the visitor's body in three points, the skull, the lower spine and the coccyx, the last vertebra of the sacral curve. The system also includes two LED light strips at each rear side of the chair. These are controlled from a computer using an Arduino[12] and a custom circuit. The chair is embedded with an XTH Sense heartbeat sensor.

[12]This is an open-source electronics platform. See https://www.arduino.cc/

Figure 5.5: The base wooden structure of the booth during the setup of *Nigredo* at Cynetart Festival, Dresden 2014.

Accompanied by an assistant, a visitor enters the booth and is invited to sit on the chair (Figure 5.6). The assistant is instructed to use a portable light to illuminate only the chair, so that the visitor cannot look at the space and cannot see the mirror. Once seated, the visitor is requested to take off shoes and shirt.[13] The reason for this is twofold: on one hand it is a technical need, for the heartbeat sensor functions only when in direct contact with the skin; on the other, it is a strategy to make visitors feel more vulnerable, which in turn, makes them more attentive to perceptual stimuli. In the three exhibitions where *Nigredo* has been shown so far, women and men alike have always accepted this condition without remarks or complaints. The assistant then blocks the skull of the visitor to the chair using an elastic headband and helps the visitor wearing the XTH Sense heartbeat sensor at the location nearest to the heart.[14]

The biosensor captures the sound of the visitor's heartbeat, blood flow and muscle contractions. The sound is digitally processed and fed back to the visitor's body in the form of new audio, visual and physical stimuli. Sounds are diffused by a hidden surround system and two subwoofers, flickering lights are generated by LED strips located behind the visitor's body, while intense mechanical vibrations are induced to the whole body using the exciters. By executing a temporal composition of auditive, light and vibrational stimuli in different combinations and intensities, the system creates a saturated stimulation fields that induces the visitor's body into a state of perceptual deprivation. In this state, the human body is not able to make meaningful grouping of internal and external stimuli, and thus the neurophysiological processes that drive the perception of both the environment and one's own body are altered (Rasmussen, 1973, 9-11). The aware distinction between what is part of one self and what is not is blurred. It is an intimate and uncanny experience of one's inner self.

5.4.3 Alternate embodiment

The experience of *Nigredo* unfolds during three phases. The first phase forces the visitor to concentrate on self-perception through sound and light. As the visitor sits down and the assistant leaves the booth, the bioacoustic sound of the visitor's heart-

[13]The assistant is always a woman in order to make both male and female visitors feel more at ease.
[14]In the case the visitor does not wish to take off shirt and shoes, the assistant politely guides the visitor out of the installation space.

Figure 5.6: The chair where the visitor sits during the experience of *Nigredo*. It is made of planed fir, painted in black and embedded with three acoustic exciters and the XTH Sense heartbeat sensor. The picture shows the chair as installed at the festival Musikprotokoll im Steirischen Herbst, Graz 2015.

beat, blood flow and muscle contraction is captured and played back by the hidden surround system and the two subwoofers.

> A live recording of a participant's heartbeat, recorded with consent, can be found online by clicking here.

The mirror is not visible yet due to the complete darkness inside the booth. Two minutes after, LED lights synchronise with the pulsations of the visitor's visceral sounds and light up rhythmically, thus enacting a simple biofeedback mechanism. At

Figure 5.7: Detail of a visitor sitting in the booth of *Nigredo* during the live experience.

this point, the visitor's heartbeat is recorded and digitally processed to sound progressively faster. This is followed by an increase in the light intensity and flickering rate (Figure 5.7). Over three-minute climax, the heartbeat together with the sound pulses of blood and muscles are digitally processed and fed back to the subject's sensory system as increasingly intense auditive and light stimuli. This passage of the piece sets up the conditions to configure the visitor's body with the instrument in a vibration mode. The natural low-frequency sound of the visitor's heartbeat, blood and muscles is digitally stretched into progressively shorter samples, which eventually form in a thick and harsh layer of sound sitting between 200 Hz and 18 KhZ. One's vital rhythm is digitally augmented by the machine to form another tangible form of the self.

> The reader is now invited to listen to an audio excerpt of this passage of the composition. The audio file can be found online by clicking here.

The second phase is a transitional moment where the visitor's vision of her own body is altered. As soon as the sound pressure level (SPL) exceeds 120 dB, thus entering the SPL range that can cause discomfort,[15] the light flickering rate becomes almost continuous and a separate LED light synchronizes with the visitor's breathing rate illuminating the mirror at periodic intervals. Suddenly the harsh sound stops and the visitor can only hear a quiet sine wave at 600 Hz. Because of the sensory shock caused by the sudden drop from a very high to a very low SPL, the fast flickering of the LED lights, and the visual distortions produced by the mirror, the visitor's vision is altered, making her unable to recognise the image in the mirror as her own. This altered state is forced onto the visitor's sensory system for one minute to sustain the visitor's feeling of being immersed in a space of sounds and lights. In the third and final phase, the visitor's body and the instrument are physically coupled. The sine wave fades out and the visitor's bodily sounds are processed and spatialised in the booth in the form of a subtle sound composition flowing around the head of the visitor.

> An audio excerpt of this passage can be found online by clicking here. Please, note that in this part of the composition the sound is very quiet and thus might not be heard if the volume of your player is too low.

The three exciters embedded in the chair are suddenly activated. By making direct contact with the skull and the vertebral column, the exciters feed back to the visitor's body her own visceral sounds in the form of mechanical vibration patterns. The

[15]The SPL threshold of discomfort is understood to sit between 115 dB and 140 dB (Newman, 1957). According to Newman there is no fixed threshold, for this kind of discomfort is a subjective phenomenon that depends on factors including age and habituation to high SPL.

visitor is submerged into a field of intense sonic, visual and tactile stimuli. Here the configuration of visitor and instrument enters the flow mode. The different vibration patterns are designed to travel through the body in opposite directions and thus create standing waves inside the visitor's rib cage (Figure 5.8).

Because the standing waves is a strong stationary acoustic vibration, it resonates the bones and the tissues internally, and thus displaces the relative position of one's body organs (Griffin and Seidel, 2011). The combination of intense whole-body vibration, spatialised auditive stimuli and flickering lights immerses the visitor in the configuration with the instrument. Sound, light and vibration interfere with the neurophysiological processes that govern the voluntary and autonomic nervous systems. This alters the rhythm of the cardiovascular and respiratory system, the perception of one's own articulations in space and the behaviour of the optical nerves (Rejali, 2003). The perception of one's own image in the mirror mutates, and with it, also the perception of one's own body changes. At last, the frequencies of the exciters increase in unison until the installation is abruptly interrupted. The configuration is broken. The visitor is left in complete darkness and silence for one minute, and then the assistant enters the booth and let the visitor out.

In *Nigredo* perceptual deprivation becomes a generative tool through the use of sound as a vibrational force. The instrument here does not control or enhance the visitor's body; once the body is strapped to the chair and its parts are physically coupled with the parts of the instrument, the latter feeds on the sounds of the visitor's body and feeds vibrations and music back to it, forming a positive feedback loop. The instrument and the human body perform through each other. The visitor can play with the system by changing respiration rate, by contracting muscles, or by talking. In this way, the sounds produced on purpose by the visitor can significantly alter the human-instrument configuration and, consequently, the experience of the artwork. But one could say that also the instrument 'plays' the visitor's body. When the instrument resonates the visitor's body using the amplified and modulated bioacoustic sounds, it alters that body's physiological processes and thus the human-instrument configuration changes. But there is a play in the work. The visitor is not explicitly told that the possibility to alter the outcome of the installation exists, neither she is told otherwise. From the liability agreement to be signed upon booking a session, to the terminology the assistant uses to explain the work, from the look and feel of the

Figure 5.8: Frontal view of a visitor sitting inside the booth of *Nigredo*.

booth and body sensors to the darkness and claustrophobic size of the installation space, everything is designed to emphasise the, apparently exclusive, machine agency over the visitor's body. The visitors thus tends to rest on the assumption that there is nothing to do inside the installation other than stay sit and be careful. By telling a half truth, a fictional narrative of control is constructed. This is done with the intent to challenge the visitor to be critical about their experience of the work and dare to play with the alleged control of the machine over their bodies. A few visitors have indeed taken the initiative in past exhibitions and have actively influenced the outcome of the piece in a range of ways, from waving their hands in an attempt to make sense of the interaction, to uttering words that would be live sampled by the instrument, or by slowing their breathing rate to try gain control of the instrument.

5.4.4 Aesthetic and Ethical Considerations

In the first and second phase of *Nigredo*, the sounds produced within the visitor's body are amplified and diffused at such a high volume that they physically resonate the space and the wooden booth. It is a phenomenon that pervades the visitor's body, meaning that it is not limited to the ear but involves all organs, and traverses the body of the instrument, it is not only played back by it. My aesthetic interest here lies in creating a configuration that allows the artwork to reach a particular state of intensity through sound and light, a particular threshold. The artwork is purposely conceived and designed to exceed the level of magnitude needed for specific corporeal and technical reactions to occur, as much as the technical means allow and as long as the visitor is not permanently harmed. Sound is a unique means in this sense, because it can penetrate human and technological parts and, by making them resonate, it disperses acoustic energy through them; it excites them in a unique, physical way that no other energy wave allows. My use of low-frequency sounds and high SPL in *Nigredo*, as well as the feedback system of bioacoustic sensors and exciters, serve to create the right conditions for sound to penetrate the visitor's body and the instrument's parts with enough force to significantly disrupt their functioning for the duration of the piece. Following Henriques (2010, 63), this can be understood as a form of *sonic dominance*: the 'intensive, immersive and visceral experience of the saturation of sound'. This concept is important for it emphasises the human body (the visitor's body in this case) as a corporeal medium which sound traverses, excites and perturbates. In so doing, this aesthetic approach to rhythm and vibration confounds the supposed clean cut between subject and object and embodies a form of affect that is relational, fluid and situated.

But *Nigredo* does not only rely on reaching intense sound levels or exceeding perceptual thresholds; it also uses almost imperceptible sounds and moments of complete silence. In aesthetic terms, silence is as important as a high level of loudness in providing the intense experience that characterises *Nigredo*.[16] In the third phase of the work, when the exciters are suddenly activated, the space is almost silent. One can only barely hear some of the frequencies produced by the exciters, for most are infrasound frequencies and therefore sit below the threshold of human hearing. This is interesting because, on one hand, silence creates a sudden emptiness in the installation space, which the visitor's ear, and her whole body, can find disorienting. On the other, it creates enough room for the visitor to become aware, even if just for a brief moment, of the changes to her body as she sees herself in the mirror for the first time. At this point, the exciters start suddenly to resonate her body from within, and the visitor can listen to the few audible vibrations through bone conduction. This creates further disorientation, for the sound forms that at first filled the space around the visitor have shifted within her body and are intensely present as a tangible energy moving across the stomach, the chest and the skull. Eventually, when the exciters stop, the visitor is left in total silence for a minute, to emphasise even more strongly than before a feeling of sudden emptiness, both in the space and within the body.

By design, *Nigredo* is an intense experience; however, with a duration of eight minutes, it is also a very brief one. By creating an intense and brief experience, my aim is to *impact* the visitor's perception and, metaphorically, her imagination. If the experience of the work lasted for too long it would loose much of its impact. Rather, the short duration of the piece ensures that the experience will not be remembered in detail; the intensity and briefness of the experience is shocking, and thus what the visitors are left with is a sense that something happened to, and within, their bodies, but it is hard for them to rationalise what exactly happened. *Nigredo* plays with the

[16]Silence in music and sound studies is a fertile topic of interest for many artists and researchers. A seminal reference, and one that I hold dear, is the work of John Cage. Among the broad range of related publications I would recommend (Cage and Charles, 2000).

edges of ethics in different ways, from deploying a stereotyped imagery of death and torture technologies (the death chair), to the use of sensory deprivation methods (the audio, visual and haptic saturation). By 'walking on the border' of the unethical the work aims to produce a lasting and thought-provoking experience, rather than simply shock the visitor. Indeed, *Nigredo* plays with the sensation of shock, but this is not the end goal in itself, it is a means. The shock provoked in the visitor is a means to impede, shortly after the ending of the experience, an immediate rational understanding of the experience and facilitate a focus on the bodily sensations that still echo in the body. With hindsight, this can lead the visitor to question the properties and capacities of her body when configured with technology. This is what distinguishes the experience of flow in *Nigredo* from other kinds of pleasurable and enhancing flow, such as the 'peak' states found in raving (Pini, 2001), or the feeling of complete immersion found in traditional music performance (Nijs et al., 2009). Whereas the latter experiences of flow are constructed through training, in *Nigredo* that experience is forced upon the visitor using a particular kind of technical milieu.

To better understand this kind of experience the work of psychologist Harry Stack Sullivan (1955) may be very useful. Sullivan defined three levels of cognition: prototaxic, parataxic and syntaxic. Upon experiencing an event, one can elaborate the experience to different extents. A prototaxic mode of experience is impossible to describe to others because it lacks symbols, it is a preverbal experience which one is incapable of communicate. A parataxic mode is prelogical, meaning that the event cannot be communicated in detail and it is difficult to discuss, such as the out-of-body experiences which some of the participant to the experiment on WBV tried to describe (see subsection 5.2.3). The syntaxic mode is easy to discuss for it relies on symbols and meanings that are common to groups of people. The experience of *Nigredo* seem to sit between a prototaxic and a parataxic mode of experience. In a prototaxic mode, the subject is in a trance state, where the ego tends to be absent and forms of automatism can take place (Gowan, 1975). In *Nigredo* this resonates with the feeling of otherness experienced by the visitors, an altered perception of the self which is perceived as extra-personal, a form of automaticity. A parataxic experience which can be discussed is, on the other hand, 'interpenetrated' by components of the near and distant past and the near future, such as anticipation and expectation. In what sound as Simondonian terms, Stack Sullivan (1955, 39) states that these components have a powerful role in the way 'potentiality in the tension becomes action'. Through a mixed experience of prototaxic and parataxic states the human-machine configuration of *Nigredo* is one and multiple; the same technical setup and aesthetic imagery is experienced differently according to the physical and psychological potentiality of each individual; the configuration is thus fixed and changeable, as I have noted earlier.

When touring with *Nigredo*, I find it interesting to spend a few hours in front of the installation to meet the visitors as they leave the work and learn about their responses by engaging in informal conversations. The responses I have seen vary greatly. Some visitors leave the installation in complete silence and do not wish to talk. Others are visibly excited and thrilled and are curious to hear from me the aesthetic motivation of the work. Some seem neutral and leave calmly. No one has complained or raised negative remarks so far, rather, visitors frequently ask: 'Can my body do this?' It is an interesting question, for it implies that the experience has prompted the visitor to question whether she is fully aware of the capacities of her body; it indicates that the experience has made her curious about what one's own body is capable of. This resonates with my own understanding of the broader resonance of the work. We live in a world where, in my view, the instinctive human fear of what one does not know is too often exploited by media and institutional organisations to enact policies of institutional racism and social segregation. With this work, I attempt to show that this kind of fear is inconsistent, for one's own body is the first and foremost thing one cannot know fully, because it is in a process of constant becoming; a form of becoming that involves other beings and technologies in a continuous and relational process of change emerging from context and shared experience.

5.5 Summary and Reflections

This chapter considered technical and artistic research on the relation of low frequency vibration and self-perception. I discussed first an artistic experiment with whole-body vibration (WBV), where I tested the capacity of an electronic instrument to affect the human body through the use of vibrational force. The findings gathered through first-person interviews showed limitations and possibilities in terms of the artistic application of WBV. This prompted me to explore the implementation of a WBV system within the frame of a more sophisticated and complete artwork, *Nigredo*. In this artwork, I discarded the use of synthesised sound to resonate the visitor's body, and chosen to resonate the visitor's body with the bioacoustic sounds produced by the body itself. This was an important step, for it afforded not only a more artistically interesting use of WBV, but it also helped me understand the central role of vibrational feedback loops in the configuration of a human body and an electronic musical instrument.

Despite the artwork being well received in the artistic community, there is one issue that is inherent to its nature. Whereas the majority of the visitors experiencing *Nigredo* find it an intense and fascinating experience, during private conversations, I noticed that some participants describe their own understanding of the work as closer to an experiment than an artwork. This is similar to the reactions of the participants to the experiment that I presented earlier. But whereas the participants' reaction to the experiment is likely related to the fact that they were invited to give formal interviews, this is not the case for the visitor's experiencing *Nigredo* in a festival setting. Here we can, once again, appreciate the importance of the milieu in defining a human-machine configuration. Of course, the milieu of the art festival, with its tickets, rooms, brochures, speeches, curators, artists and visitors, authorises, in the eyes of the visitors, a certain kind of daring aesthetic choices which may not be received with the same open attitude in a different context, as it emerged during the experiment on WBV I conducted at STEIM. So, the milieu is not only a site where things happen, it is the very medium that defines how things happen. As a sound wave is altered by the medium it passes through, a configuration is transformed by the milieu it unfolds into.

From my viewpoint, however, this understanding of the finished artwork as something resembling an experiment is completely understandable. The artwork, even though it reached its final form, maintains an inherent experimental nature. My intent in creating *Nigredo* was not to create a spectacle nor an interactive artwork per se. Rather, the work is conceived as a test bed for alternative corporeal experiences. In contrast with other artworks which investigate affective modes of experience through direct embodied interaction,[17] I do not know how the experience of each visitor will be like, and I have no interest in predict it nor plan it. Each visitor's experience is

[17]See for instance Lone Bertelsen's analysis of the work *Intimate Transactions* by the Transmute Collective (Bertelsen, 2012).

different, and the perception of the artistic weight of the work is highly dependent on who experiences it, their past, their present condition and their expectations. I consider the artwork successful for it is capable of conveying bodily sensations, feelings and emotions that one has not experienced before, and which force one to think critically about the political and ethical relations of body and technology. This might not be what most people expect from an interactive artwork, yet, as an artist working with body technologies, I believe this to be a greatly challenging responsibility to fulfil.

Chapter 6

Practice Pt.II: Corpus Nil

6.1 Introduction

The experiment on gesture expressivity and muscle sensing and the related artwork that I will present here, *Corpus Nil*, are significantly different, yet they share a similar aesthetic investigation and, in my view, they complement each other. Here I will discuss the relations between them. The creation of *Nigredo*, the performative installation which was discussed in the previous chapter, was guided by a core principle: to balance the performer's intentionality with the instrument's stake in the performance. The purpose of doing so was to establish a process which mutually engaged performer and electronic instrument, a corporeal feedback loop that could displace a subject-object relationship. The creation of *Corpus Nil*, the artwork that I will consider next, follows the same principle and shares the same aim. However, the two works have two major differences. First, while *Nigredo* is presented as a time-based installation to be experienced by one visitor at a time, *Corpus Nil* is contextualised in a different setting, gestural musical interaction in a public performance. So, whereas in the former work the performer sits in a private space and no movement is required to interact with the instrument, in the latter the performer is on a public stage and gestural interaction is necessary to interact with the instrument.

Second, a further difference between the two works lies in their genesis. *Nigredo* emerged from an artistic experiment which was specifically planned to test the basic method I wanted to explore in the final artwork. *Corpus Nil*, on the other hand, was largely informed by three scientific experiments contextualised within the broader program of our research team - which included Prof. Tanaka and Dr. Caramiaux - whose focus was on gesture expressivity for musical interaction. The reason why this is important is twofold. First, as a team, we conducted those experiments to test specific hypotheses that emerged from our research program. As an individual researcher, I conducted those experiments being aware of which particular aspects could have been useful in the realisation of my artistic ideas.

Secondly, the use of scientific findings for the creation of an artwork requires an attentive process of translation, as I stressed on many occasions in this text via Stengers (2000). Our scientific experiments were conducted in a laboratory context where all conditions were regulated. Every aspects of those studies was directed thoroughly by the experimenters, including the participants' movement. Although we asked for the participants' opinion in one experiment, it can be said that, in this case, the participants themselves were physiological subjects whose interest in the experiment we did not acknowledged (*ibid.*). In a real world scenario instead the situation is different. The performance conditions, including room temperature, magnetic interferences and the like, cannot be controlled, and the movement of a performer is highly dynamic. More importantly, the performer experiences her own body, the instrument and the context in particular ways; during an artistic performance *an economy of desire is always at play*.

Thus, how to reconcile such an economy of desire with normative science? While the following experiments deal with a primarily physiological body, they do so in order to grasp very specific material mechanisms which can enable a corporeal communication between a body and a machine. However, when, during the performance of *Corpus Nil*, that mode of communication is established through the link of physiological signals and software algorithms, the human body ceases to be an exclusively physiological entity. Through training, discipline and attunement, it is the lived and immaterial body which becomes configured with the machine. The machine is incorporated by the body in complex ways which exceed the physiological domain. This emphasises the need for a careful selection and interpretation of the scientific findings to ensure they are meaningful in the specific condition of a public performance. As Roger Malina (2006, 15) bluntly puts it, 'Most science is normative and need make no appeal to extra disciplinary sources for its advancement'. Thus, crucially, the scope of this research is not the production or re-staging of normative science; it is about 'working outside current paradigms, taking conceptual risks', following Malina, so as to mindfully merge disciplines towards new practices of experimentation. This will result in contrasts and dissimilarities which must be considered and which, in fact, produce the richness of art and science practice itself. Another significant aspect of this issue is that this mode of transdisciplinarity, what Malina calls 'deep art-science coupling' (*ibid.*), requires the artist-researcher to have an in-depth knowledge of all the fields being engaged with. This is necessary to highlight contrasts, exploit complementary aspects and generate connections among science, art and theory, as for the present research project. In the case of *Corpus Nil*, this deep coupling of art and science will be more evident because of the two sites where the artwork was developed: a EU-funded research project and my personal practice-based artistic research.

Thus, in the next sections, I will elaborate on the aspects of the experiments that are more relevant to my research. The three related papers, which detail the technical contribution of my research in its entirety, are referenced in the relevant passages and can be found in the Appendix of this document. This will allow us to understand the physiological basis of human movement and how a machine can be programmed to become sensitive to it. Starting from section 6.3, I will discuss how the phenomenal and immaterial body enter the frame of this experimentation and play a crucial role in the final performance, *Corpus Nil*.

6.2 Understanding Gesture Expressivity Through Muscle Sensing

The following three-part study is the result of collaborative work with Dr. Caramiaux and Prof. Tanaka. In elaborating on these studies I will keep using the 'we', as in the previous chapter. The rationale behind this series of experiments was twofold. On on hand, we wanted to test the extent to which an electronic instrument can sense the expressive variations in the physical gestures of a performer through muscle signals, rather than using muscle signals as a direct input. On the other, we wanted to test the capacity of the instrument to influence the performer's physical gestures by producing sounds starting from the performer's muscle signals. The specific scope in terms of my own research was to explore how the configuration of a performer's physiological and lived body with the parameters of an electronic instrument can produce both an affective experience and an expressive musical interaction. Whether in the previous experiment I used acoustic vibrations to affect the performer, in this case I explored the inverse process: to use the bioacoustic vibrations and bioelectrical signals of the performer's body to affect the instrument.

To that end, I selected and combined resources from the study of the relation between automaticity, body schemata, muscle activation, instrument and auditive stimuli. Using those resources, together with the expertise of my colleagues, we put together a specific set of wearable sensors and algorithms to extract high-level information on muscle activity and sonify those information. This implementation, which I will describe next, proceeded incrementally throughout the development and analysis of the experiments. This set of hardware and software is not precisely the same I have used for the final performance, *Corpus Nil*. In particular, the software used in the performance is designed using the idea of configuration as a template; it is a semi-autonomous software which I programmed drawing inspiration from the theoretical analysis of the technological body discussed in chapter 3.

6.2.1 Gesture Expressivity

A generic definition of gesture in human-computer interaction comes from Kurtenbach and Hulteen (1990), who defined a gesture as 'a movement of the body that contains information'. In psychological study of non-verbal communication, Kendon (2004) states that 'Gesture [...] is a label for actions that have the features of manifest deliberate expressiveness'. It has to be noted that Kendon does not intend deliberateness as in the control of the expression, but rather as in the voluntary act of expressing a meaning. From these definitions it is possible to extract a series of keywords which characterise gesture in the context of this experiment: movement, dynamic, information, deliberate expressivity. A recomposed definition of gesture is as follows: A gesture is a dynamic movement of the body (or part of the body) that contains information in the sense of deliberate expression. This definition applies to the kind of gesture which our experiments focused on, it is not provided as a universal definition of gesture. As we gathered from the discussion on body schemata, pre-conscious performance and automaticity in subsection 3.4.1, one does not consciously control every aspect of a gesture. Rather, the intentionality of expression is superposed to the pre-conscious mechanisms of body schemata and entangled in complex ways with one's psyche, desire, training and technical framing. However, to fully grasp the experiments we conducted it is necessary to specify the kind of gesture we examined, and the above definition serves that purpose. I will come back to the issues of automaticity, training and technical framing when discussing *Corpus Nil*, for they add significant insight to the scientific literature.

How to define gesture expressivity then? In my field of practice, that of the performance with electronic musical instruments, and more precisely in the community of the conference on New Interfaces for Musical Expression (NIME), much research is dedicated to the analysis and design of systems that allow gestural expressivity.[1] In this field, expression is understood to be musical expression, connecting it to the art of all musical performance (Jordà, 2005; Dobrian and Koppelman, 2006). In instrumental performance of classical music, for example, musical expression is directly related to a player's variation on a piece, which characterises her interpretation. One pianist may interpret an established repertoire composition differently than another pianist. One may vary the dynamics (soft and loud moments) or tempo (speed) of the music, and perform different gestures to execute these musical changes. We can think of this as inter-user variation (Palmer, 1997). Or, a single performer may interpret the same composition differently at different performances - this may depend on their emotional or psychological state or the audience feedback as well as their personality and unique style.[2]

To this particular understanding of gesture expressivity we added an insight extracted from the work of HCI researcher Catherine Pelachaud (2009) with embodied conversational agents. These are embodied agents capable of engaging in conversation with one another as well as with humans by employing the same verbal and non-verbal means that humans do. In Pelachaud's work, gesture expressivity is understood as *how* a gesture is performed - in other words, the potential variations in the way a gesture is physically executed. Variation in gesture performance can exist across different users or within a single user in multiple iterations recreating the same gesture primitive.

The artefact of variability can also occur due to a lack of skill to perform it or due to noise in the motor system. When muscular fatigue arises, the body may optimise resources by autonomously adopting a body schema that does not match the physical gesture intended by the performer. As a result, the performer may play a phrase differently (see my early discussion of automaticity in subsection 3.4.2). This differs from variation as the deliberate intention to nuance gesture execution to modulate its meaning. Hence, we propose the term gesture expressivity as deliberate and meaningful variation in the execution of a gesture. The term gesture expressivity should not be confused with the definition of expression which was discussed earlier in sub-

[1] http://www.nime.org

[2] Pianist Glenn Gould, for instance, is acknowledged among the most uncompromising classical musicians not only for his remarkable musical skills, but also for the unique and unorthodox style that characterised his interpretations (Dutton, 1983).

section 3.2.3, for the former refers to the variations in the performance of a physical gesture and the latter to the particular forms of embodiment of things, living and non-living. Later, in section 7.5, I will combine these two definitions to extend the meaning of expressivity in computationally-mediated musical performance.

6.2.2 Describing Gesture through Muscle Sensing

Now that I have specified which kind of gesture and expressivity we investigated through our experiment, I will describe the physiological mechanisms involved in the execution of a gesture. I will consider the mechanism of muscle activation and the related biosignals, the electromyogram, or EMG, and the mechanomyogram, or MMG. The characteristics of both biosignals are illustrated in Table 6.1. The reason behind this analysis is that the technical aspects of my own work relies on configuring these physiological components with the sound-generating devices of electronic instruments. This requires a detailed understanding of both how muscle activation works and how an electronic instrument can observe muscular activity to link it with musical performance. This description will necessary be highly technical and, to safeguard those readers who may not be specialised in this field, I will attempt to render it in a graspable writing style without omitting the details.

Human limb gesture is initiated by the activation of one or multiple muscle groups (Kaniusas, 2012). Of the two types of muscles found in the human body, smooth and striated, the latter are those subject to voluntary control and are attached to the skeletal structure by tendons. Voluntary muscle control is part of the somatic nervous system (SNS). This is a part of the peripheral nervous system which works in tight connection with synapses and muscles to govern the movement of muscles and the integration of perceptual stimuli. The SNS operates through two kinds of nerves: the afferent nerves, which handle the transport of signals from sensory receptors to the central nervous system (CNS); and efferent nerves, which transport signals the other way around, from the CNS to the muscles. In other words, the afferent nerves are an interface to the worlds outside of one's own body. The efferent nerves handle the internal self-organisation of the body. It is through the efferent nerves that muscle activation takes place. At the onset of stimulus integration, when a

	EMG	MMG
Type	electrical	mechanical
Origin	neurons firing	muscle tissue vibration
Description of	muscle activation	muscle contraction force
Freq. range	0-500 Hz	0-45 Hz
Sensor	wet/dry electrodes	wideband microphones
Skin contact	yes	no
Sensitivity area	local	broad (due to propagation)

Table 6.1: Itemised characteristics of the EMG and MMG.

stimulus is perceived, the SNS sends an electrical voltage, known as action potential,[3] to the motor neurons. When the action potential reaches the end plate of a neuron it passes to the muscles. The passage of electrical voltage is enabled by a junction that innervates the skeletal muscle cells and is able to send the electrical potential throughout a muscle to reach all the muscle fibres, this is called a neuromuscular synapse. A network of neuromuscular synapse and muscle fibres is known as a motor unit (MU).

At this point, the electrical voltage (motor unit action potential, or MUAP) causes an all-or-none contraction of a muscle's fibres. All-or-none means that the MUAP can trigger either all the cells of a muscle or none of them. A gradation in a muscle contraction is achieved by changing the number of MUAPs firing and their frequency. By activating many muscle units very fast, the body produces a high level of force; vice versa, by activating few muscles at a slow rate the force produced is low. By positioning surface electrodes on the skin above a muscle group, it is possible to register the MUAP as an electrical voltage. The resulting signal is known as the EMG (Merletti and Parker, 2004). This is the sum of all the motor unit action potentials (MUAPs) at a specific point in time. It is a stochastic signal because any number of MUAP pulses is triggered asynchronously.

So, while muscle contraction is the product of a bioelectrical effect, it results in a biomechanical effect. When the muscle cells contract, they produce a mechanical

[3]The action potential is different from the perceptual potential discussed in the previous chapter.

vibration, a muscle twitch, which lasts about 10-100 ms. This twitch causes a subsequent contraction of the whole muscle. By means of its oscillation, the mechanical contraction of the muscles can be picked up as an acoustic signal. Using a microphone on the skin above a muscle group one can record an acoustic signal produced by the perturbation of the skin. This signal is known as MMG (Oster and Jaffe, 1980). There is a crucial difference between the EMG and the MMG, which is the reason why studying their combination can provide great insight into the physiology of movement. The EMG carries information on the neural trigger that activates the muscle, it informs us of the deliberate intention of performing a gesture (Farina et al., 2014). The MMG, on the other hand, carries information on the mechanical contraction of the muscle tissues, informing us of the physical effort that shapes the gesture (Beck et al., 2005). In this way, the two signals provide complementary information on muscle activity (Tarata, 2009), an information that, as our experiments will show, provide insights on the expressive articulation of a gesture (Figure 6.1).

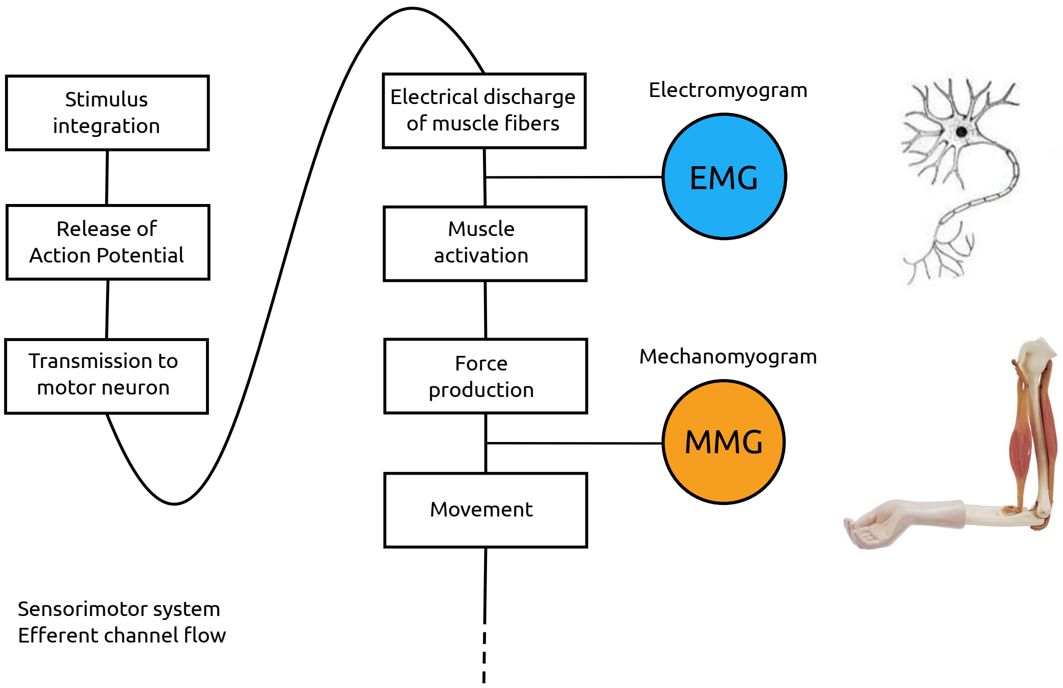


Figure 6.1: Diagram of the efferent nerve information flow illustrating the muscle activation process. The blue and orange circles indicate respectively the EMG and MMG signals. The location of the circles illustrates the different stages of the activation process at which the signals are captured (assuming non-invasive recording methods using on-the-person stationary or ambulatory sensors Silva et al. (2013)).

Muscle activation is influenced by several kinds of stimuli, including interoceptive, exteroceptive and proprioceptive stimuli. Importantly, muscle activation is also influenced by visual and auditive stimuli. The influence of auditive stimuli on the sensorimotor system is particularly relevant to my argument on the importance of vibration in the performer-instrument configuration, even more in the context of *Corpus Nil*, for the performance relies on the capacity of the instrument to change my movement, my psyche and my embodiment. Studies in neuroscience (Lotze et al., 2003), psychology (Cardinale and Bosco, 2003), human-computer interaction (Caramiaux, 2012) and musical performance (Godøy, 2003) showed that sound affects both the mechanism of muscle activation and the perception of one's own body. Importantly, sound is intended here as both audible vibrations (air conducted sounds) and physical vibrations (bone conducted sounds). Those studies suggested that human movement is influenced by a strong audio-motor connectivity. In particular, Lotze et al. (2003) showed that this association of sound and movement is not only related to action-perception loops; it also actively influences one's corporeality by freeing up resources of the motor system to increase the connectivity of limbs movement and auditory perception. This relation goes as far as to alter the perception of one's body based on the timbre of an auditive stimulus, as Tajadura-Jiménez et al. (2015) recently demonstrated.

6.2.3 Experiment

In terms of sensor technology, these experiments are all based on the idea of multimodal interaction (MMI), a method used in human-computer interaction. It consists in integrating multiple sensing modalities to increase information on the user's physical gesture. This information, in turn, can be used to increase the bandwidth of interaction offered by an electronic instrument. MMI uses different modalities that offer complementary information about user input. These modalities might include, for example, voice input to complement pen-based input (Oviatt et al., 2003). In our experiments, spatial and physiological sensing modalities are combined in different ways. The combination of complementary modalities was useful because it provided information to better understand expressive aspects of the user input that could not be deduced from a single input modality. In regard to the evaluation of these experiments, we used a combination of qualitative and quantitative methods according to the particular aim of each experiment. Often, due to our combined use of resources from different disciplines such as biomedical engineering, musical performance and human-computer interaction, we analysed the same phenomenon using different methods to improve the likelihood of reliable results. The methods included the collection of datasets, interviews, audio recordings and video recordings. This material was then analysed using different methods for each experiment, including qualitative observation of plotted data, audio samples and video recordings, and the extraction of features from physiological datasets combined with their quantitative analysis.

This series of experiments consists of three parts. We started from a basic hypothesis and then progressively developed our approach towards more focused ideas. In Part 1, a pilot study, we used MMG sensing alongside spatial motion capture and inertial accelerometer sensing in a multimodal configuration. We used this setup to see how an instrument can characterise the spatial, temporal and activity dimensions of a performer's physical gestures. In Part 2, we used EMG and MMG in a bi-modal configuration to look at the ways in which complementary aspects of these signals could be exploited, and sonified, for sonic interaction. In Part 3, the most significant part of the series of experiment, we used again a bi-modal EMG and MMG sensing interface, but this time we focused on analysing specific features of a physical gesture, and eventually, we concentrated on the 'power' of a physical gesture.

The basic definition of power in physics is the amount of work produced per unit time. Or, in other words, it is the amount of energy required to cause a displacement divided by the time it takes to provoke the displacement. In this chapter, the meaning of power we refer to is the particular one used in the literature on the study of expressive gesture introduced earlier (Wallbott, 1998; Pelachaud, 2009). In this literature, power is defined as the kinetic muscular force that characterises a physical gesture. It involves the dynamic variation of the intensity of gesture, which in turn, is related to the degree of acceleration of body parts.

Part 1

The first experiment was a pilot study. We examined the complementary information about gesture expressivity when a musical gesture is captured through three sensing modalities (Donnarumma et al., 2013a), including MMG, accelerometer and motion capture. These modalities detect physiological, movement, and spatial position information, respectively. We analysed a set of twelve gestures created for one of my previous pieces of biophysical music entitled *Music for Flesh II* (Donnarumma, 2012c). I was the only experimental subject in this experiment. While this placed a clear

Figure 6.2: The author performing the gesture vocabulary from one of his existent performance during the first part of the experiment on gesture expressivity, Goldsmiths, University of London, 2014.

constraint to the extent of our findings, for this pilot study we wanted to examine gesture performed by a practitioner musician who already had extensive experience with physiological and interactive sound technology.

We captured the MMG signal using the XTH Sense, the biophysical musical instrument created by the author which we also used in the previous experiment (see subsection 5.4.1). In this case we recorded two channels of MMG at a sampling rate of 48000 Hz; the biosignals were captured from the left and right arms over the wrist flexor, which is a muscle group close to the elbow joint that controls finger movement. The accelerometer sensor was a 3-axis DUL Radio (Analog Devices ADXL345) sending wireless data through a Nordic transceiver with a bandwidth of 2.4 GHz, and sampling rate of 100 Hz. The sensor was located on the back of the forearm, close to the wrist. The motion capture system was an Optitrack Arena. This consisted of a full body suit, with 34 markers, and 11 LED/Infrared cameras (V100:R2) with a sampling rate of 60 fps (frames per second). We recorded 24 rigid bodies, that is, groups of markers representing the position of a limb part.

The gesture vocabulary comprised empty-handed gestures performed in mid air which I had created drawing on a metaphor of 'touching sound' with my hands (inspired by Waisvisz's work seen in subsection 2.5.2). A detailed description of each gesture is attached to Appendix D. Each gesture was repeated ten times with different expressive articulation, that is, changing speed and intensity in each iteration. (Figure 6.2). Once all gestures and iterations were recorded, we plotted the data from the different modalities and produced observations based on a visual analysis. By looking at both physiological and spatial data recorded from the gestures executed with high, medium and low force, we found that physiological and spatial modalities complemented one another. More specifically, we described their complementarity in the following terms:

1. Only the physiological modality could sense the preparatory activity taking place before the actual gesture;
2. Variation of gesture characteristics (such as strength and speed) were detected by modulation of signal in different modalities.

These findings indicated that an experienced performer can vary independently different aspects of an expressive gesture, and that those variations can be sensed by an instrument based on muscle sensing. This however represented only a preliminary result based on myself as the only participant, and thus required a more detailed testing. In the next experiment, we engaged a group of users to test further implications of the results described here.

Gesture 1	EMG	MMG
extend arm outward		
strongly clench fist for constant tension	X	
move clenched fist upward/downward		X
Gesture 2		
place elbow on a desk		
slowly rotate horizontally forearm		X
repeat rotation increasing speed	X	
repeat rotation increasing force	X	X
Gesture 3		
lift elbow at shoulder level		
slightly contract wrist upward/downward	+	X
slowly move elbow upward/downward	-	X
repeatedly contract fingertips	X	X

Table 6.2: The training gesture vocabulary of the second part of the study of gesture expressivity through muscle sensing. According to the literature, cited below, the X marks which biosignal is expected to show a higher level of activity. The + and - signs indicate that the biosignal activity is expected to show a significantly and rapid increase or decrease.

Part 2

In the second experiment, we examined two problems: first, how the different ways in which a user articulates a gesture can be sensed by an instrument using muscle biosignals; and second, how the articulation of a gesture is affected by the sonification of muscle biosignals. We introduced EMG sensing in combination with MMG and used them together as bi-modal input to an interactive sonification system (Donnarumma et al., 2013b). Then, we studied the ability of a group of five non-experts users (four males, one female) to activate and articulate MMG and EMG separately using a given gesture vocabulary. The users could rely on a sound feedback which we created by sonifying the biosignals (Figure 6.3). One of the users used to be a musician, although he did not practice any more, while none of the others had a musical background. No user had any experience with physiological technology or wearable sensors.

Figure 6.3: A participant performing the gesture vocabulary (Table 6.2) during the second part of the experiment on gesture expressivity. He is wearing headphones to listen to the sonification of the biosignals which, as the findings of this part of the study will show, helps learn specific gestures.

The MMG signal was captured using the XTH Sense at a sampling rate of 44100 Hz. For the EMG we used the BioFlex dry electrode sensor by Infusion Systems.[4] The EMG signal from the BioFlex was digitised with an Arduino (BT-V06) and sent over Bluetooth to the host computer using custom firmware. The signal was initially sampled by the Arduino at 500 Hz. To create a coherent bi-modal system, we up-sampled (digitally increased the sampling rate of) the EMG in the host computer to match the MMG sampling rate. The XTH Sense software was modified to process the two modalities in parallel in equivalent ways. The MMG and EMG were first directly sonified, and then used as control data to enable the user to drive the movement-to-sound mapping of three gestures.

This time, the gesture vocabulary (illustrated in Table 6.2) was designed from scratch by drawing upon complementarity of MMG and EMG described in the biomedical literature (Jobe et al., 1983; Madeleine et al., 2001; Day, 2002; Silva et al., 2004). Each gesture was designed so as to prompt the users to articulate their arms in particular ways, which, according to the literature, should have produced a certain amount of activity in the MMG and the EMG. In order to help the users understand when each biosignal was produced, we sonified the MMG and EMG signals in two distinct ways in real time as a form of feedback. We were not interested in replicating the results documented in the literature, but rather in testing the ability of users with no previous experience with physiological technology to become aware and control distinct aspects of muscular activity through interactive sound feedback. Through an offline data analysis of the recorded EMG and MMG signals we analysed the physical dynamics behind the users' control of different aspects of their muscle activity. The results showed that:

1. Without previous training only one user was able to deliberately vary the degree of activation of EMG and MMG signals independently
2. Following a short training session guided by the experimenter, four users were able to activate separately EMG and MMG to varying degrees;
3. Gestures that required the activation of a smaller amount of muscles were more helpful for users to learn how to separate the activation of the EMG and MMG;

[4] See http://infusionsystems.com/.

4. User-specific variations on the gesture articulation yielded different activity at the physiological level.

These results showed that muscle sensing can give indication of a user's intention to perform a gesture and that, when given auditory feedback, users are able to perform gestures which highlight differences in complementary modes of the EMG and MMG. That said, our analysis is based only on gestures performed with audio feedback, whereas it could be more consistent to add a preliminary phase where the users perform the gesture vocabulary without audio feedback. This would allow a deeper comparative analysis of the sensor output information. Overall, this experiment points out that muscle sensing allows an electronic instrument to detect expressive aspects of a physical gesture, and that this kind of sensing technology can be exploited by users in a voluntary fashion during musical interaction with an electronic instrument. Especially when auditive stimuli based on the performer's muscle signals are provided by the instrument.

Although not formally studied, it is worth mentioning that, while designing the system, Prof. Tanaka and myself, the former having a long experience with EMG-based interface, and myself having an extended practice with MMG-based interface, managed to control the differences across biosignal much more smoothly. This may suggest that there are factors, such as training and gesture-mapping design, that can facilitate a heightened awareness of different aspects of muscular activity in response to interactive sound feedback. The limited number of users involved in this study did however undermine the generalisability of these findings. This issue was tackled in the next experiment, where we tested a further hypothesis by involving a larger number of participants.

Part 3

In the final and most significant experiment, myself, Dr. Caramiaux and Prof. Tanaka built on the insight gained from the two previous studies to focus on expressive variations of gesture from a user-oriented, qualitative and quantitative perspective (Caramiaux et al., 2015). My initial idea for this experiment was prompted by the interaction concepts I was developing at the time for *Corpus Nil*. I wanted to develop a means whereby an instrument could analyse high-level features of bimodal muscle biosignals to learn about expressive aspects of physical performance. We began developing the experiment and slowly merged my initial idea of extracting high-level features from muscle biosignals with Dr. Caramiaux's interest in understanding the meaning of the variations of those features across different types of gesture. We shared a common interest in finding a quantitative way of using variations in high-level biosignals features in an public music performance. As a result, I selected and documented an initial set of feature extraction methods, and Dr. Caramiaux refined that set of methods and implemented them in Matlab,[5] an offline data analysis software. These were used to analyse the dataset collected during our experiment. Following the study, I implemented the feature extraction methods we had selected for real time performance using the software Pure Data.[6] In the process, I have also refined them to better fit the musical and performative goals of the piece.

The initial hypothesis at the core of this experiment was that, through physiological sensing, and particularly muscle sensing, an instrument can track expressive dimensions of physical gesture. Upon analysing the findings of the experiment, we refined our hypothesis to focus on a specific dimension of expressivity, that is, power, or the kinetic muscular force that characterises a physical gesture, as defined earlier. Human limb gesture is nuanced in a number of different ways. One can change how fast to perform the gesture (speed), how much space the gesture execution is taking (size) or how tense the body is while executing the gesture (intensity or power). These variations combine and contribute to convey the expressive content of a gesture. Expressiveness can thus be characterised by movement qualities: *activity*, which relates to variations in speed; *expansiveness*, related to variations in size, and *dynamics*, related to variations in intensity (Wallbott, 1998). This approach has been elaborated in the well known Laban Movement Analysis (LMA) (Laban, 1963), originally used as a method for describing, notating and interpreting human movement in everyday and professional life, and later used as a standard in the study of dance. This approach has also been applied to understand movement qualities in terms of physical effort. Chi et al. (2000) used LMA to derive dimensions of expressiveness to be applied in the synthesis of expressive movements for animated characters.

[5]See http://matlab.org.
[6]See http://puredata.info.

One way to consider expressive interaction is to go beyond geometrical and temporal description of gesture by considering movement qualities (Fdili Alaoui et al., 2012), that is, dynamic components such as power. As seen at the onset of this chapter, the basic definition of power in physics is the amount of work produced per unit time. It is, in other words, the amount of energy required to cause a displacement divided by the time it takes to provoke the displacement. According to Pelachaud (2009, 4), power corresponds to the intensity of movement dynamics (as defined by Wallbott). The hypothesis underpinning this third study is that the dimension of gesture intensity, or power, is an expressive dimension that is suitable for tracking through physiological sensing, in particular, muscle sensing.

We asked a group of twelve participants (eight females, four males) to perform several trials of a set of gestures, taken from a predefined vocabulary, and variations of those gestures in power, size and speed. The participants had no previous experience with either interactive music instruments or physiological sensing technology. The gesture vocabulary included two types of interactions, one with a surface which provided haptic feedback and one in free-space with empty hands. A questionnaire following the trials gauged the participants' perceived difficulty in performing gesture variations as well as their subjective understanding of power of a gesture. The gesture vocabulary was designed to require an increasing level of fine motor control. We sought to design tasks whereby participants would be invoked to vary the power of each gesture on its own or in combination with related dimensions of expressivity such as gesture size. In doing so, we wanted to inspect the relationship, in spatial and temporal extent, between power and movement dynamics.

We captured EMG and MMG signals from the gestures of the participants and recorded the signals for offline analysis. Both biosensors were placed on the participant's forearm (Figure 6.4) and the data was captured according to the same specification described in the previous experiment. Then, we selected a set of features to be extracted and analysed from both the EMG and MMG signals. In the prostheses control literature, the predominant signal feature is its amplitude (Hofmann, 2013). Here we proposed to compute additional features in the frequency domain. Our set of features included amplitude, zero-crossings and spectral centroid. Amplitude refers to the signal amplitude over time. The amplitude computed on the EMG and MMG signals has been shown to be related to the force exerted while executing the

Figure 6.4: The sensor setup used in the third part of the experiment on gesture expressivity. Pictured are both the biosensors we used to capture MMG and EMG from arm gesture. The rightmost image shows the XTH Sense, at the top, and the Bioflex, at the bottom.

gesture (Perry-Rana et al., 2002). Zero-crossing indicates a point where the signal in the graph of a function changes from positive to negative by crossing the zero value. The number of zero crossings in a signal is linked to the frequency of the signal. For low-frequency components such as those in the MMG, where the Fourier transform[7] might lack resolution, this feature can be more informative. On the other hand, the feature can be used to discriminate signal from noise (Peeters, 2004). Spectral centroid refers to the mean frequency value in a signal chunk. We used the same method to extract the spectral centroid for both signals. The signal window had a temporal length of about 1 s. The overlap was about 10 ms. We used a Fourier analysis with the same number of bins than the number of samples in the windowed signal to ensure a maximal resolution. The centroid was then computed on the spectrum. A complete technical report on our feature extraction methods can be found in Caramiaux et al. (2015), which is also attached in section D.1.

From the analysis of the questionnaire we found that for the users the notion of movement 'power' is very different from the conventional definition found in physics, which was described above. This kind of power for them is an ambiguous subjective dimension of movement which they understand in different ways according to the presence or absence of haptic feedback. When haptic feedback is present, they tend to define movement power as muscular tension (or exertion by pressure), whilst when haptic feedback is missing they tend to define it as kinetic energy (or dynamic variation of intensity). According to the participants, power also depends on the gesture

[7]This is the process of decomposing a sound or any other periodic function into the distinct waves which constitute it.

performed and the other expressive dimensions engaged in the gesture (e.g. speed), which of course we know to be true from physics. In order to understand more fully how the subjective meanings of power reported by the users are reflected in their physical gestures, we compared the responses to the questionnaire with the set of features in the time and frequency domains described above. This analysis showed that:

1. Participants were able to modulate muscle tension in gestures;
2. This modulation can be captured through physiological sensing.

In more detail, we found that:

1. Exertion by pressure is more reliably explained via EMG signal amplitude since muscles oscillate too slightly to produce meaningful changes in the MMG;
2. Dynamic variation of intensity is better captured through MMG sensing, more precisely in the frequency domain;
3. The ability to perform variations in power depends on the type of gesture performed;
4. Gesture power and speed are dependent, that is, they influence each other and cannot be modulated separately, as in basic physics.

6.2.4 Discussion

The discussion of these findings can be divided in three macro areas: haptic feedback, dependency of power and speed and gesture design. We use the term haptic feedback to indicate the presence, or lack thereof, of a surface onto which a gesture is executed. The term power is used to indicate the variations in kinetic muscular force which are related to the degree of acceleration of body parts, as described earlier.

When performing a gesture, haptic feedback does not influence muscular tension (measured as the amplitude of the EMG signal). In other words, one can intentionally vary muscular tension independently from the type of gesture (a surface gesture with haptic feedback or a free space gesture in mid air). On the other hand, the presence of haptic feedback does affect the dynamics of the forearm muscles, as we have shown by inspecting the MMG spectral information. Indeed, the number of zero crossings carries information on the activity of the muscle during gesture execution. We showed that muscular activity increases for free space movements, and mainly for those movement involving wrist rotations or dynamic changes in the gesture execution (such as 'drawing' in mid air the four consecutive corners of an imaginary square). To sum up, moving in free space induces articulations between the forearm and the hand which dynamically activate multiple forearm muscles (better captured via MMG as noted above). On the other hand, performing a gesture which requires to exercise pressure on a surface mainly solicits movement of the arm as a whole (better captured via EMG as discussed above).

Concerning the dependency of a gesture's dimensions, we found that power is an expressive aspect of gesture that can be intentionally modulated by varying the tension in the muscle. We showed that, by taking advantage of the richness of information in physiological signals, an electronic instrument can capture such modulation through EMG amplitude analysis. Varying tension, however, has an incident on the speed of execution of a gesture. As the basic definition of power found in physics implies, power and speed are intrinsically linked, and this of course applies to limb movement as well, as emerged in our experiment. On the other hand, size and power are separable in the sense that they can be modulated independently, although the nature of this mechanism is not clear yet.

Finally, in terms of gesture design, the results of Parts 2 and 3 indicate that the type of gesture has an influence on the way users can perform variations in in size, speed and power. In Part 3, the gesture vocabulary has been designed to encompass gestures requiring complex biomechanical operations like wrist torsion coupled with articulation of the arm. This has allowed us to show that biomechanics has a direct influence on the way muscle sensors capture movement power. First, the intensity range of muscle tension which can be applied to gestures involving limb torsion is limited; especially if compared to simpler gestures which do not require torsion. This is because even when a limb torsion is performed 'naturally' (with no variation) a fairly high muscular tension is already present. Therefore there is no much room to increase muscular tension when asked to do so. Second, complex gestures in free space involve a higher dynamic activity of the muscle which can be captured by analysing the MMG signal in the frequency domain. Interestingly, complex articulations in the forearm lead to higher partials in the frequency response of the muscle. The same is observed for gesture including abrupt changes in their shape, such as 'drawing' a square in mid air.

6.3 From Scientific Findings to Artistic Creation

The findings discussed above, in combination with the notions of incorporation and rhythmic becoming discussed in chapter 3, form the basis for the creation of my work *Corpus Nil*, a body art performance. Here I will first discuss the translation of the experimental findings in insight for artistic creation, and then discuss how the theory has shaped the technical implementation and the artistic vision. During the experiments on gesture expressivity described above, we found that by sonifying bioacoustic vibrations and bioelectrical signals from the performer's body, an electronic musical instrument influences the player's articulation of physical gestures (Donnarumma et al., 2013b). The sonification of physiological signals thus helps a performer focus on the physical articulation of her body, which implies that biosignal sonification can be used to decrease the focus towards symbolic interaction with the instrument. This is useful to create a more corporeal interaction of performer and instrument. But it is not enough to produce a performer-instrument configuration, for this kind of interaction may still be conceived in terms of subject-object relationship.

A further finding from our experimental work on gestural expressivity is useful to address this issue. We demonstrated that an instrument based on muscle signals can track expressive variations in the articulation of a physical gesture. It can sense changes in specific aspects of muscular activation, such as muscular tension - through the EMG amplitude - and the dynamics of muscular force - through the MMG zero crossing (Caramiaux et al., 2015). These changes in the mechanism of muscle activation may be intentional or not, and depend, as we have argued, on factors such as the presence of a surface against which to exert muscular force, the changes in speed of a gesture and the specific gestures performed.

Thus, what these experiments show is that by examining the physiology of human movement one can understand how a performer's movement is generated rather than how it happens in space. The generation of movement happens through the configuration of the performer's voluntary motor control, her physiological constraints, the body schemata, the presence or absence of sound, and the object, or lack thereof, against which muscular force is exerted. As these elements influence one another in a process of continuous negotiation movement is manifested in space. Importantly, there are configuration modes such as flow and automaticity which exceed the physiological body and yet drastically affect movement and expression. The qualities of movement as it becomes apparent (size, velocity and abruptness) are a result of that negotiation and, in this sense, are the result of an entanglement of conscious action, pre-conscious schemata and subconscious automatism.

The analysis of muscle biosignals provides thus an entry point to both the intentional and unintentional aspects of the articulation of physical gesture because it describes the way in which a movement is articulated rather than the way in which it is manifested in space. In other words, a physical gesture might not occur as initially intended by the performer or it may arise independently from the performer's will, drawing on a particular technical milieu and an immaterial economy of desire (see subsection 3.4.2). Importantly, both technical milieu and immaterial processes can be affected by working through particular thresholds of sound, vibration and light. From this standpoint, the understanding of the physiological basis of movement and their intrinsic relation to technical and immaterial processes is key to this research. It affords for the development of performance strategies which open up musical performance with electronic instrument to unintentional factors involved in the articulation of a physical gesture, specificities of the technical milieu in which the performance takes place and the particular forms of attunement that player and machine can establish.

Starting from these findings and reflections, I have created the instrument used in *Corpus Nil*. Technically, the instrument tracks, sonifies and creates sounds in response to three aspects of a physical gesture: overall muscular tension, abruptness of the contraction and damping, that is the rate at which the muscle recovers its initial shape following a contraction (the details of the artistic development will be described in the next sections). This means that the instrument can be controlled by the performer to a certain extent, for the instrument sonifies, and responds to, both the aspects of a physical gesture that are intentionally performed and aspects of the mechanisms that underlie the articulation of the gesture. In other words, the instrument senses and sonifies aspects of a player's physical performance that may not be fully intentional, yet are integral to the performer's corporeality. Damping, for example, is an aspect of muscular activity of which the performer cannot be fully aware, for it relates to the time that muscle cells require to relax and contract again, which depends on fatigue, body temperature, type of contraction and haptic feedback. Thus, by sonifying the damping of an arm muscle, for instance, the instrument may produce sounds that the performer does not expect to occur. The performer in turn, may adapt her physical gestures to the instrument's response to achieve the intended musical goals. By doing so, the instrument's sonic output reflects some factors related to the tension of the performer's body between intention and pre-conscious performance (Merleau-Ponty, 1978; Gallagher, 1986). In this configuration, the instrument's musical operations have a dual link with the audio-motor connectivity of the player's sensorimotor system (Lotze et al., 2003). They are directly conditioned by it and they physically affect it at the same time.

However, my interest in designing this kind of system goes beyond its technical implementation. I envisioned and designed this type of system so as to experience a particular kind of technical incorporation, to embody, as it were, the practice of experimentation which this thesis argues for. Being unaware of exactly how the instrument will respond to my movement, or which aspects of movement it will respond to means that I have to learn how to relate to the system; I have to establish a relation with it by listening to audible sounds, haptic vibrations of the stage floor and light patterns. This requires intense training and discipline, before, during and after a performance. It is in the process of training that the scientific findings of our experiments find a meaningful correlation with the theory. By training particular tensions, pressures and contractions, as the ones described in the above experiments, to learn how the instrument will react, I do not only discipline my material body; I also train my psychological and phenomenal body to reach, together with the instrument, particular thresholds of sound and vibration, which are similar to the experience of sonic dominance described by Henriques (2010). This kind of training is a form of rhythmic becoming, for *I learn to be affected*, to use Despret's idiom (Despret, 2004). Let us turn to the description of the performance to elaborate further on this.

6.4 Corpus Nil: A Solo Body Performance for Sound and Light

Corpus Nil is a twenty-minute body performance for solo performer, biophysical technologies, surround sound and interactive light.[8] The work is performed by myself and is presented in a black box theatre with a seated audience. In this piece, I perform a slow choreography of muscular contraction and limb torsions that morph the body into a piece of flesh to which the audience can hardly attribute human features (Figure 6.5). Here, I purposely use the term 'morph' to describe the series of changes that the body undergoes as a slow, smooth and gradual transformation. The choreography does not consist of a fixed series of movements, rather it indicates five key bodily postures which I can adopt by performing a diverse range of movements. The

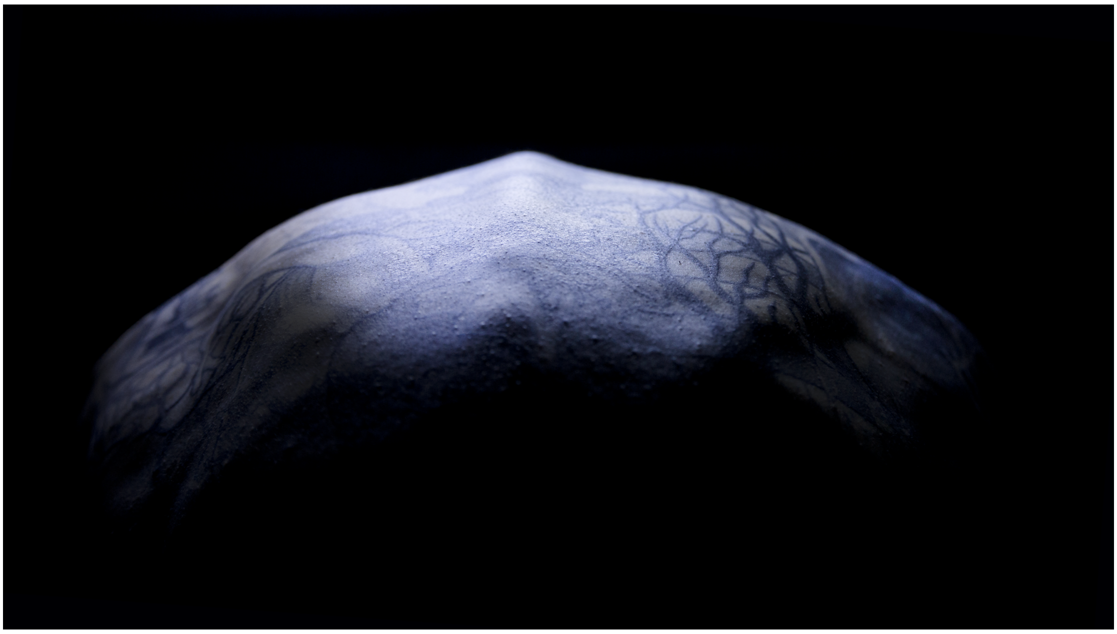


Figure 6.5: A rear view of the author's body on stage at the beginning of *Corpus Nil* during a private preview event in London in 2015.

way I move to adopt a given posture depends on the kind of sound and light patterns the instrument produces. As I move, the bioacoustic vibrations and electrical

[8]The project's webpage, including a video, pictures and further information, can be found at http://marcodonnarumma.com/works/corpus-nil/. So far, the performance has been shown multiple times in the US, UK and Germany.

voltages from my body are captured by wearable sensors and sent to the instrument. The instrument extracts a set of features from the raw data: amplitude, zero-crossings and spectral centroid (the features are the same as the ones defined earlier in Part 3 of section 6.2.3). The features influence the behaviour of a set of algorithms whose output consists of sounds and light patterns. I used the term 'influence' because the algorithms perform a set of processes autonomously and the physiological data is not directly mapped to the instrument's parameters, but rather to higher level variables that can influence the algorithm in different ways.

The physiological aspects of the performer's muscular activity are used as a connective material between a performer's body and an electronic instrument. But, crucially, our dialogue does not stop at the level of physiology. It takes place through thresholds of sound and vibration that affect my potential movements, my psyche and my corporeality. In this process of becoming, my body becomes one with the instrument; they form a hybrid body, a configuration of human and technological parts where my body learns to affect the instrument and be affected by it. The work thus shifts the focus of the performer-instrument relationship from the performer's control over the instrument to a direct corporeal engagement between the two; a process of incorporation unfolding through the rhythm of sound, vibration and light. It is a kind of human-machine configuration which affords the exploration of the expressive capacity of the body through the machine, and vice versa, the exploration of the expressive capacity of the machine through the body.

6.4.1 Tools

To create this work, I borrowed hardware technology and software methods from two fields, biomedical engineering and human-computer interaction. More precisely, I have used biomedical sensors, multimodal sensing and feature extraction algorithms to configure the performer's body and the musical instrument. The biomedical sensors are electrodes and chip microphones, which I discussed earlier in section 6.2. The electrodes, embedded in a BioFlex wearable armband,[9] capture the electrical discharges from the neural activity that trigger muscle tension, the EMG (Merletti and Parker, 2004). The raw EMG signal indicates the rate of muscle activation and the

[9]See http://infusionsystems.com/

intensity of muscle contraction. The chip microphones, integrated in the XTH Sense wearable sensor (Donnarumma, 2011c), capture the bioacoustic sounds produced by the oscillation of muscular tissue during contraction, the MMG (Oster and Jaffe, 1980). The bioacoustic sounds indicate the dynamics of the muscle contraction and the level of force produced by the muscles. The muscle signals are used in a bimodal setup to provide the instrument with complementary information about the muscle activation mechanisms through which my movements are generated (Tarata, 2009). Then, I use a feature extraction system to extract salient features from raw sensor data. Feature extraction, as seen in the experiment above, is a computational method that consists of the implementation and use of mathematical or statistical functions to extract high-level information from the data, as opposed to using the raw signals (Guyon and Elisseeff, 2006). In this way, the instrument extracts from the raw muscle signals aspects of the body's muscular activity that are related the expressivity of the gesture (as defined in this chapter). Those aspects include the overall muscular tension, abruptness of the contractions, and damping, the rate at which a muscle recovers its initial shape following a contraction.

> Before proceeding to the next sections, the reader is invited to watch a video documenting the performance. The video file can be found online by clicking here, or alternatively here.

6.4.2 Biosignals, Algorithms and Sound

The sonic composition shifts across textural constructions and microtonal variations, while a play of lights, shadows and darkness shows and hides the shape shifting body on stage from the spectators' eyes. The subtle combination of movement, sound and light emphasises the alternative bodily forms enacted on stage, as if it was ascribing alternative qualities to the flesh. The play of echoes and shadows embraces the body so that the skin and the bones appear as new surfaces, the fingers and the neck seem to move as new limbs (Figure 6.6).

Using three sensors worn on the upper part of my arms, the instrument tracks the EMG and the MMG from my body as I perform the choreography. A custom set of feature extraction algorithms extracts a set of high-level biosignal features - three for

Figure 6.6: The author performing the first part of *Corpus Nil*. Since the limbs, neck and head are painted in black and are not illuminated by the LED light, the performer's body looks like a piece of flesh.

each biosignal. The feature set does not represent the movement per se, for it does not account for the shape of movement in space. Rather, it indicates specific traits, such as muscular force, abruptness of a contraction, and damping of the muscular tissues, that characterise the articulation of the movement. This is important because, as seen earlier, to observe the articulation of muscular activity, as opposed to the resulting movement in space, implies to gain information on both intentional factors determining the player's physical gesture and mechanisms of muscle articulation that are not intentionally controlled by the performer. The feature set is used to influence the behaviour of three main algorithms, where each deals respectively with aspects of sound production, audio mixing and musical intensity of the piece. The instrument's network of algorithmic processes is dynamic enough to provide highly unexpected responses. This is a feature that I programmed to let the instrument surprise me with unexpected sonic and light responses to which I have to adapt in a very short period of time. The pool of synthesis modules consists of a bank of twenty oscillators, an additive synthesis module and a device which directly plays back the MMG as it is captured from the performer's body. The limited amount of sound sources is intentional, and serves to produce a minimal set of pitches. Musical variation happens through microtonal changes and timbre shifts driven by the biosignals' feature set.

Sound production

Sound forms are produced by an algorithm which sonifies the muscles bioacoustic vibrations using a bank of twenty sine wave synthesisers. The sonification is driven by the analysis of the MMG power spectrum. That is, the bioacoustic signal is analysed in the frequency domain to gather how much signal energy is at each frequency in the range 2-22 Hz. This range was chosen according to the three grades of muscular activity indicated by Orizio et al. (1990): low muscular activity produces a signal whose core energy sits between 1-11 Hz, medium activity between 11-15 Hz, and high activity between 15-22 Hz. The energy measured in each of the twenty frequencies is mapped to the amplitude of a synthesiser. This allows the instrument to orchestrate twenty synthesisers according to the articulation of my movements. Each synthesiser has a predefined pitch, which changes through microtonal variations induced by the fluctuations in my muscular tension (indicated by the EMG amplitude).

By analysing the power spectrum of my bioacoustic vibrations, the instrument identifies distinct intensity levels of the body's muscular activity. These intensity levels are related to the motor unit's articulation: for instance, a simple contraction, such as gently rotating a shoulder, activates a relatively low amount of motor units, which result in the signal's energy increasing in the lower end of its spectrum; a more complex articulation on the other hand, like rotating a shoulder and bending the neck, activates a higher number of motor units and produces energy in the higher end of the spectrum. The instrument is programmed to distinguish muscle activity levels and thus infer the complexity of a muscle articulation. When a complex muscle articulation occurs, the instrument modulates the volume of each synthesiser in order to foreground the sounds produced by the sonification of the higher partials in the MMG power spectrum. When a less complex articulation is identified the inverse happens, the instrument makes more prominent the output of the synthesisers sonifying the MMG lower partials.

> To better understand this sonification method, please listen to the following audio recording, available by clicking here. In this excerpt, the sound is produced only by the bank of synthesisers sonifying the MMG spectrum as described above. It is possible to clearly perceive a series of microtonal variations driven by the changes in the EMG amplitude of my limbs.

Audio Mixing

The output of each synthesiser is mixed in real time by the instrument itself. It uses an algorithm to compute a physics-based dynamic system that simulates a bidimensional string. The behaviour of the string controls the volumes of a ten-channel digital audio mixer (Figure 6.7). The string is composed of twelve masses linked to each other sequentially, where each mass can move on a vertical axis. Because each mass is connected to a following one, the movement of one mass provokes a subsequent movement of the next one, and the same happens iteratively across all the masses. The vertical position of each mass is mapped onto the volume of an audio channel. The higher a mass bounces, the louder the volume of the linked channel.

The instrument selects two biosignal features at random every forty seconds and maps them to the vertical position of the first mass and the last one, which are those

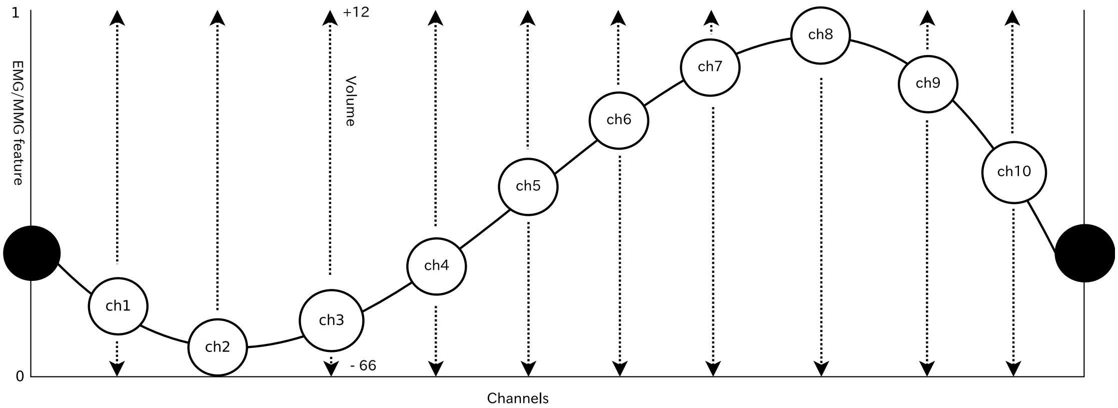


Figure 6.7: Diagram showing the functioning of the bi-dimensional string model in *Corpus Nil*. Each circle represents one of the masses composing the string. The masses can move only in the vertical dimension and are linked sequentially. Particular features of the EMG or MMG signals drive the vertical displacement of the black masses. These in turn, provoke a subsequent vertical displacement of the white masses across the 'Volume' axis, changing thus the volume of the related channels in the digital audio mixer.

holding the string together and exciting the movement of the other masses. I do not know in advance which muscle features are being chosen by the instrument. Practically, as I move, the nuances of my muscular tension excite the simulated string, and because the string's behaviour is dynamic I cannot predict how the sound levels will be mixed. Rather, I have to progressively adapt muscular tension levels to the changes in the sound mix. The sound output may even go almost silent, at which point I can only try to excite the instrument enough to get the levels up. The algorithm computes four different damping behaviours of the string. In other words, the simulation of the string material is changed by the instrument cycling randomly through four presets: stiff, jittery, soft or hard.

> An audio excerpt exemplifying this process of audio mixing is available by clicking here. The periodic increase and decrease of the sound levels is driven by the behaviour of the string model. Please note, this audio sample, and the following ones, were extracted from a different performance than the one documented in the previous video.

Saturation Feedback

Finally, the instrument uses a further algorithm to intensify the loudness and saturation of the music by progressively feeding back its sonic output to itself. Essentially, the instrument creates a semi-controlled sound feedback that increases according to the incremental amount of tension I exert throughout the performance. The algorithm uses a buffer to accumulate the amplitude values of my neural signals. The buffer corresponds to the amount of feedback applied to the overall sound output. The more intensely my brain commands the muscles to move, the more the sound output is fed back onto itself, producing an increasing resonance of specific sound frequencies. In this way, the accumulation of muscular tension in my body results in given sound frequencies being amplified until they are completely saturated. The point is that on one hand, I must exert muscle tension to perform the choreography, and on the other I have to be mindful of how much tension I exert to avoid the audio feedback becoming too strong before the performance ends. This dynamic system of algorithms is put into place for two reasons. First, to increase the instrument's stake in the piece, while interfering with my agency over it. And second, to shift my attention from the control of the instrument's symbolic parameters to the modulation of muscular force in response to the instrument. I move my limbs being mindful about the muscular tension and then I have to listen out for the instrument's response to understand what my movement has caused. This allows the instrument and my body to engage with each other at a corporeal level.

> The following is an audio excerpt from live performance demonstrating the feedback process described above. The file is available by clicking here.

6.4.3 Reorganising the Performer's Body

The performance consists of a series of movements that test the limits of muscular tension, limb torsion, skin friction and equilibrium. At the beginning of the performance, the theatre is completely blacked out. I lie on the stage in a foetal position. My whole head and most of my arms are painted in black (Figure 6.8) so that the only body parts the audience can see are the back, shoulders and chest. I wear two EMG and MMG sensors on the upper part of my arms to capture the biosignals produced

Figure 6.8: Before a performance of *Corpus Nil*, the performer's head, neck and arms are completely painted in black. This in combination with the interactive lighting and the particular choreography of the piece makes the performer's body on stage appear as an unfamiliar living being.

by the muscles of the upper torso, shoulders and neck. A custom built LED light is placed on the floor facing my body.

As the performance begins, I start a choreography through which the body is morphed into unnatural forms, hybrid body shapes that do not look entirely human. In the beginning, my knees are on the floor, and my torso is completely bent forward to touch the floor. I balance the weight of my body by pushing the knees against the stage floor and perform subtle movements with my shoulders. The instrument begins to sonify the bioacoustic vibrations produced by the muscle contractions using a few synthesisers. This establishes the configuration mode of vibration. The music is gentle and barely audible. The movements grow in intensity and spatial extension until I shift the body balance onto the neck and slowly lift my back up. As the movements become more complex a higher number of muscle units is activated and higher frequency partials emerge in the MMG spectrum. These are captured by the instrument and sonified through the remaining synthesisers. As the movements intensify the sonic texture of the sonification becomes more dense, and the music becomes more present.

At this point, I use the head to press firmly against the stage floor and thus lift my back completely up. The back is held vertically to allow the audience to see it fully; my arms are crossed behind the back while the hands hold the feet. By this time my concentration level is high. The muscular tension I have to exert to hold the body in this position is intense and the sound and light submerge me. The instrument and myself have entered a configuration mode of flow. I breathe. The breathing is very deep so that my back excessively swells up every time I inhale. After about three minutes, I fall back recovering the initial foetal position. Here, all the twenty synthesisers are active and the result is a rich drone composed of several sonic layers. Audio resonances occur naturally due to the overlapping of certain sound frequencies produced by the synthesisers. After two minutes, the inactivity of my muscle prompts the instrument to mute the synthesisers and output the audio feedback accumulated until this point in a slow crescendo. This is my cue to start performing the second part of the choreography (Figure 6.9). I begin moving the shoulders again, but this time the movements are frantic. To the audience, it looks like something within the piece of flesh on stage is pushing against the skin to break free. After about a minute I let one of my arms break free and fall onto the floor. I fully extend the arm outward, then try to lift my elbow several times by pushing the palm of my hand against the floor. The motion is irregular, in a similar way to that of a newborn horse trying to lift his legs for the first time. I perform similar gestures with my other arm and I enter the final position of the choreography. Here, I hold

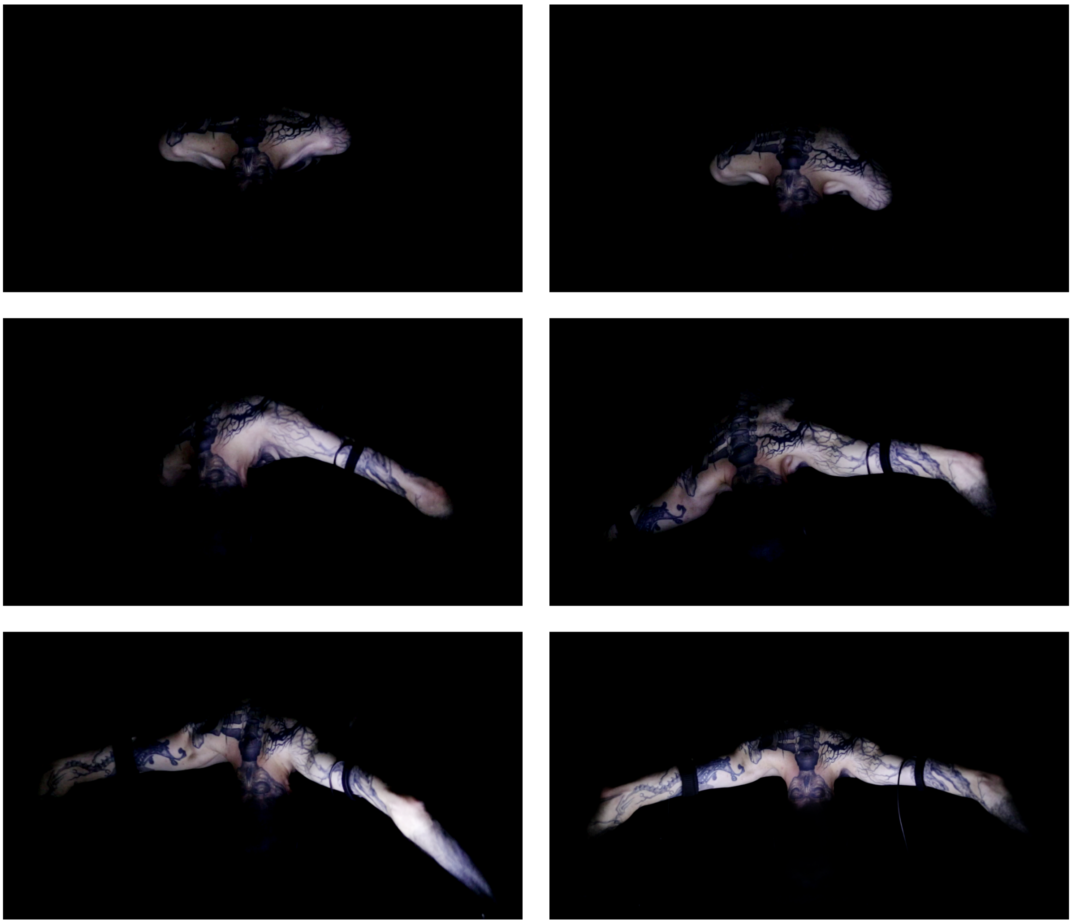


Figure 6.9: A sequence illustrating the different stages of the second part of the choreography for *Corpus Nil*. The limbs emerge from the mass of flesh as if they were trying to escape it. Eventually, the neck and both arms are pushed against the stage floor and used to move towards the LED light facing the performer.

my neck and hand palms against the floor, sustaining my body weight. The feedback crescendo stops, the light intensity increases and I stay still in this position for about thirty seconds. The instrument again takes the cue from my inactivity to mute the feedback sound and play back the direct sound of my muscle contractions. As I move my arms and neck forward as if they were three legs, the deep low frequency sound of my muscle is clearly audible through the subwoofer. The sound is amplified to be deep and loud enough to resonate the stage floor, the audience's seats and the whole theatre.

> The audio recording of this passage can be found by clicking here. Please note, this audio file includes very low frequencies which may not be discernible unless listened through good-quality headphones or sound system.

I progressively move towards the light in front of me, in a similar way to which certain moths are attracted by the light of a lamp.[10] As I get closer to the light, the sound volume increases and, as I almost touch the light by contorting my neck and shoulders, the sound stops and the light goes off. The performance ends, and complete darkness is kept for about forty seconds. As this description suggests, the type of configuration I created for *Corpus Nil* is purposefully designed to constrain my capacity of movement. To produce those movements I have to carefully balance the muscle tension throughout my body and repeatedly shift my balance onto different body parts. The biomechanical constraints of the human body are understood here not as a limitation but rather as a space of play which makes possible the reorganisation of my body parts.

With 'reorganisation' I mean that the parts of my body literally change function. My neck takes up the function of a leg and supports my whole body on the floor. The arms become two legs, which allow the body to move forward. The back turns into a chest, it breathes and hold the limbs together. What enables the body to reorganise its parts is its particular configuration with the instrument and the context. The body's position on the stage floor changes according to the musical and aesthetic goals of the piece, and it is influenced by both the audible sounds produced by the instrument and the acoustic resonance of the stage floor, which the body perceives as a tangible vibration on the skin. As the body parts shift to a different position and acquire a new function, another kind of reorganisation takes place: the reorganisation of the instrument's algorithms. As the muscle signals inform the instrument of the changes occurring in the performer's body, the instrument reorganises itself; it may mute or enable a given set of algorithms and re-arrange the array of mappings that link the

[10]This is normally at an angle, since moths read light as the moon.

muscle biosignal features to the sonification modules. As a result, the instrument responds to the performer with a range of vibrational, auditive and visual stimuli which, in turn, influence the way in which the body is reorganised in a variable, dynamic feedback loop.

This kind of reorganisation process is twofold, for it happens at once in the human body and the instrument. Through their configuration, performer and instrument do not only influence each other, but progressively condition the rearrangement of their respective parts, forming thus an unfinished technological body. The reorganisation of the technological body enacted on stage is inspired by the 'body without organs', a notion envisioned by Artaud in his last work,[11] and later elaborated by Deleuze and Guattari (1987). The body without organs does not lack its organs, but rather, the organs lack the particular organisation which one is given at birth, as Deleuze and Guattari explained. It is a disorganised or not-yet-organised body, a pluripotent body where each organ is subjected to local perturbations, internal and external forces that act upon it and modulate its function. In a similar way, the technological body on stage is a not-yet-organised body. The body parts - arms, legs, muscles, veins - are metaphorically taken apart and physically reorganised with the instrument's parts - the sensors, the LED light and the algorithms. Together, they form a novel kind of body, unknown, partial and at times disturbing.

6.4.4 Aesthetic Considerations

Corpus Nil is a process of bodily composition through flesh, sound and light. On one hand, this performance is concerned with manifesting a transgressive approach to societal models of the human body. The piece shows a body made of flesh that mutates unexpectedly, evolving from an amorphous cluster of skin and muscles to an animal- or insect-like body. On the other hand, by making the performer's body unrecognisable, the piece aims to free the spectators' imagination, it allows each spectator to see a different kind of body. This is a way to play with the audience's imagination; the spectators know that the body on stage is the body of a performer, they see hints of human traits, but at the same time, what their eyes see cannot be recognised as

[11]The work in question is the radiophonic play *Pour en Finir avec le Jugement de dieu [To Have Done With The Judgement of God]* (Artaud, 1947), which was shelved by French Radio the day before its scheduled airing.

a human body as they know it. Since the head, arms, hands and legs are painted in black and are not illuminated by the light on stage, they are invisible to the audience view. This confuses the audience understanding of what the thing moving on stage actually is. The contrast between my pale skin and the tattoos covering most of my body facilitates this mechanism. The only parts of my body which can be seen are the shoulders, chest and neck, but, because of the intricate tattoos, the muscles, joints and skin surfaces visually mix with one another. The effect is vivid enough to prompt interesting feedback from the audience. Most spectators I have talked with about the work had not understood that the drawings on my body were tattoos, and were led to believe the piece utilised video projections directly on my body, or that I wore a costume, or even that the body on stage was not real.

The manifestation of this process of bodily composition is enabled by the particular configuration of the performer's body with the instrument. The sounds and lights emerging from the biosignal readings and processed by the instrument are essential in constructing, or confusing, the visitor's understanding of the process taking place on stage. The design and manipulation of both the digital synthesisers and the bioacoustic sounds captured from my body aim to create a high degree of dynamism in the musical composition, and, simultaneously, induce the spectators in a state of entrainment. In the first half of the piece, for example, the music consists of a progressively denser sound texture growing for approximately ten minutes. The sound composition rapidly evolves from quiet and simple sound forms into one loud and complex body of sound; when the peak of the climax is reached, the body of sound splits in two bodies. By moving the two bodies of sound across the octophonic sound system, the bank of synthesisers produces beating. Beating is an acoustic phenomenon caused by sound waves of slightly different frequency approaching the ear. As the different sound waves interfere with one another, sound is perceived alternatively soft and loud, according to a periodic variation.

The beating caused by the microtonal variations produced by each synthesiser is combined with a rhythmic light pattern, and it is scripted to occur in the moment when the performer's body on stage begins to visibly mutate, as if it was swelling up. A repetitive, multisensory rhythm emerges from the combination of the beating effect, the light patterns and the vibrations that resonate the audience seats. The rhythm induces a sense of flow, or entrainment, in both the audience and the performer, which, combined with the bodily composition on stage, alters and heightens the visitor's perception. In so doing, the experience of the piece becomes akin to a ritual; a ritual of bodies, machines, sounds and lights to mark the birth of the new body on stage.

Similarly to *Nigredo*, the aesthetic of *Corpus Nil* could be described as unsettling or confrontational, for it is characterised by a play of darkness and light patterns, physical strain and an intense level of sonic stimulation. By adopting this kind of aesthetic I aim to create a piece of art that is engaging and artistically relevant without being overtly beautiful and immediately appealing, but rather disturbing and strangely graceful. I have developed this kind of aesthetic not to convey a necessarily negative vision of the world, nor to merely shock the audience; rather, in a similar way to *Nigredo*, in this piece shock is a means to challenge the spectators to question their criteria of beauty. There is a tendency in technologically-mediated performance to equate the artistic value of an artwork with its level of displayed beauty and uncritical engagement. In my view, this is an unnecessary way of assessing an artwork, especially in the case of an artwork that relies on technological instruments. Human beings have created a world characterised by a state of constant war and social injustice, where human and non-human lives are affected and controlled to varying degrees through the strategies of advanced capitalism, including food processing, environmental degradation, inequality, censorship and surveillance. This condition, in my view, is significantly influenced by the ways in which human beings relate to technology. Therefore, I reject the idea that the role of art is that of producing a limbo of beautifully rendered clouds to stare at in order to discard reality. In my humble opinion, there is a need for more art, and especially technologically-mediated performances, that are provocative, thought-provoking and radical. Beauty is a subjective matter, not a universal criteria. As long as a piece of art can convey something unique and worth reflection, its beauty, or lack thereof, is secondary. A performance that may seem disturbing or disconcerting at first, may eventually reveal a particular kind of grace and delicateness that one has not experienced before.

6.5 Summary and Reflections

In this chapter, I discussed practical research on the relation of gestural expressivity, physiology, electronic instruments and sound. The series of studies presented in the first half of this chapter offered an understanding of expressivity in terms of its underlying physiology. We showed the capacity of physiological technology to sense expressive aspects of a performer's physical gestures and track variations of those expressive aspects. Additionally, we reported on the effectiveness of muscle biosignal sonification to influence the execution and short-term learning of given gestures. The experiments were pivotal in the conception and creation of *Corpus Nil*, a solo body art performance for sound, light and biophysical sensors. In this piece, the insights on biosignal feature extraction, bimodal sensing and gesture design garnered through the experiment were refined and adapted to configure the performer's body with the instrument. The instrument is equipped with a set of algorithms that, beyond tracking expressive aspects of the player's performance, have the capability of producing unexpected responses to the player's performance. This allows the two to share the stakes in the performance outcome; although *Corpus Nil* has a fixed temporal structure, both the performer and the instrument have the capacity and the room to improvise and thus have a similar weight in determining the outcome of the piece.

This performance thus lies in between a determined temporal structure and a space for improvisation. I do acknowledge however that the instrument is capable of a higher degree of improvisation. After much thinking, I chose not to explore fully the improvisational capacity of the instrument to prioritise a visual and sonic consistency throughout the performance. It is thanks to this consistency that this particular kind of artwork can be appreciated as a finished piece in the specific setting of a theatre. That said, the instrument's improvisational capabilities pose an interesting challenge for future work: to create a fully improvisational musical performance where there is no scripted structure of pre-determined movement, and musical expression arises spontaneously from the configuration of the performer's interpretation and the instrument's performance.

The question is, would such a piece be musically interesting? I would argue so, although this would require a clear frame in terms of musical style and type of physical interaction in order to offer a consistent aesthetic experience. The lack of temporal structure should be counterbalanced by a defined musical style, but this could be achieved during the performance itself. At the onset of the performance, the performer could begin by exploring a sound palette provided by the instrument through a simple mapping of bodily gestures to pitch and loudness, for instance. The instrument could then deploy machine learning algorithms (Bishop, 2006; Caramiaux et al., 2013) to match specific patterns in the biosignals to given sound manipulations. The selection of the biosignal patterns could occur in terms of movement qualities; these could include the qualities analysed in *Corpus Nil* such as abruptness, overall energy and damping, and other qualities that represent variation of muscular activity over a longer period of time, such as fatigue, expertise level and habituation in performing a certain movement pattern. The instrument could then use this information to autonomously vary the gesture-sound mappings and prompt thus the performer to keep exploring the mapping space without being certain of what results her physical gesture will yield. As a result, the performance would unfold gradually, from a basic type of configuration to an increasingly complex one. The risk then would be that the performer-instrument configuration could become overly complex, which could undermine the musical delivery and the appreciation of the performance by both player and audience. This issue could be avoided by providing the performer, or the instrument, or both, with the capacity to reset their configuration, meaning that, as soon as the set of gesture-sound mappings grows too complex, they could initiate a mechanism that reverts the mapping array to its initial state.

Chapter 7

Discussion

7.1 Introduction

This chapter will elaborate on the artworks and experiments presented in the prior chapters through the lens of my proposal of configuration; in so doing, the chapter will discuss the implications of this enquiry in the context of the literature review discussed in chapter 2 and chapter 3. I will begin by re-stating the problematic, hypothesis and research questions at the core of this research, as a means to specify once again the context of my practical work. Then, I will discuss specific aspects of the human-machine configurations created in *Nigredo* and *Corpus Nil* and contextualise them in the artistic and theoretical landscape I set up in the literature review. This will deepen our understanding of the aesthetic and political qualities of the particular kinds of configurations I have created.

7.2 Statement of the Problem

The core problematics of this research are how to understand the performer-instrument relationship in musical performance, their embodiment as a technological body, and what the role of sound in that relationship can be. This represents a challenge because musical performance is a highly complex activity that entails the programmatic combination of a performer's motor skills, perception and intuition, an instrument's physical and musical affordances, and the auditive and haptic feedback of sound (Leman, 2008). The conception, study and practice of traditional musical performance is frequently characterised by the corporeality of the relation between performer and instrument (Sudnow, 1978; Berliner, 1994; Godøy, 2003). But this is often not the case in electronic music performance. In this case, the corporeal bond tends not to be a distinctive feature, for electronic instruments offer a mode of interaction that, although it is embodied in varying degrees, occurs mainly in a symbolic domain - that of software parameters - rather than in physical terms (Cadoz, 2009; Gurevich and Cavan Fyans, 2011). A subsequent implication I have noted is that electronic musical performance tends to be conceived, by instrument makers, performers and audiences alike, more often in terms of control over a system than in terms of corporeal engagement. This view implies a propensity towards the understanding of the performer-instrument relationship as that of a subject and an object. As such, it is a view that risks to constrain the role of the instrument to that of a control interface, and that of the player's performance to input data. This exposes the need to construct an alternative conception of the performer-instrument relationship, one that takes into account that musical expression occurs not only through audible sounds and embodied interaction, but also through an exchange of affective forces, to use Merleau-Ponty's terminology (Merleau-Ponty, 1978).

The hypothesis I propose is that the performer-instrument relationship is a configuration. Which means that instrument and performer are fitted to each other to perform specific processes, and as they perform, they affect each other through acoustic vibrations. To say that performer and instrument are configured means to acknowledge that their respective properties and capacities are interwoven and become increasingly so through biomediation (Clough, 2008). Key to this hypothesis is an understanding of sound as a material force that resonates bodies (Henriques, 2011). Sound as a force that, beyond its function as a conveyor of meaning, affects human bodies and instruments at a physical, visceral level (Goodman, 2009). This entails extending the meaning of corporeality, that is, the physiological, phenomenological and cultural basis of embodied practices (Mauss, 1936; Merleau-Ponty, 1978). Here corporeality is to be understood as a capacity yielded by the performer-instrument configuration, rather than by the performer alone. To test my hypothesis, at the beginning of this thesis, in chapter 1, I set up the following research questions:

Q1: How to think forms of technological embodiment in sound and body art performance beyond the dichotomy human-subject versus instrument-object?

Q2: How to use sound to create artistic performances which impact and heighten the sensitivity of both performer and audience to the cultural and political implications of the technological body?

Q3: And how can this particular kind of aesthetics extend our understanding of the relation between corporeality, expression and technology in sound and body art performance?

The literature review presented in chapter 3 allowed us to answer the first research question by reviewing a range of theoretical resources and discussing their similarities and contrasts. This was consolidated into the analytical device of configuration, in chapter 4, which helps us see the technological body in sound and body art performance as an ecology of material, lived and immaterial components standing always in tension against each other. Then, chapter 5 and chapter 6 have provided initial answers to the second and third research questions by presenting two experiments and two related artworks I have created. Here, I will refine and probe the answers to the second and third questions by drawing together the theoretical, technical and aesthetic insights gathered so far; the scope of this discussion is to describe and analyse a set of micro- and macro-politics of configuration, as defined in section 4.1, by evaluating the relationships between my artworks and those presented in chapter 2.

7.3 Sound, Vibration and Perception

7.3.1 Organs of Control, Enhancement and Affect

In *Nigredo*, the instrument magnifies the bioacoustic vibrations produced by the visitor's body. I use the term instrument to refer to the whole physical installation of the piece, for the wooden booth, the mirror, the LED lights and the exciters are active parts of the instrument as much as the computer, the sensors and the algorithms. The magnification of the bioacoustic sounds makes the visitor's body literally resonate with the instrument's parts. What may be considered a clear separation of the human body from the instrument is put into question. The work establishes a configuration where the human visitor is not the subject and the machine system is not the object, but rather they both constitute a technical milieu where each maintains its own agency. Here I refer to Stiegler's notion of technical milieu. This is a crucial element to the understanding of *Nigredo* because it renders technological systems as both constituted by and constituent of human corporeality. From this perspective, the instrument's parts - its physiological sensors, transducers and algorithms - can be seen as 'artificial organs' (Stiegler, 2011a). Organs that together with the heart, lungs and eyes of the performer form a configuration.

Whereas all visitors participate in the creation of a perceptually saturated space through the properties of the technological instrument, the experience of *Nigredo* varies according to the kind of body and personality of each visitor. This is an aspect of the work that specifies further its micro-politics of configuration. The experience of the work varies because each visitor's individuality and body are unique; body size and shape, heartbeat and breathing rate, personality and attitude towards the artwork differ significantly from one visitor to the other, and this affects the modalities whereby the configuration unfolds. The work is based on a forceful and visceral configuration between the parts of a human body and those of the instrument, but this configuration varies, in positive and negative respects, depending on the specific properties and capacities of the human body that experiences the work. This makes it possible to think of this kind of configuration as one and multiple at once; whereas the mechanism of this particular configuration remains the same through different iterations of the work, the properties of different kinds of bodies alter the way in which instrument and visitor perform through each other.

A criticism to this point might be that it is difficult to understand where the agency of the human body lies in *Nigredo*, for the visitor is strapped to a chair with little possibility for movement. This aspect of the work does indeed recall Eaton's *Bio-Music* systems, which he has used to conduct experiments with sensory deprivation where the visitor had not agency at all (Eaton, 1973). On the other hand, one could understand the visitor's role in *Nigredo* as limited to that of a subject experiencing a sensory enhancement, as in Rosenboom's early biofeedback musical performances (Rosenboom, 1976). But if we look at these three works through the lens of the macro-politics of configuration they rest upon, it is possible to describe significant differences among them. In Eaton's work, the instrument is an organ of control, a tool for the enforcement of sensitivities, as he has stated in his own writings (Eaton, 1973). In this, Eaton's work limits its own scope. In his attempt to induce a controlled psycho-physiological state, the generative, imaginative potential of sensory alteration, that is, the capacity of the body to create original sensory information without relying on external stimuli, is excited only to be exploited as a means of normative enforcement.

In Rosenboom's early biofeedback pieces, on the other hand, the instrument is a tool to enhance the human mind, according to his own account of the works (Rosenboom, 1976). To borrow his own words, the instrument in his works has the function of augmenting the mind and elevating man from its condition of 'homo faciens'. Eaton's approach to sensory bombardment and Rosenboom's view on mind enhancement make evident an interesting tension. A tension that situates sound performance with physiological technology in a challenging ground between a narrative of control and one of enhancement. This problematises the configuration of human bodies and machines as a cultural concern. Rather than taking either of the two sides, *Nigredo* offers an alternative.

The type of configuration I created for *Nigredo* enables performer and instrument to be physically linked through vibration; this link conditions, and emerges from, a process that produces both anew, a process of biomediation, borrowing Clough's terminology (Clough, 2008). When the visceral vibration emitted by the visitor's body is captured and digitised by the instrument, it becomes a variable that influences the operational code of the machine itself. The flesh vibrational force becomes a vector of affect (Spinoza, 1677b; Clough, 2008), in the sense that it escapes the boundaries of the visitor's body in which it originates to become an integral part of the instrument's functioning. This kind of affect is viscerally intimate in two senses of the term: on one hand, it emerges within a private and personal context, on the other, it involves a very close connection of the visitor and the instrument. In the darkness and privacy of the installation space, parts of the visitor's skin sweat in direct contact with the instrument's metal plates, while the vibrations of the visitor's internal organs displace and heat up the membrane of the microphone sensor. Then, when the sound is processed and played back by the instrument, it makes the visitor's internal organs and the instrument's parts literally resonate out of the same acoustic energy. This gives rise to a feedback loop where *the human and the machine perform through each other*.

In *Nigredo*, techniques of perceptual deprivation are detached from a narrative of control or enhancement and deployed as a means to unlock specific physical, perceptual and cognitive potentials of the human body for different modes of operation that actively involve the instrument. In other words, the scope of the work is not to control or enhance the visitor's body through technology, but rather to make the body and the technology uncannily intimate with each other. In fact, I play with the conceptions of mind control and enhancement by offering misleading information to the visitor at the onset of the experience, and by recalling, with the raw and military-like physical design of the installation, a stereotypical imagery of torture. The intention is to test the visitor's preconception of what the experience of a technologically-mediated artwork should be by forcing them to have an experience that can be hardly described as either positive or negative, because it is neither fully pleasurable nor completely unpleasant. It is intensely intimate.

7.3.2 Human Bioacoustics as a Medial Energy

Nigredo uses sound as a vibrational force to produce corporeal alterations, visceral processes that affect the body of a visitor in varying degrees of intensity. But the corporeal alteration is not the end goal in itself. Sound, in this work, is the means through which the visitor's body and the instrument are configured. Through the sound they exchange they extend into each other. Thus, the artistic experience that characterises *Nigredo* sidesteps a subject-object relationship. The experience of *Nigredo* is not about the representation of, or interaction between, a subject and an object; it is about the configuration of a human body and a technical instrument into an unfinished entity, a body that is composed of multiple parts interlaced with one another. It is 'a production of different machinic arrangements', using Kohso's words (Kohso, 1995), or a type of human-machine configuration, in my own terms, where the internal sounds of human organs act as a medial energy between the performer and the instrument. Acoustic energy that mediates between perception and algorithms, between the ear and the speakers, between the eyes and the visualisation of one's inner bodily motion.

From this viewpoint, the micro-politics of configuration found in *Nigredo* are aligned with those underpinning Mikami's installation *World Membrane and Dismembered Body*, discussed in subsection 2.2.1. In Mikami's work, the visitor's body lays on a clinical bed inside an anechoic chamber and the sounds of the visitor's heart and lungs are amplified, manipulated and diffused in space. The internal bodily sounds are turned into parameters that guide the digital manipulation of the sounds themselves and their spatialised diffusion. The sound parameters are visualised through a growing abstract net projected onto the walls of the chamber. Beyond their clear technical similarity, *Nigredo* and Mikami's work have a conceptual point of convergence. The configurations manifested in both works can be understood, borrowing Hayles's arguments, as producing an 'amalgam' of different components, a material-informational body. This is an incomplete body because it develops through a 'continuous construction and reconstruction' of diverse forms of embodiment (Hayles, 1999, 3). This process of construction and reconstruction is a form of becoming that comes forth through the configuration of the human body and the electronic instrument. Participating together in a perceptual feedback loop, the visitor's body and the instrument become, at once, one and multiple bodies throughout the duration of the performance.

But this is where the two works diverge. Whereas in Mikami's piece the bioacoustic sounds are made audible and visible, in *Nigredo*, they are also made tangible, for the instrument mechanically resonates the flesh, bones and skull of the visitor. In *Nigredo* the feedback is not only perceptual but physical as well. The core principle that *Nigredo* rests upon is to enact a configuration between the visitor and the instrument by creating a corporeal feedback loop. This points to a significant difference between Mikami's work and *Nigredo* in terms of the macro-politics of configuration they rely upon. According to Mikami's own statement, in her work the visitor's bodily sounds are manipulated in a way that creates a gap between the perception of one's own body and the sound and visuals diffused in the room (Mikami, 1997). In her view, this gap causes an overwhelming feeling of disconnection, as if one's own corporeality was 'under erasure' (*ibid*). This is supported by the lack of a tangible medium that connects the visitor with the electronic instrument. The visitor is a passive listener in the configuration of Mikami's work; there is a distance, both physical and conceptual, between the body and the instrument that purposely impedes them to reach a configuration mode of flow. In this way, Mikami aims to address the effect of applying informatics to the observation and scrutinisation of the human body, a process that, as she sees it, often ends up emphasising the ambiguities of the human perceptual world as opposed to the (supposed) determinacy of the technological world (*ibid*).

It is the shift from passive listening to active resonance that distinguishes the configuration of *Nigredo*. The visitor in *Nigredo* is a performer, for she has an active role in the outcome of the piece, and the material resonance of her body is necessary for the installation to function. The configuration of *Nigredo* eliminates the distance between the body parts and the machine parts by fitting them to each other, allowing thus their exchange of physical vibrations. As a result, performer and instrument enter a mode of flow. However, this particular mode of flow is not only about reaching a state of immersion. It saturates the auditive, visual, perceptual and haptic channels. This excess of stimuli produced by the instrument, and in particular the intense skeletal resonance, disrupts the workings of the visitor's internal organs. The instrument subjects the performer's body to a stimulation field that greatly exceeds the limits of everyday human experience in the world. The performer's body does not recognise the stimuli produced by the machine as an external input, rather it processes them as part of its internal states, for they directly excite the muscle receptors. In so doing, the boundaries of one's corporeal awareness are loosened and confused by the experience, yet not detached from it. On one hand, the aim of the work is to prompt the visitor to question the capacities of her own body when configured with the technological parts of *Nigredo*. On the other, the intention is to encourage a reflection on the capacities that societal models ascribe to human bodies and technologies, and, by extension, on the possibility that those capacities may be surpassed or undermined through particular strategies, independently from one's gender, age, moral values or beliefs.

Here it is useful to recall Salter's *Just Noticeable Difference*, which we have discussed in subsection 2.2.1. There, a visitor lays down on a custom-made floor which is embedded with twelve full-frequency exciters, similar to the ones used in *Nigredo*. The movements of the visitor's body are captured by pressure sensors embedded in the floor surface. The body motion data is used to slightly influence a quasi-determined composition of vibration, sound and light that takes place beneath, above and around the visitor's body (Salter, 2012). Some aspects of the audience reactions to *Nigredo* are comparable to those reported by the visitors of Salter's work. The threshold of perceptual potentials seems to be touched upon in a similar way by both works. Not surprisingly, the two works prompt similar physiological reaction, as they use similar technology. Differently from Salter's installation however, *Nigredo* does not investigate the way humans are accustomed to perceive; rather, it examines the implications of amplifying human perception through a positive feedback loop. When, through the machine, the visceral pulsations of the human body are turned into new material bodily stimuli, the instrument and the human body collapse into each other and amplify their configuration. *Nigredo* produces an excess of sensory information by mixing the bioacoustic vibrations resulting from physiological processes of the visitor's body and the sonic manipulations of the instrument's software. Borrowing Hayles' language, it can be said that the configuration of *Nigredo* affords an intermixing of the informational codes yielded by the visitor's body and the electronic instrument (Hayles, 1999). In other words, the body and the machine intimately share informational code. They become active parts of a technological body, one that bears an emerging corporeality on its own. It is an experience that originates from a zone in between viscera and circuits, flesh and sound, and which afterwards, may unfold through reflection and hindsight.

7.4 The Corporeality of the Technological Body

7.4.1 Shared Control and Constraint

At a higher level of analysis, the kind of performer-instrument configuration created for *Corpus Nil* shares the same key elements of the configuration created for *Nigredo*: physiological sensors, human body parts, algorithms, light and sound. But, at a lower scale of analysis, those configurations reveal a substantially different micro-politics. Differently from *Nigredo*, the configuration of body sensors and computer algorithms in *Corpus Nil* allows the instrument to analyse the performer's muscle activity in a highly detailed way and respond thus to the player according to specific expressive traits of her performance. The feature extraction algorithms the instrument is equipped with allow it to match subtle nuances in the articulation of a muscle contraction with equally subtle nuances in the articulation of the musical output, which are partly mapped beforehand and partly produced by the instrument in real time.

The dialogue between the performer and the machine is established at a technical level, but it is through training and attunement that their configuration unfolds. By training through threshold of rhythm, in the form of sound, vibration and light, before, during and after a performance, I become attuned with the system, I learn to affect its operations and to be affected by its reactions. Without my physiological body this kind of human-machine configuration would not be possible, yet, it is my phenomenal and immaterial body which becomes attuned with the system, incorporates it and performs through it. Thus, the particular micro-politics of configuration which *Corpus Nil* rests upon are determined by direct physical engagement, mutual information and shared control. The attention to the subtlety of both muscle articulation and musical output comes from the fact that the whole performance is conceived as a gradually shifting orchestration of sound forms, light patterns and flesh constructions. It is a slow movement of affective forces produced by sound, light and the performer's body. There are surely a few moments in the performance where things change drastically, yet the success of the piece depends on delivering a spectacle using small details and progressive changes which lead to unforeseen events. The instrument therefore is intentionally designed to operate as subtly as I do. This does not mean that it is programmed to imitate my behaviour, rather, it is designed to produce unexpected sonic responses that match the subtlety of my movements with the subtlety of sound manipulations. Importantly, the instrument is programmed to respond in ways that can surprise me and thus force me to adapt my movements by negotiating a compromise between different body schemata, or by learning new ones.

Crucially, as long as I am fully conscious of my movements, my dialogue with the instrument is dull. It is difficult to even call it a dialogue, for, in that moment, I merely try to think which movements would fit better a given passage. Fortunately, soon after the performance begins there is a liminal moment when my intentional negotiation of body schemata in response to sound and light fades into the feeling of being moved by the external force of the instrument. The actual dialogue between the instrument and myself begins in this moment when I become unconscious (Blackman, 2014), that is, once I reach a given threshold through the rhythm of sound, vibration and light. When this happens I enter the configuration mode of automaticity: I unwillingly cease to plan my movements and let my own body being moved by the instrument and the vibrational patterns it produces. This shall not be reduced to a basic instinct to move, for it involves the acceptance of an extra-personal force in guiding one's own body; it is a form of *otherness developed with and through the instrument*, a state of being other than my 'normal' body which emerges and feels in different ways according to a given technical milieu (the amount of speakers, their layout, the room size, the amount of spectators, the type of event, and so on).

Thus, the instrument has a stake not only in the musical delivery, but also in the way I move and feel my body. Our configuration actually makes me learn to move and learn to feel my body in ways I could not experience otherwise.[1] My approach here is to share with the instrument the control over the outcome of the piece, and

[1]I described a similar process when discussing how I learned to listen again through the configuration of my body and the hearing aids, see section 4.2.

to the extent described above, the control over my body. The instrument and myself are in a state of continuous tension with each other, where the properties of the performer's body and those of the instrument alter each other. It is a metastable equilibrium (Simondon, 1992) from which music and movement emerge.

This kind of micro-politics is reflected in the musical composition strategy at the heart of this piece. Drawing on Lewis's work with his instrument Voyager (Lewis, 2000), reviewed in subsection 2.4.2, the musical composition of *Corpus Nil* lies in between generative music and algorithmic composition. Lewis' instrument listens to the music produced by an instrumentalist, translated in MIDI messages, and responds by imitating, opposing or discarding the musician's input. The instrument is capable of responding in a highly unpredictable, and yet musically meaningful way to what the performer plays (Lewis, 2000). The sonic aesthetic of Voyager rests upon the principle of multirhythms. It uses groups of asynchronous algorithms which produce a diverse range of sound behaviours according to pitch sets, microtonal variations and tempo that each group chooses by itself. The instrument in *Corpus Nil* listens to the performer in a way that resonates with Lewis' Voyager. But rather than listening to musical input, the instrument 'listens' to the performer's muscular articulation. The instrument I created for *Corpus Nil* does not aim to achieve the level of polyrhythmical complexity and automation that characterise Lewis' instrument. It does however deploy a comparably complex system of sensors, feature extraction algorithms and sonification methods, and it similarly lacks triggers, buttons or straightforward input commands. Thus, at a technical level, my interaction with the instrument happens in terms of sonic and physical engagement, in a similar way to Lewis' performances with Voyager. In *Corpus Nil*, thinking in terms of symbolic interaction - which parameters control what, is not useful for I cannot know exactly how the instrument will respond.

However, differently from Lewis' performances with Voyager, where the player interacts with the computer software by playing a separate instrument, in *Corpus Nil*, the player interacts with the software in terms of the material and immaterial forces between the player's body, the instrument's sensors and the stage. The tension that the limbs exert on the stage floor is captured as a varying electrical voltage and digitised as a musical parameter; the muscle contractions resulting from the release of that tension produce bioacoustic vibrations, which are in turn amplified and played back by the instrument. Since I cannot see my body, and I can barely see anything at all, articulating the nuances of the movements in order to make my body morph into specific shapes is challenging. This requires to completely focus my attention on how aspects of my bodily performance influence the instrument's responses. I have to heighten the sense of touch to distinguish variations in the vibration of the stage floor under my skin, listen to the audible sounds surrounding me, and deeply concentrate on my sense of proprioception.

The heightening of perception soon turns into bodily automatism driven by the instrument. While I can modulate the relation between the position of the limbs, their level of muscular tension, the sound modulations and the sound pressure level, this modulations do not happen purely according to my intention. The need to heighten the sense of touch and proprioception so as to grasp the instrument's responses configures my body and the instrument in a mode of flow. As I become completely immersed in the performance, the instrument keeps providing changing responses, and thus our configuration unfolds. My body exchanges bioacoustic vibrations and bioelectrical voltages with the instrument, and the instrument uses those biosignals to generate sonic responses that vibrate the stage floor under my body and light patterns that flash into my eyes.

The micro-politics of configuration in *Corpus Nil* explores how physical interaction with an electronic instrument can be musically meaningful when the performer's intentions, in terms of movement and musical composition, are intentionally limited and constrained. In so doing, this micro-politics overlaps with a particular kind of macro-politics of configuration; one concerned with breaking and proposing an alternative to the tired structure of a subject-object relationship which is too common to technological performance. This kind of dichotomy, in my view, frames many of today's artistic applications of human-computer interaction technology as exercises in thoughtless and effortless engagement. To displace such a dangerous dichotomy, this piece builds upon the approaches of Lewis, Waisvisz and Tanaka and expands them into a twofold strategy of interaction: on one hand, the interaction with the instrument is instinctive, subtle and, at times, undermined; on the other, the performance purposely and programmatically strains and constrains my body so as to reach an attunement with the system. The attention to the physical and intuitive engagement with the instrument is something I draw from Waisvisz's work. In his performances with The Hands he appears to almost literally touch sounds floating around him, stretch and extend them. Using a set of spatial and inertial sensors combined with triggers and keys, The Hands translate his movement into musical parameters in a subtle and nuanced way (Waisvisz, 2006b). It is from the subtlety of the interaction that musical expression comes forth, vivid and engaging. Although his approach does rely on a subject-object relationship, this relationship is open, instinctive and physical, rather than effortless and predetermined. For this piece, I draw on Waisvisz's approach to interactive music as a physical engagement open to intuition and surprise. At the same time I extend his approach by sharing with the instrument the control over the outcome of the piece and the articulation of my movements, pushing the sensory and psychological thresholds of my body to the point where I 'loose' my willing agency and open up to the technical milieu.

Thus, differently from Lewis' performances with Voyager and Waisvisz's pieces with The Hands, musical interaction in *Corpus Nil* happens at a visceral level, as Tanaka (2011) would call it. Tanaka, as we have seen in subsection 2.4.1, uses the term visceral to describe his gestural music performances with the Biomuse, a bioelectric music controller. For Tanaka, the interaction is visceral when the performer and the instrument communicate through physiological signals. In his view, this is because physiological sensing offers information on how the gesture is generated, as opposed to buttons, pedals or spatial sensors that inform the instrument on how the gesture is manifested. Tanaka's vocabulary of physical gestures with the Biomuse tends to consist of evident and intentional gestures in space, for he conceives of visceral interaction through physiological sensing as an interaction based on the intentionality of a performer's gesture. In *Corpus Nil*, my approach to visceral interaction differs. In this piece, the choreography is conceived to purposely limit my capacity of movement, while the instrument analyses and responds to both intentional and unintentional aspects of muscle articulation. This is achieved by extracting high-level features from the raw biosignals, such as abruptness or damping of muscle contraction, that are not intentional but depend on the type, speed and force of the gesture and the surface or object against which muscular force is exerted. It is this technical feature of the instrument which allows to break free from symbolic interaction and enter the domain of latent potentials, sensory thresholds and immaterial processes such as the mode of automaticity I experience throughout the piece.

7.4.2 Sensation and the Material the Body is Made Of

The way in which the human body and the technological instrument are used in *Corpus Nil* constructs an alternative form of embodiment. It is an alternative embodiment in the sense that it does not resemble any other body in particular, but rather configures, through sensors, sound and light, the human and the technological parts into an alternative body. As I move, the physical articulation of my limbs, the subsequent instrument's responses and the affective forces I experience are learned by my body not as a mere bodily mechanism, but as a specific motor program, a body schema that yields a given expressive value. To put it in Merleau-Ponty's words, my body incorporates a given motor mechanism and the subsequent instrument's response 'as nothing more than possibilities of achieving certain expressive or musical values' (Merleau-Ponty, 1978, p.146).

However, this way of learning is neither fully conscious, nor completely stable. As discussed above, this is a form of incorporation; a process where the instrument is not perceived as an external object or a prosthesis, in the traditional sense, but rather becomes gradually a part of the human body, creating a new morphological imagination (Weiss, 1999), a new understanding of one's own body as one and multiple, fixed and changeable. In this kind of configuration the instrument is at once present and absent: we relate to each other and establish a dialogue, but unless a software glitch occurs or I feel excessive pain, I do not think about the laptop sitting in a corner of the room or the sensors strapped to my arms.

Here we can observe once more the relation between performer-instrument configuration and body schemata. The configuration is not a body schema per se; our configuration is a complex metastable equilibrium of physical, psychological and cognitive potentials enabled by the particular technical milieu of the performance. Within this precarious balance between the material and the immaterial body, I may perform, or fail to perform, specific body schemata, but the point is that there is no correct way of executing a movement. The most successful performance is the one where I am able to let movement emerge from the rhythm of sound, vibration and light. In other words, the way in which body schemata are performed, compromised, changed or created anew is guided by the configuration of the performer, the instrument and their context. The aim is not to perform correctly, but to reach a certain level of entrainment, which enables movement to arise. As my intentions, both in terms of musical outcome and physical performance, are constrained, an observer finds difficult to define whether the instrument acts upon the body or vice versa. In fact, they both act upon each other. Yet, during the performance, a nuanced and programmatic interaction between performer and instrument transpires; an ambiguous and yet meaningful mode of interaction is increasingly revealed as, on stage, the body of flesh, sensors, light and sound mutates from an amorphous, pulsing body into a living and unfamiliar creature making its first steps in the world.

The kinds of body schemata I perform, or fail to perform, during the performance should not be understood as involving exclusively bodily operations. The instrument is an integral and active part of those body schemata. During the performance, I have to mindfully weigh the bodily effort required to execute a specific movement; and to do so, I have to rely on developing a progressive understanding of how the audible sounds, tangible vibrations and light patterns that the instrument produces vary with my movements. The reason is twofold. On one hand, my bodily postures are physically challenging and to simply maintain my body in a certain position requires a high level of muscular tension. On the other hand, I do not know beforehand how the instrument will respond and thus I have to explore both my movements and the instrument's reactions gradually, similarly to how the instrument explores my movement by extracting high-level features from the muscle biosignals. In this kind of configuration, both the performer and the instrument are subjects and objects. What is brought to life by this micro-politics of configuration is an unfinished body, a temporary body that emerges from the feedback loop between the physical gestures I perform and the sonic and light responses of the instrument. This argument can be better understood by calling upon Deleuze's analysis of Bacon's paintings, which was discussed in subsection 3.2.3. Deleuze's analysis is useful because it makes a distinction between the human body per se, and the material forces that influence the expression of human embodiment (Deleuze, 1981). This is an important distinction because it specifies the human body as a malleable and multiform matter. In so doing, Deleuze endows the body with the potential to be remodelled and acknowledges expression as the result of that remodelling.

In *Corpus Nil* the body is a material shaped by muscular force and affected by sound. Expression, in this work, does not lie exclusively in the human body, for it emerges from a feedback loop between the performer and the instrument that sculpts the body's shape. From this viewpoint, *Corpus Nil* has some similarities, and differences, with the biofeedback body suspensions of Stelarc. In those performances, Stelarc's body is suspended from the ceiling using ropes and fish hooks that pierce his skin while a few 1.5-2 cm needle electrodes inserted in his flesh capture electrical signals from the muscles which are amplified and diffused in the form of sound (Linz, 1992). One can see at least three forces acting upon the Stelarc's body. There is the gravitational force which pulls the whole body down towards the floor. There is the force of the ropes which pull the body towards the ceiling. But there is also a local force, which is the one exerted by the fish hooks upon the skin. Each of those forces modulates each other in a way that produces a metastable equilibrium, borrowing Simondon's term (Simondon, 1989). Hanging in mid air, the stillness of the performer's body is only an external appearance. As a matter of fact, the forces produced by the ropes, the hooks and the gravitational force are contrasting and modulating each other, and their tension is made evident by the deformation of the performer's skin. The physical forces that sculpt the body become its expression.

Borrowing again from Deleuze, it can be said that the impact of Stelarc's suspension is not fuelled by the weaving of a narrative, but rather it comes about through the action of forces. Deleuze refers to 'the action of forces upon the body' (Deleuze, 1981, 33) as a sensation, as we have already seen. To further explain his meaning of sensation, he has defined it as the opposite of sensational. The sensation is felt and lived but cannot be easily described, whereas the sensational is a too descriptive representation that cannot be easily felt nor lived. As seen earlier in subsection 3.2.1, Deleuze has exemplified the meaning of sensation by looking at Bacon's painting technique. In his view, the physical movement of the brush performed by Bacon on the canvas is the force that makes the drawing of the head mutate into something else, something that is not a human nor an animal face. By looking at the amorphous body on the canvas, one can feel the sensation of those forces, their rhythm. This is the moment when the sensation is brought to light.

Similarly, in *Corpus Nil*, the physical tension of the muscles, the sound and the responses of the instrument are the forces that make the body mutate into something else, an unorganised or not-yet-organised body of flesh, sensors, sound and light. By looking at my body on stage one can feel the sensation of those forces. The rhythm of those forces that make my muscle extend and contract is exposed by the unnatural posture of the limbs and expressed by the rhythmic deformation of the skin. Some may think of this performance as a disturbing spectacle. Indeed, after a show an audience member expressed this feeling in a private conversation with me. This happens because what is left before the eyes of the audience members is a human body as material, as flesh, as sensation. 'The body is revealed only when it ceases to be supported by the bones' (Deleuze, 1981, 16). The performer's body on stage is flesh displaced by the external force of sound, the internal force of the muscles, its arrangement with the instrument and the immaterial processes of automaticity and entrainment. In this sense, the body in *Corpus Nil* is a body whose organs have been reorganised, a body whose skin is not any more a protective and sensing layer but rather a structural organ, in that it gives a new kind of physical, perceptual and visual organisation to the body.

The kind of analysis helps us point out another element that distinguishes the macro-politics of configuration in *Corpus Nil*. This is a reflection on the kinds of pure and thoughtless beauty, and beautifully 'normal' bodies, displayed by many technologically-mediated performances today. These kind of normalised cyborgs may please the senses, but in fact are an unfair and uncritical response to the ungentle, harsh, unforgiving and unbalanced society that human beings and technology have contributed to create. *Corpus Nil* is intended to be a critical reflection on this understanding of beauty in technologically-mediated artworks. It is intended to be a display, and a first hand visceral experience, of another kind of body, unformed, ungendered and unfamiliar. Its form is disturbing simply because it does not meet the expectations of human perception, it does not resemble closely enough a living creature, its physical traits are not enough human for it to be acknowledged as such. And yet, the body on stage is full of life, struggling with its few means and energies to come to life, to be individuated, to acquire a distinctive form, to be, perhaps, acknowledged. Does this make that disturbing body human enough? Or, put differently, is the common meaning of 'human' enough to describe that body? These are the questions that the work intends to prompt in the spectators leaving the theatre at the end of the performance.

7.5 Expressivity and Configuration

Taking my cue from the concepts elaborated so far in this chapter, I will now shift the focus of the discussion from the particular aspects of my artworks to a general analysis of expressivity in technologically-mediated performance. Paraphrasing the third and last question I asked at the onset of this thesis and recalled at the beginning of this chapter: What kind of expressivity arises from a performer-instrument configuration? Or, put differently, how does the characterisation of expressivity in musical performance change when performer and instrument are configured according to particular kind of micro- and macro-politics?

In musical performance, expressivity tends to be considered an exclusive capacity of the player that depends on action and volition. Such an understanding of expressivity however is incomplete, I argue, for it overlooks two things. First, be it an algorithmic system or an acoustic instrument, the instrument has an active role in the expressive outcome of a musical piece (Green, 2011). Its sonic properties and material qualities afford a distinct musical expressiveness and a varied range of interactions (Gurevich and Cavan Fyans, 2011). Second, action and volition are not inseparable aspects of expressivity in musical performance. Even in the performances of Lewis, Waisvisz and Tanaka, which rely on intentional physical gestures, the player's intentionality depends on a range of material and immaterial processes which engage at once conscious and pre-conscious, thresholds and potentials, cognition and psyche. On the other hand, certain kind of performances may rely on discarding entirely the immediate intentionality of the performer, as in the works of Stelarc and Marussich.

On this basis, I propose that, by analysing the performer-instrument embodiment as a configuration, it is possible to extend the meaning of expressivity in technologically mediated musical performance. This requires us to identify and join two kinds of expressivity which are rarely examined together in electronic musical performance; one kind of expressivity is found more commonly in gestural music performance while the other more often characterises body performance art with technology. We can look at the work of Stelarc, Marussich, Lewis, Tanaka and Waisvisz through the lens of configuration in order to specify this kinds of expressivity. First, I will specify the type of configuration that is common to the performances of those artists, and then I will identify two specific kinds of expressivity.

In the performances by Stelarc, Marussich, Lewis, Tanaka and Waisvisz, performer and instrument are physically fitted to each other and each of them performs processes that affect the other. The instruments used in the performances of Stelarc and Marussich fit the bodies of the performer. The hooks, the ropes and the methylene blue are purposely arranged with Stelarc's and Marussich's bodies, and thus instrument and performer influence each other according to their respective qualities. Lewis's Voyager, Waisvisz's The Hands and Tanaka's Biomuse are physically fitted to the bodies of their respective players, and, in different ways and with different degrees of influence, they interact with each other. In all the performances of those artists, the interaction with the instrument can be described as: programmatic, in that it develops according to given musical or performative goals; situated, in the sense that it is influenced by the audience feedback and the venue; and technically specified, meaning that their instruments have distinct sonic properties or material qualities. What differentiates this common configuration in each work is the fact that it relies on different kinds of expressivity according to the type of performance practice.

During Stelarc's and Marussich's performances, the interaction of performer and instrument occurs implicitly through the physiological processes that the properties of the performer's body and the instrument enact. This implicit type of interaction happens as a result of the negotiation between the instrument and the performer's body. In the case of Stelarc the instrument consists of ropes, hooks, pulleys, rocks and electrodes, and in the case of Marussich the instrument comprises of thermal regulation, methylene blue and a glass box. Importantly, their negotiation is situated in a particular context: Stelarc's body hangs from the ceiling of a gallery, while Marussich's body sits still in a glass box inside a theatre. The different milieu enable and alter the configuration of the performer and the instrument and the way it is experienced by the audience. The situated negotiation of performer and instrument causes their configuration to shift across intermediate states of embodiment without the need for evidently intentional gestures. This constant shift across states of embodiment is a particular kind of expressivity, akin to the expression described by Deleuze and Guattari (1987). This kind of expressivity can be felt only through sensation, in the sense Deleuze (1981, 33) used; it is through a sensation of the physical and physiological forces at play in the performance that this kind of expressivity is felt, for it tends not to be externalised by evident, intentional bodily gestures; it is incorporated.

On the other hand, the performances of Lewis, Waisvisz and Tanaka, rely on an explicit type of interaction, meaning that the player intentionally performs instrumental gestures (Cadoz, 2009). Body schemata and unintentional aspects of bodily performance do influence the performer-instrument interaction, but the aesthetic of the artworks relies on an explicit interaction. This interaction consists of actions that apply physical energy to the instrument (Hunt, 2000), either in the form of acoustic sounds of a traditional instrument, as for Lewis, or in the form of sensor data, as for Tanaka and Waisvisz. In each case, it can be said that the performer acts according to a combination of intentional gestures, pre-conscious body schemata, psychological states and contextual conditions. When the player's actions and the instrument's feedback combine successfully according to the musical goals of a piece, a distinctive interpretation of a given musical piece emerges. This constitutes a specific kind of expressivity which is apparent, meaning that it tends to be externalised through clearly visible and idiosyncratic physical gestures. This kind of expressivity is similar to the gesture expressivity I have analysed in subsection 6.2.1.

This analysis shows a twofold characterisation of expressivity in technologically-mediated performance. To sum up, one kind of expressivity depends upon sensation (Deleuze, 1981); this is the sensation of the forces that displace the performer-instrument configuration across different states of embodiment. These can comprise physical and physiological forces, as for the ropes that help suspend Stelarc's body or the sweating process that manifests the presence of methylene blue over Marussich's skin. An audience can feel the sensation of the action of those forces on performer and instrument, but can hardly perceive it. This kind of expressivity is fleeting and it can be felt only through equally fleeting details: the subtle variations in the tension of Stelarc's skin, or the slowly increasing amount of sweat drops on Marussich's body. Another kind of expressivity in technologically-mediated performance relies on formed musical ideas. These take the form of an organised series of audible sounds and rhythms of acoustic resonances, as Varese (1966) would call it, and physical gestures performed to meet, or play with, the expectation of an audience. During the performances of Lewis, Tanaka and Waisvisz, musical phrases and sound forms externalise the play between the performer's creativity and the instrument's distinctiveness. They make apparent the programmatic modalities whereby the configuration of performer and instrument unfolds. In so doing, they show how a particular configuration relates to, and emerges from, the interpretation of a given score and the conditions of a particular milieu.

In my own works, *Nigredo* and *Corpus Nil*, I merge, to different degrees, these two kinds of expressivity by drawing together performative strategies from the body art performances of Stelarc and Marussich with the techniques of musical interaction of the gestural performances by Lewis, Waisvisz and Tanaka. In both pieces performer and instrument have a similar stake in the outcome of the piece, the corporeality of the interaction between performer and instrument is highlighted (in positive and negative respects), and the musical composition, despite being based on a scripted temporal structure, maintains a significant degree of unpredictability. Both the configurations I created for *Nigredo* and *Corpus Nil* investigate how the agency of the performer can be constrained or affected by the electronic instrument, at a physical, perceptual, psychological and cognitive level, *and* how this enables different micro- and macro-politics of configuration, which relate to more general political and ethical issues on body and technology.

7.6 Re-reading Technological Embodiment

The scope of this research was twofold. On one hand, it critically discussed the integration of human and machine at a cultural and political level. On the other, it showed how such understanding can inform the way in which sound, software and hardware technologies are used in the performing arts. Along this journey we discussed bioacoustic sound as a medial energy, electronic instruments as organs of affect, extended corporealities and the sensations of material-immaterial bodies. This helped us construct a conception of human bodies and instruments as highly configurable entities. A conception affording the investigation of extended modes of artistic expression with sound technologies. This research tapped into the relation of sound and sensorimotor system to explore the expressive potential of the performer-instrument configuration. By configuring physiological aspects of muscle activation with the sound processes of an electronic instrument, this work offers an understanding of the artistic implications of combining conscious and pre-conscious bodily mechanism with the operations of an electronic musical instruments. The focus on sound, as both auditive and palpable impulse, and its relation to physiology and perception in musical performance is pivotal in this work. Sound is physical matter capable of infiltrating and conditioning both human and technological bodies. As such, sound exists in a space in between human bodies and machines, or better, it is the medium they are immersed in and communicate through in embodied practices. In other words, sound provides an active means through which human and machine interaction can be corporeal.

Another point that was made throughout the text is that the human body develops biologically, physically and cognitively through the intermixing with other (organic or machinic) bodies in an iterative process of becoming. I argued that, since this form of intermixing is prone to errors and miscalculations, the configuration of human and machines cannot be understood as seamless. Rather, errors, glitches and miscalculations are the seams that join human and technological capacities. Thus, the process of human-machine becoming may be hindered or blocked by those errors, or become more resilient by incorporating and resolving them. From this iterative process, a new body emerges. This is a living instance made of human bodies and technological instruments that are 'taken apart and put together', as Donna Haraway has put it (Haraway, 2003, 8). As noted on different occasions in this text, such idea is not speculative but rather practical. The advance of wearable technologies, everyday biometric devices, biotechnology for implants, and stem cell engineering is but a proof of those new bodies. Human embodiment today comes in the form of configured human-machine bodies. It is the outcome of a joint process of becoming where humans and machines mutate mutually (by co-constituting each other's properties), differentially (according to a technical milieu) and asymmetrically (by ramifying their properties each on its own terms). The driving force of my work was to, on one hand, research the artistic, technical and cultural implications of this process of becoming, and on the other, explore and demonstrate ways in which human-machine configurations can be manipulated, redesigned and created anew.

This research thus testifies to the affective capacity of the material relationships that link human and technology in sound performance. Their material relationship is affective in that their physical contact and mutual information produces extended or altered corporealities in sound performance; it expands the ways in which sound and music can be expressed and experienced. In this view, technologies are understood as more than functional tools, for they co-produce modes of expression through their configuration with the human body. Furthermore, this work shows that technology conditions embodied musical performance, and thus provides an extended understanding of corporeality, one where corporeality emerges from, and constitutes, the configuration of human and technology. This view has implications for the understanding of technological embodiment in general. Technology and human beings are conceived here, each on its own terms, as participants of a dialogue that can be generative, disruptive or confrontational, because it can extend, alter or assault the modes of expression that characterise each of them. Configuration rests on the acknowledgement that humans and technological instruments have fundamentally different capacities which complement each other, at a physical, cognitive and psychological level. Their complementarity is just a starting point. It is the origin of interrelated corporeal processes that amplify themselves and echo through embodied practices.

Chapter 8

Conclusions

8.1 Stating the Contributions

In the prior chapters, I have tackled the research questions presented at the onset of this thesis by providing a discussion of selected analytical resources and practical research. Initially, I have laid out the previous artistic works that relate to my own research, then I have constructed a thoretical framework and explained how it has informed practical research. Then, I have discussed two experiments and two artworks which have offered technical and artistic insights into different kinds of performer-instrument configurations in electronic musical performance. Finally, in the previous chapter, I have expanded the understanding of the aesthetic, technical and political implications of this thesis by discussing the configurations I created in my artworks in the context of the theoretical and artistic literature review. This chapter will conclude the thesis by stating its contributions, reflecting on the mode of research that I have adopted and considering the gaps in previous research that this work fills. To bring the thesis to a close, I will elaborate some final thoughts regarding the broader implications of my proposal of configuration in terms of the relation of society and technology.

This research consists of three main contributions: the analytical device of configuration; two sound-based performances; a set of artistic and scientific experiments and the related hardware-software toolset. The notion of configuration is offered as an analytical tool to think technological embodiments in sound performance, bodies where the human incorporates the technical. It draws from the key concepts of human unfinishedness, technical incorporation and biomediation. The idea of configuration allows us to analyse these hybrid bodies as embodied ecologies, where the distinction between subject and object is replaced with a map of relations between things. These relations are, at once, material (physical and physiological), immaterial (psychological and relational attunement), lived (phenomenological) and programmatic (cognitive), and are dependent on the particular milieux and historicities they move through. By considering the micro- and macro-politics of human-machine configurations, we have seen that those relations are neither self-contained, nor in perfect equilibrium; rather, they are metastable, in continuous tension against each other and the normative standards they are embedded in. It is by embodying the perturbations and partial resolutions of the material and the immaterial, the lived and the cognitive, the human and the technical that technologically-mediated performances convey specific cultural, political and ethical views. To grasp how such different aspects of human embodiment work through and with each other, I have identified three interrelated configuration modes in musical performance: vibration, flow and automaticity. In vibration mode, the human and the technical parts are coupled by the rhythm of tangible vibrations and audible sounds which submerge them; a positive feedback loop of vibration and sound is established. This can lead to the flow mode. Here the distinction between player and instrument, self and other becomes blurred and, if the particular milieu provides adequate conditions, a player experiences a state of entrainment. However, for this to happen training and repetition must be practiced; flow, or entrainment, is a state which has to be carefully constructed with and through the instrument. The third configuration mode is automaticity, a transitional phenomenon where the instrument acts upon and guide the player's body, intensely enough to be perceived as an extra-personal force. Trespassing one's usual thresholds of sound, effort, repetition and sensation is key to automaticity.

Using the notion of configuration and the three modes of vibration, flow and automaticity as a design template, I created two sound-based performances, *Nigredo* and *Corpus Nil*. These engage my own body and the bodies of public audiences in intimate, tense and confrontational relationships with computer software, body sensors, loudspeakers and transducers. In so doing, these works establish human-machine configurations which displace the dichotomy of human-subject versus instrument-object through a particular aesthetics: intensely intimate sensory and physical experiences, disturbing uses and abuses of the performer's body, and feedback processes where sound becomes a forceful vector of affect. The scope of these artworks, and the aesthetic they rely upon, is to *impact and heighten* the audience's sensitivity to cultural and political issues surrounding the configuration of human and technology in today's society. Instead of detaching the arts from political concerns or asserting a universal political statement, my intention as an artist is to force the audience to doubt, distrust and discredit the social models against which human bodies and technologies are assessed; so that new, alternative models can be envisioned. *Nigredo* and *Corpus Nil* are offered to the artistic and research community as 'specimens' to observe, copy, modify, dismantle and criticise in order to gain a better understanding of human-machine configurations and their cultural and political implications.

The third contribution of this work lies in the artistic and scientific experiments I have conducted in collaboration with Prof. Tanaka, Dr. Baptiste Caramiaux and Dr. Marije Baalman. These experiments have produced an insight on physiological computing methods for corporeal human-computer interaction. At a technical level, the experiments have generated findings on the effect of vibrations on the sensorimotor system and the understanding of gesture expressivity with muscle sensing. We have shown how specific vibrational patterns can produce vivid and highly subjective experiences; and how an electronic instrument equipped with muscle sensors and feature extraction software can sense higher level features of muscular activity, which can be useful in designing more corporeal interactions with machines. At a more general level, this experimental practice has allowed us to emphasise the limits and merits of a deep coupling of art, science and theory. In this context, the material physiological body which the experiments have analysed provides only a partial understanding of the problematics of human-machine configuration, which also involves immaterial, phenomenal and cognitive aspects exceeding purely scientific analysis. As this thesis has hopefully showed, this limit can be overcome by placing scientific experimentation in a dialogue with theoretical and artistic investigation. Doing so helps detail the differences and similarities across theory, science and art which, being intrinsically linked to distinct methodologies, must be confronted critically in order to generate novel viewpoints and practices of experimentation.

On the other hand, the study of the physiology of movement and its coupling with auditive and haptic perception emphasises the importance to integrate a detailed understanding of the material body into our theoretical analysis of human-machine configurations. This does not mean to accept and rely on reductionist understandings of technological embodiment. It means to simply acknowledge the role of material processes (physiological, vibrational and technical) in enabling, altering or disrupting the tensions between the lived, the immaterial and the cognitive body. For their metastable equilibrium is what forms the ecology of the technological body.

Inasmuch as my research skill allows I regard this work thorough and compelling, but I am also aware of its limitations. One of these limits is the extent to which the analytics I built can be applied to a context other than artistic practice. While in its present form the thesis provides resources in this sense, in future research, I want to abstract the analytics from my own personal practice as an artist, without denying its intrinsic relation to artistic experimentation. One way of tackling this issue is to work through the limitations of the way I currently conceive the notion of configuration. The need to constrain the idea of configuration to the context of musical and body art performance, forces it to elide other problematics, which it could actually help tackle. One of these problematics is subjectivity, or how one maintains an individuality in the face of its relational experience, which involves continuous encounters and configurations with both human, non-human and technological others. Of course, this is related to issues of gender and ethics, which I have pointed to earlier in section 4.5, and slightly touched upon in particular occasions in the thesis.

Limitations of this work can also be found at the artistic and technical level. While the hardware-software instruments I created for both artworks have high stakes in the performance, they are not capable of learning across different performances. This makes them oblivious, so to speak, to the historicity of both the work and the performer's body and thus limits their role in the human-machine configuration. Together with Dr. Caramiaux we had wanted to tackle this issue by creating an agent-based instrument; a computational system which is aware of its own actions, its context and its history and can subsequently act on its own accord (to the extent it is programmed to do so). However, the research process has not allowed us the time to pursue this implementation, which does not only require a detailed insight into adaptive machine learning techniques (a branch of artificial intelligence). It also calls upon for a reworking of the notion of configuration so as to consider the artistic and cultural implications of computational learning and machine ethics, as well as the subsequent hybrid modes of expression and affect. Can an autonomous machine be capable to 'understand' or deal with affective experiences such as flow, entrainment, automaticity? And if such a machine could have a body, how should that body look like, should it be gendered, normalised, monstrous? And why? Could it be integrated with the performer's body? If so, what kind of incorporation process would the performer and the machine experience? My future research will engage with both these questions and the theoretical limits highlighted above by leveraging the transdisciplinary methodology I developed during the present enquiry.

8.2 A Reflection on the Research Genesis

This research has consisted of iterative cycles through diverse resources, including the study of theoretical literature, the development of experiments and tools and the creation of artworks. Despite the tendency, throughout the past three years, for the research to become progressively systematised, there was no hierarchy and little linearity across the use of the resources. Rather, theoretical resources inspired ideas for the experiments and the artworks, and vice versa, the latter generated insights that informed or disrupted the theoretical approach. Gradually, as the practical aspects of the enquiry developed into actual artworks and concurrently, my understanding and mastering of the theoretical resources reached a finer level of detail, the theoretical and practical sides of the research began forming a consistent body of arguments. One could argue this research is a configuration in itself.

This iterative mode of research can be understood in terms of Gregory Bateson's framework of levels of learning (Bateson, 1972). Learning, for Bateson, is not only the process of learning new skills but also the process of learning how to learn. Learning is therefore a recursive and emergent phenomenon, according to Bateson. In his view, learning can be described in terms of different levels, where each level differs from the others, yet they all influence one another. These levels can be outlined as follows. The first level, what Bateson has referred to as 'Learning 0', involves the simplest phenomenon, that of an individual responding specifically to a stimulus. At the second level ('Learning I'), the response to the stimulus changes because errors of choice are corrected according to a set of alternatives; the individual learns new skills. At the third level ('Learning II'), one learns how to identify the patterns of a context, and thus, in addition to being able to correct a response to a stimulus, the individual learns how to learn.[1]

Bateson's framework is useful in detailing how the present enquiry developed. The initial stimulus for this research was the account of individuation by Simondon, which I read for the first time at the beginning of my doctoral studies. Exam-

[1]Bateson has described also a third level of learning (Learning III) where all the learning modes are simultaneously present and, due to significant contradictions in the experience of learning, one engages in a third-order process of learning. This happens, for Bateson (1972, 273), through a profound reorganisation of one's distinctive mental and moral qualities and it can lead to enlightenment on a specific subject matter or to the development of psychosis.

ining his ideas on becoming - the constant shifting of human embodiment through temporary phases (Simondon, 1992), I felt compelled, as an artist, to explore how sound technology affects the perception of the self, and which aesthetic and technical implications this relationship between sound technology and self-perception bears. I asked how could I make an instrument capable of affecting one's self-perception, and perhaps, offering novel ways of experiencing one's own body? This was my initial question. It was a coarse question, and it had been already explored by other artists such as Mikami (1997) and Salter (2012), yet I felt it was worth exploring it as a starting point. My understanding of the problem developed further as I examined other resources on the theme of becoming, via Deleuze and Guattari (1987), and trans-individuation - the understanding of technology as an integral part of human personal and collective development (Stiegler, 2011a).

Concurrently, while researching papers on the relation of low frequency vibrations and human perception, I discovered an interestingly uncanny military report on a series of experiments on the effect of induced low frequency vibrations on the human body (Lowry and Bosley, 1962). This report acted as a bridge between the notions of becoming and trans-individuation and the modalities of an exploration, at an artistic and technical level, of the material relationship of human beings and machines. As I began mastering the theoretical notions of becoming and trans-individuation, it became increasingly clear how they could inform my artistic practice. Eventually, the research process turned practical and I conducted the artistic experiment on the effect of vibrations on the sensorimotor system described earlier. The experiment in turn, provided the insight for the creation of *Nigredo*, a complete and finished artwork. Bateson (1972, 279) placed an emphasis on the role of art in the process of learning. In his view, aesthetic experience fills the gap between what is more or less unconsciously learned in Learning II and the immediate actions and responses that characterise Learning 0. In this enquiry, the role of the artistic practice was not that of a simple outlet, but rather that of a means to mediate between the formal research process and the artistic intuition and vision I had been developing. As a result, the idea of configuration began to form.

Having developed a research workflow that allowed me to relate theoretical notions to my artistic practice, and vice versa, to use insight from the practice to analyse critically the theory, the research focus became more narrow. As I read further literature, specifically on the posthuman condition (Haraway, 1991; Hayles, 1999; Braidotti, 2013), affect and biomediation (Spinoza, 1677b; Clough, 2008), the analytical device of configuration began to take an increasingly clear form. At this point, I decided to explore the use of configuration in gestural musical performance, which has been my main area of practice for several years now. This impetus came to me at the same time when, together with my colleagues, we had began gathering interesting scientific results on the relation of physiological muscle sensing and expressive physical gestures in electronic musical performance (Donnarumma et al., 2013b,a). As I worked on creating *Corpus Nil*, I kept reading further theoretical works, ranging from Merleau-Ponty (1978) to Henriques (2011), along with scientific literature on biosignals, biomechanics and feature extraction. Then we conducted further experiments, whose findings, which we reported in (Caramiaux et al., 2015), informed the technical and artistic research on muscle sensing that I was conducting at the time. Eventually, all these resources coagulated into the practical realisation of *Corpus Nil*, which in turn, allowed me to investigate further the idea of configuration and its implications for electronic musical performance.

Importantly, once completed and submitted the manuscript I was fortunate enough to defend this thesis before two stakeholders in body theory and new musical instrument design, respectively Prof. Lisa Blackman and Prof. Sergi Jordà. Their thoughtful comments, both during the defense of the thesis and with their written reports, have helped me make the thesis stronger and more precise by highlighting the contradictions and ambiguities of the first version of this manuscript. Among their compelling suggestions, the most significant ones regarded, on one hand, extending the notion of configuration by investigating the topic of automaticity and the feminist engagements with incorporation; and on the other, strengthening the scientific contributions while reflecting on my approach to practice-based research. This is useful to emphasise that, of course, what is laid out in this manuscript as a whole, more or less linear analysis is the result of distinct experiences, methods, ideas, errors and misinterpretations.

As any other doctoral research, this project has radically changed the way I identify myself as a researcher, an artist and a human being. When I started, in 2012, the proposal for my doctoral studies was solely focused on creating a new musical instrument. However, as the description of the thesis genesis suggests, doing research, at least at a doctoral level, is a strange mix of sudden deviations and convergences, slow and multilayered learning processes and, in the case of practice-based research, the seemingly spontaneous embodiment of creative ideas. In the end, my research project turned out to be much more complex and ambitious, but the complexity and the ambition have not been always easy to deal with! What research methods courses generally do not teach is how to acknowledge one's own intuition, errors, desires and personal background while translating a particular research process into a text. I believe that balancing inventiveness with self-reflection, openness of arguments with analytical precision, intuition with logic is crucial to good academic writing. This is something I have learned only once the current research project approached its completion, but I am sure it will be of great help in my future endeavours.

8.3 Final Thoughts

Machine technology today (often literally) opens up the human body to enable drastic changes that affect both its form and its cultural meaning. Because of the advance in physiological technology, transplants, genomics, prosthetics and the like, human bodies that change form and capacities are more than common. This exposes the open-ended nature of human beings. But human nature is not open-ended just because machine technology makes it so. The human body has always been open to changes, it was never an immutable object. If it was not for the continual changes and reactions provoked by the relation with other beings, instruments and the environment the human body would be lifeless. In other words, the liveness of the human body depends on interactions with others, living and non-living. From this point of view, the configuration of humans and machines is a constitutive part of the human being rather than a futuristic perspective of transcendence. Moreover, when we interact with technologies, we are not only forming our own individuality but we are paving the way for the future individuation of that technology as well. Human beings and the technologies they create develop their potential qualities iteratively by interacting with each other.

The interaction of human beings and technologies can be balanced in different ways along a continuum between control and configuration. However, to rely on strategies of control means to centre the discourse on a supposed antagonism between humans and machines. Such antagonism does not only negatively emphasises the differences between the two. It also posits a hierarchical understanding of the living and the non-living, a view which fails to grasp that both humans and machines contribute to the emergence of cultural models. This work affords the conception of an open-ended mode of interaction, a configuration of the human and the machine which takes place at a physical and physiological level and emerges through embodied practices. This is not only an artistic standpoint, but a political one as well. It is a statement against the reductive notion of body instrumentality that advanced capitalism is instilling into the cultural fibres of our society. A notion whereby the human body is merely a source of data used to build genomic databases, make computations, customise social network and control conforming and superfluous wearable technologies in the uncanny privacy of our isolated individual space. A lifeless body enchanted with self-indulgent predictions, obsessive 'notifications' and unasked-for fitness advice brightly shining out of mini displays.

Drawing on a transdisciplinary approach embracing theory, science and artistic practice, this research posits a standpoint whereby the human being is an entity that can be configured with technology through the vibrational force of sound. The co-dependence of human beings and machines is emphasised as a potential for unconforming modalities of embodiment. More importantly, this enquiry stresses the need to purposefully reassess, alter and design the configurations of human bodies and technology. The artworks I have created and discussed in this thesis represent my personal vision of how human-machine configurations can be designed and performed. What those artworks show is therefore a fraction of the multiple and pluripotent human-machine configurations that can be created. This research invites practitioners in the field of technologically-mediated performance, and especially those taking their early steps in the field, to take part in a process of creative intervention in the micro- and macro-politics of human-machine configurations. It is a plea for a politically-conscious engagement of artists and researchers with the kinds of corporealities that emerge from human-machine configurations and their significance in reinforcing, altering or challenging societal models.

Appendix A

Publications and Interviews

Book Chapters

Donnarumma, M.
2014a. Fluid flesh and rhythmic skin: on the unfinished bodies of Stelarc. In *Meat, Metal Code: Contestable Chimeras - Stelarc*, R. W. Kluszczyński, ed. Gdansk: Łaźnia Centre for Contemporary Art.

Donnarumma, M.
2014b. Nigredo: Configuring Human and Technological Bodies. In *Experiencing the Unconventional - Science in Art*, T. Schubert and A. Adamatzky, eds. London: World Scientific.

Journals

Caramiaux, B., M. Donnarumma, and A. Tanaka
2015. Understanding Gesture Expressivity through Muscle Sensing. *ACM Transactions on Computer-Human Interactions*, 21(6):31–31:26.

Donnarumma, M.
2015. Biophysical Music Sound and Video Anthology. *Computer Music Journal*, 39(4):132–138.

Proceedings

Donnarumma, M.
2014. Notes on Bimodal Muscle Sensing for the Sonification of Indeterminate Motion. In *Proceedings of the International Conference on Movement and Computing*, Pp. 170–171, New York, NY, USA. ACM.

Donnarumma, M., B. Caramiaux, and A. Tanaka
2013a. Body and Space : Combining Modalities for Musical Expression. In *Work in Progress for the Conference on Tangible, Embedded and Embodied Interaction*, Barcelona. UPF - MTG.

Donnarumma, M., B. Caramiaux, and A. Tanaka
2013b. Muscular Interactions Combining EMG and MMG sensing for musical practice. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Seoul. KAIST.

Donnarumma, M. and A. Tanaka
2014. Principles, Challenges and Future Directions of Physiological Computing for the Physical Performance of Digital Musical Instruments. In *Proceedings of the Conference on Interdisciplinary Musicology*, Berlin. Staatliches Institut für Musikforschung.

Selected Interviews

ARTE.tv
2015. Mon Corp Est Mon Instrument.

Ludovico, A.
2015. Interview with Marco Donnarumma. *Neural*, (50):18–20.

Morsi, A.
2015. Entrepreneurs Corner: Marco Donnarumma. *IEEE Pulse Magazine*.

Perry, P.
2014. Nigredo - Private experience of altered self-perception. Available at: http://bit.ly/1Gml6kQ.

Udvardyova, L.
2015. Marco Donnarumma. A performative techno-body for the SHAPE platform. Available at: http://bit.ly/1MXDHoe.

Appendix B

Presentations and Awards

Conferences, Symposia and Lectures

2015 15th International Conference on New Interfaces for Musical Expression (NIME), Baton Rouge, LSU.

33rd Conference on Human Factors in Computing Systems (ACM CHI), Seoul.

2014 9th Conference on Interdisciplinary Musicology (CIM), Berlin, Staatliches Institut für Musikforschung.

Posthumanities International Network Workshop, London, Goldsmiths.

Invited Lecture, New York City, Stevens Institute of Technology.

14th International Conference on New Interfaces for Musical Expression (NIME), serving as Poster and Demo Chair, London, Goldsmiths.

International Workshop on Movement and Computing (MOCO), Paris, IRCAM.

Invited Lecture, New York City, NYU.

2013 What is Sound Design...? Symposium, Edinburgh, The Edinburgh University.

Invited Lecture, Zagreb, IEEE Elevate.

Invited Lecture, Plymouth, University of Plymouth.

13th International Conference on New Interfaces for Musical Expression (NIME), Seoul, KAIST.

7th International Conference on Tangible, Embedded and Embodied Interaction (TEI), Barcelona, UPF-MTG.

Presentation of Practical Work

2016 *Corpus Nil*, ReSense Festival, Berlin, Spektrum.

Corpus Nil, The Games Europe Plays, London, University of Greenwich.

Corpus Nil, Creative Tech Week, New York, NY, Clemente Velez Arts Center.

Corpus Nil, Chicago, IL, Defibrillator Performance Art Gallery.

Corpus Nil, Sonic Cyborgs, Poughkeepsie, NY, Vassar College.

Corpus Nil, ZKM:GLOBALE, Karlsruhe, ZKM.

2015 *Nigredo*, Musikprotokoll im Steirischer Herbst, Graz, Kunsthaus.

Corpus Nil, NIME Conference, Baton Rouge, LSU.

Corpus Nil, Private preview, London, Goldsmiths.

2014 *Nigredo*, Cynetart Festival, Dresden, Festspielhaus Hellerau.

2013 *Nigredo*, TransitioMX, Mexico City, CENART.

Nigredo, Sonic Acts Festival, Amsterdam, STEIM.

Awards

2014 Cynetart Award for Computer Based Art, for *Nigredo*, Dresden, Trans-Media-Akademie Hellerau.

2013 TransitioMX Prize for New Media Art, for *Nigredo*, Mexico City, CENART.

Appendix C

Appendix to Practice Pt.I

C.1 Experiment Questionnaire

The following is the questionnaire used during the experiment on the effect of vibrations on the sensorimotor system conducted at STEIM with Dr. Marije Baalman, in February 2013. The experiment was discussed in subsection 5.2.3.

Regarding the moment the visitor left the installation

1. How do you feel?
2. What was the experience of the space over the course of the installation?
3. What was the experience of your body over the course of the installation?
4. How long were you in the space? How long did it feel?

Regarding the moment the visitor entered the installation

1. What do you remember as you first entered the installation?
2. What did you see as you entered the installation?
3. What did you hear as you entered the installation?
4. If you heard something, can you say where was it coming from?
5. What was the sound like?
6. What did you feel as you entered the installation?

Regarding the personal experience of the visitor

1. Did you feel like you were alone in the space?
2. Did it feel like a private space?
3. How did you experience your body?

Regarding the visitor's understanding of the audio visual composition

1. How did you experience the evolution of the piece?
2. How many sections did the piece have?
3. Please name each section and describe it.
4. What did you see, hear?
5. What tactile sensations did you feel?
6. What other sensations did you experience?
7. Did you at any point feel any particular sensation or emotion?
8. Why do you think that happened?
9. Was there any moment when what you did changed something?
   (if yes) When did this happen?
   (if not) Why you did not try to change something in the composition?
10. Can you describe the ending of the piece?

Regarding the visitor's personal remarks

1. Is there anything else that you think is important to tell us?

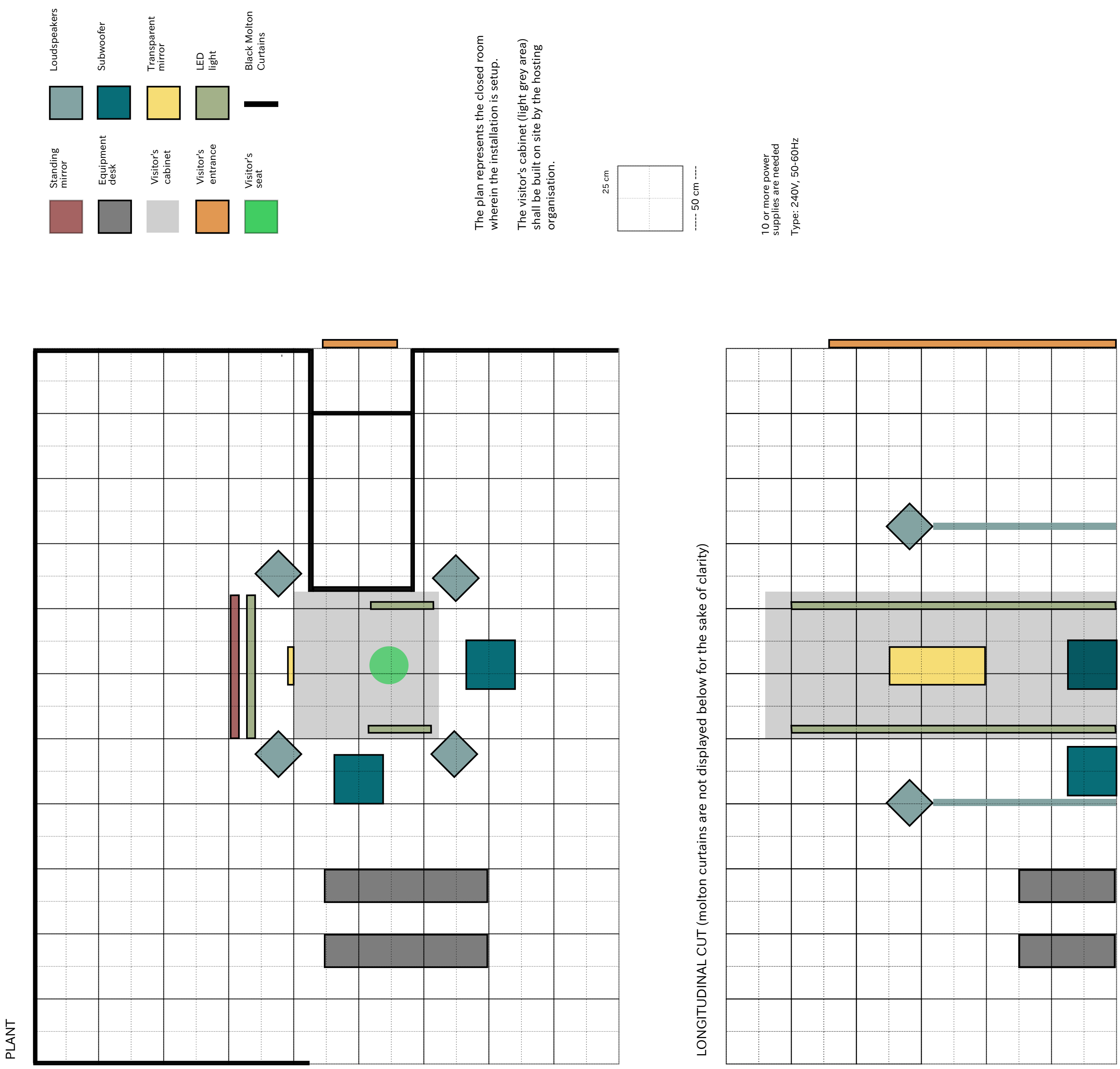
C.2 Nigredo Setup Documentation

Dimensions and Weight

Nigredo is installed inside a booth made of wooden frames. The booth is installed inside a larger room. The booth shall be built on site before the author's arrival according to the Autocad drawing and building instructions attached. The booth is built by assembling wooden frames. Each frame is first covered with black molton so to make it appear as a flat wall. Then, all the frames are assembled together. The visitor sitting inside the booth should only see black walls. Wood, staples, and nails should not be visible from within the booth.

Space Features

The booth has to be located within a closed and blacked-out room. This is the room where the author's equipment will be set up. The dimensions for this room are ideally W 11 m x H 4 m x D 9 m. The booth should be safely fixed to both the floor and ceiling of the surrounding room; it is useful to place an anti-friction rubber mat below the floor panel of the booth, so that the booth remains stable. The setup plan for the work follows on the next page.


Loudspeakers
Subwoofer
Transparent mirror
LED light
Black Molton Curtains
Standing mirror
Equipment desk
Visitor's cabinet
Visitor's entrance
Visitor's seat
The plan represents the closed room wherein the installation is setup.
The visitor's cabinet (light grey area) shall be built on site by the hosting organisation.
25 cm
----- 50 cm ----
10 or more power supplies are needed
Type: 240V, 50-60Hz
PLANT
LONGITUDINAL CUT (molton curtains are not displayed below for the sake of clarity)

Appendix D

Appendix to Practice Pt.II

D.1 Selected Full Papers

In order to detail the scientific and technical contribution of this enquiry, this section features the full articles documenting the three-part study of gesture expressivity through muscle sensing which I discussed in section 6.2. The experiments and the subsequent articles were produced in collaboration with Dr. Baptiste Caramiaux and Prof. Atau Tanaka at Goldsmiths, University of London. The references to the published articles are listed below in reverse chronological order to highlight the progression of the study. The full articles are attached in the next pages following the same order.

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Caramiaux, B., M. Donnarumma, and A. Tanaka
2015. Understanding Gesture Expressivity through Muscle Sensing. *ACM Transactions on Computer-Human Interactions*, 21(6):31–31:26.

Donnarumma, M., B. Caramiaux, and A. Tanaka
2013a. Body and Space : Combining Modalities for Musical Expression. In *Work in Progress for the Conference on Tangible, Embedded and Embodied Interaction*, Barcelona. UPF - MTG.

Donnarumma, M., B. Caramiaux, and A. Tanaka
2013b. Muscular Interactions Combining EMG and MMG sensing for musical practice. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Seoul. KAIST.

Body and Space: Combining Modalities for Musical Expression

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TEI 2013, February 10-13, 2013, Barcelona, Spain
ACM

Abstract
This paper presents work in progress on applying a Multimodal interaction (MMI) approach to studying interactive music performance. We report on a study where an existing musical work was used to provide a gesture vocabulary. The biophysical sensing already used in the work was used as input modality, and augmented with several other input sensing modalities not in the original piece. The bioacoustics-based sensor, accelerometer sensors, and full-body motion capture system generated data recorded into a multimodal database. We plotted the data from the different modalities and offer observations based on visual analysis of the collected data. Our preliminary results show that there is complementarity of different forms in the information. We noted three types of complementarity: synchronicity, coupling, and correlation.

Author Keywords
multimodal interaction; NIME; interactive music performance; gesture; expressivity; biosignals

ACM Classification Keywords
H.5.5 [Sound and Music Computing]: Methodologies and techniques.

Introduction

Multimodal interaction (MMI) is the integration of multiple modalities (or input channels) to increase information and bandwidth of interaction. MMI uses different modalities that offer complementary information about user input. These modalities might include, for example, voice input to complement pen-based input [9]. The combination of complementary modalities provides information to better understand aspects of the user input that cannot be deduced from a single input modality. The analysis of combined information could be useful in the contexts involving forms of user expressivity in input.

Research in game control, sign language recognition, and prosthesis control looks at complementary use of spatial aspects of hand gesture, and physiological biosignals such as muscle tension (electromyogram, or EMG). Zhang et al. combined EMG and accelerometer (ACC) data in a gesture recognition system for the manipulation of virtual objects [11]. Li et al. [7] demonstrate an automatic Chinese sign language recognition system based on EMG and ACC. Fougner et al. show that the multimodal use of EMG and ACC was effective in reducing the number of EMG channels needed compared to a biosignal-only prosthetic interface [6].

Audio, video, and motion capture modalities were used alongside EMG, heart rate or EKG, electroencephalography or EEG by [8] in a study focusing on social interaction in traditional musical ensemble performance.

In the field of New Interfaces for Musical Expression (NIME), sensor-based systems capture gesture in live musical performance. In contrast with studio-based music composition, NIME (which began as a workshop at CHI 2001) focuses on real-time performance. Early examples of interactive musical instrument performance that pre-date the NIME conference include the work of Michel Waisvisz and his instrument, The Hands, a set of augmented gloves which captures data from accelerometers, buttons, mercury orientation sensors, and ultrasound distance sensors [5]. The use of multiple sensors on one instrument points to complementary modes of interaction with an instrument [1]. However these NIME instruments have for the most part not been developed or studied explicitly from an MMI perspective.

In this work-in-progress report, we show the relevance of considering biosignal-based multi-modality for the analysis of expressive musical gesture. This follows initial work looking at the integration of biosignals with relative position sensing [10]. Here, we describe a system for capturing three input modalities from the arm gestures of a musician. We then present the data from the different modalities together to look at the relationships amongst them. We identify three types of complementarity and discuss perspectives for future work.

Method

We conducted a pilot study recording musical gestures using 3 input modalities, and performed an observation-based analysis on mutual relationships in the data. The different modalities (mechanomyogram or MMG, accelerometer, and motion capture) detect physiological, movement, and spatial position information, respectively.

Sensor apparatus

The MMG is a signal generated by subcutaneous mechanical vibrations resulting from muscle contraction. For this we used the Xth Sense (XS), a biophysical NIME instrument[1]. The XS consists of an arm band containing an electret condenser microphone (Kingstate KECG2742PBL-A) where acoustic perturbations from muscle contraction are digitised as sound at a sampling rate of 48000 Hz. Two channels of MMG were recorded, from the right and left arms over the wrist flexors, a muscle group close to the elbow joint that controls finger movement. The right sensor was located on the ring finger flexor, and the left one was slightly offset towards the little finger flexor.

The accelerometer sensor was a 3-axis DUL Radio (Analog Devices ADXL345) sending wireless data through a Nordic transceiver with a bandwidth of 2.4GHz, and sampling rate of 100Hz. The sensor was located on the back of the forearm, close to the wrist.

The motion capture system was an Optitrack Arena. This consisted of a full body suit, with 34 markers, and 11 LED/Infrared cameras (V100:R2) with a sampling rate of 60 FPS. We recorded 24 rigid bodies, that is, groups of markers representing limb part positions.

Data acquisition
The data collected was comprised of:

- 2 MMG audio signals, along with 6 amplitude/time domain sub-features extracted from analysis of the MMG audio stream;
- one 3D vector from the accelerometer;
- 24 rigid bodies, consisting of 7D signal for each rigid body: 3D position and 4D quaternions

[1]Developed by the first author.
http://res.marcodonnarumma.com/projects/xth-sense/

The data was synchronised and captured by custom software developed in the Max/MSP graphical programming environment[2]. The data was time tagged, and stored in text format for offline analysis.

Gesture vocabulary
We used an existing piece of interactive music entitled *Music for Flesh II*, a work for XS that has had repeated performances by author 1 [4]. In the piece, the XS sends MMG from arm gesture to a computer programme to articulate sound and further process sound with the same muscle data. The composition is based on a vocabulary of 12 arm gestures. These gestures comprised the gesture vocabulary for our experiment.

The gestures, described in metaphorical, musical terms are:

1. Shaking bells
2. Scattering sound grains 1
3. Stretching sound 1
4. Stretching sound 2
5. Dropping something small
6. Rotating bells
7. Grasping the void
8. Shaping a wave
9. Throwing a sound wave
10. Holding a growing force
11. Scattering sound grains 2
12. Rotating wheel

[2]http://www.cycling74.com

Figure 1: Example gesture *Stretching sound 2*

Each gesture was repeated 10 times with different expressive articulation, that is, changing speed and intensity in each iteration. Fig. reffig:gesture illustrates a trial of gesture 4 (*Stretching sound 2*). This gesture consists of fast wrist rotation, and faster flexion of the distal phalanges.

A detailed description of each gesture as well as the complete database can be seen on-line[3].

Results

In this section we report results focusing on the mechano-myogram and accelerometer data. In the following graphs the accelerometer x, y, and z axes are the green, red, and blue traces, respectively. The MMG sound wave is the black trace.

[3]http://marcodonnarumma.com/submissions/TEI2013/

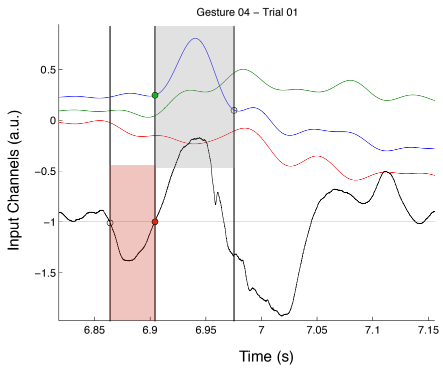

Figure 2: Detail of the MMG and ACC attack envelopes.

Fig. 2 shows the MMG (black) and ACC (blue, green, red) data recording from Gesture 4 (fig. 1). The red zone highlights the onset of muscle activity. The grey zone highlights the onset of accelerometer data. The initial activity in the muscle anticipates accelerometer data, with a second peak in MMG coinciding with the first peak in ACC. This shows the preparatory activity in the muscle at the beginning of a gesture that is not reported by the accelerometer sensor.

The graphs in Fig. 3 show two iterations of Gesture 1 (*Shaking bells*), a gesture that consists of multiple repeated contractions of the right hand fingers. The gesture was executed with two different kinds of expression, weak (low muscle force) and strong (high muscle force). By plotting the MMG and the 3 axes of the ACC data, we are able to see if the signals are coupled - whether the different modalities parallel each other, and coincide, or not. At a weak articulation the oscillating nature of the finger grasping is slightly visible in the MMG trace. The accelerometer axes do not seem coupled to the MMG or to each other. At a higher articulation force, the signal for all the modalities undulates at close frequency in a coupled manner.

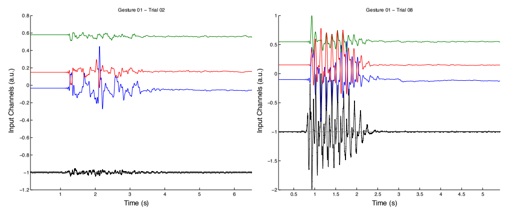

Figure 3: Gesture 1 executed at two different force levels.

Fig. 4 shows a more complex gesture, (*Scattering sound grains 2*). This consists of repeated *subito* finger clasping alongside swift wrist rotation. Here we see a change in correlation across modalities over the course of the gesture. Based on this shifting correlation, we divided the gesture into three segments. The first and third segments exhibit high correlation between MMG and ACC components, while in the second segment the subtleties of the MMG envelope are not correlated with the peaks in the ACC data.

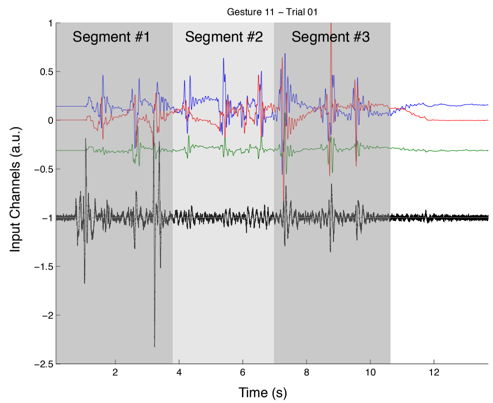

Figure 4: Correlation and independent variations of MMG and ACC channels within the same gesture.

Discussion

Synchronicity

In Gesture 4, we noted a time offset between MMG and ACC onsets. This may be due to different factors. The two modalities - muscle force and limb acceleration - may be asynchronous. One modality may have a lower latency than another. Or, the corporeal sensor may detect preparatory activity of the body that is not seen in the spatial/physical sensors. This could have useful application whereby the preparatory nature of one modality may aid in anticipating the arrival of data on another modality.

Coupling

We noted that coupling of modalities can vary with changing expressivity of the same gesture. In Gesture 1, during weaker articulation of the gesture, the MMG and the 3 ACC axes were decoupled while at stronger expression of the same gesture, we observed tighter coupling in these modalities. This may indicate that two "regimes" can be engaged: either a low force with fairly independent signals or high force with coupled signals. This has potential to be the subject of further study.

Correlation
We observed the shifting of cross-modal correlation within the span of one gesture. We visually segmented zones that displayed high and low correlation between MMG and ACC. This may point out differing levels of dependency between muscle control and the resulting movement. Interestingly, the ACC data in Gesture 11 have more or less the same amplitude throughout the gesture, but the MMG amplitude varies greatly, pointing out a difference in dynamic range in the different input modalities. This may be studied in more detail using automatic feature extraction methods [2], to examine quantitatively which features of the MMG and ACC signals are correlated.

Observations on other modalities
In gestures characterised by finger contractions (1, 2, 4, and 11), unless a marker is positioned on each finger, the tracking of phalange movement is not detected. Motion capture is, however, useful in conveying information about the movement of other parts of the body such as head and torso. Studies of musical instrument performance [3] point out the importance of such corporeal movement to musical expressivity. This auxiliary information, beyond the constraint space of multiple input modes sensing limb gesture, could be useful in multimodal musical interaction.

Conclusion

This paper reported on preliminary work applying a Multimodal Interaction approach to analyse expressive musical gesture. By using three distinct modalities to track gesture in the performance of an existing NIME-type work, we were able to make several early observations on the relationships between the kinds of information reported by the different input channels. We found that: the complementarity across different input modalities may be due to differing sensitivity of sensors to the preparation of a gesture; what seems like a single musical gesture may be comprised of different sections where the relationship amongst modalities may change over time; a range of modalities might detect the independent control different aspects of a single gesture.

The results presented are initial observations on a subset of the data we collected. One challenge in working across a diverse range of information-rich modalities is in the data management and numerical processing. Signal acquisition and synchronisation across free-standing hardware systems, different sampling rates, and network communication latency pose additional technical challenges that would need to be rigorously addressed in an in-depth study.

One element that made up part of our capture session which we did not report on in this paper is the capture of audio (of the musical output) and video (of the performer conducting the gesture). These media channels could provide useful points of reference, and might, given the appropriate configuration, even be exploited as auxiliary input modalities.

Acknowledgments

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. FP7-283771.

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Muscular Interactions

Combining EMG and MMG sensing for musical practice

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ABSTRACT

We present the first combined use of the electromyogram (EMG) and mechanomyogram (MMG), two biosignals that result from muscular activity, for interactive music applications. We exploit differences between these two signals, as reported in the biomedical literature, to create bi-modal sonification and sound synthesis mappings that allow performers to distinguish the two components in a single complex arm gesture. We study non-expert players' ability to articulate the different modalities. Results show that purposely designed gestures and mapping techniques enable novices to rapidly learn to independently control the two biosignals.

Keywords

NIME, sensorimotor system, EMG, MMG, biosignal, multimodal, mapping

1. INTRODUCTION

Muscle activity can be detected by using two distinct biosignals, the electromyogram (EMG) and the mechanomyogram (MMG). The former is a series of electrical neuron impulses sent by the brain to cause muscle contraction. The latter is a sound produced by the oscillation of the muscle tissue when it extends and contracts.

Biosignals have been largely adopted in diverse fields, from human-computer interaction, to medical engineering, affective computing, and embodied musical performance. Biosignals have been used in NIME in a diverse range of musical instruments and interface systems ([10]). Different types of biosignals have been used. Some, such as brainwaves (EEG) and galvanic skin response (GSR), are not directly related to movement, but rather to mental and physiological states, and thus fall outside our focus in this paper. The EMG and MMG, are useful in tracking limb movement in performance.

Previous work with EMG in NIME has been presented in [9]. The present authors have separately reported work on use of the EMG [15] and MMG [2] for live musical performance. We have looked at muscle signals in a multimodal context for EMG with ultrasound rangefinders [15] and MMG with accelerometers and motion capture systems [3], but to our knowledge, EMG and MMG have not previously been compared in a musical context.

We present a combined analysis of these two types of muscle sensing. We establish a gesture vocabulary using examples reported in the biomedical literature that describe differences between and complementarities of the signals. With these gestures, we create musical mappings where these differences and similarities are heard through sonification and audio processing. We then study the ability of non-expert users to play this bi-modal biosignal musical interface.

We first give an overview of the sensorimotor system and a brief review of biomedical literature comparing EMG and MMG. We next describe the bi-modal EMG/MMG system, its hardware, gesture vocabulary, and mappings as used in the study. We then present an evaluation of the system followed by results, including interviews conducted with the study participants. We identify tendencies within the group and discuss perspectives for future development.

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2. MUSCLE ACTIVATION MECHANISM

The human sensorimotor system is a chain of interdependent physiological activity that includes: mechanoreceptor stimulation, neural transmission, central nervous system (CNS) integration, transmission of efferent signal (i.e. a neural trigger fired by the CNS), muscle activation, force production, and movement [12]. Figure 1 illustrates the sensorimotor system flow, and indicates when EMG and MMG are produced.

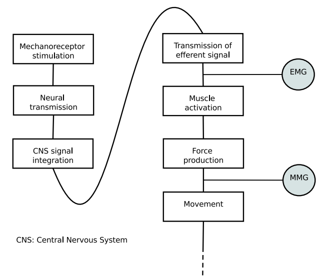

Figure 1: Sensorimotor system information flow.

The EMG is an electrical voltage that results from neuron firing causing muscle contraction. It can be detected using surface electrodes that make electrical contact through the skin. The contraction of a group of muscle fibers (also known as motor unit) results in stochastic bursts of electrical activity [4].

The MMG is an acoustic signal generated by subcutaneous mechanical vibrations resulting from muscle contraction. It can be captured with surface audio microphones

[11].

By simultaneously sensing EMG and MMG from the same movement, complementary information on a gesture can be captured. The signals are produced at different points in the execution of gesture. They are interrelated and present several kinds of relationships.

Previous studies have demonstrated EMG and MMG relationships that vary according to the type of contraction and sensor location. Madelein et al. [8] found that EMG and MMG have different *activation* mechanisms depending on the type and force level of muscle contraction. It has been reported that EMG detection is negatively affected by the distance of the EMG sensor from the muscle activation area [1] (*localisation*), whereas the MMG signal is more easily detectable due to its *propagation* qualities, which allows the signal to be transmitted through tissue surrounding the contracting muscle [13]. Gordon et. al showed that, during free-hand forearm rotation, EMG amplitude in the posterior muscles is lower than in the anterior muscle [5] (*relaxation*). Jobe et al. [7] found that, during throwing and pitching gestures, forward arm acceleration in space lacks EMG activity in the deltoid and arm muscles (*acceleration*).

We selected *activation*, *localisation*, *propagation*, *relaxation*, and *acceleration* to design a vocabulary of physical gestures to be performed with a bi-modal, biosignal-based interface created for this study.

3. BI-MODAL EMG/MMG INTERFACE

3.1 Signal acquisition hardware

We used existing musical EMG and MMG sensor systems together in a bi-modal configuration. For the MMG we used the Xth Sense (XS), a biophysical music system[1]. The XS consists of an arm band containing an electret condenser microphone (Kingstate KECG2742PBL-A) where acoustic perturbations from muscle contraction are digitised as sound at a sampling rate of 44100 Hz. For the EMG we used the Infusion Systems BioFlex dry electrode sensor[2]. The EMG signal from the BioFlex was digitized with an Arduino BT-V06 and sent over Bluetooth to the host computer using custom firmware[3]. The EMG signal was sent over Bluetooth connection through a virtual serial port created on a laptop running Linux Ubuntu 10.04. The signal was initially sampled by the Arduino at 500Hz. To create a coherent bi-modal system, we upsampled the EMG in the host computer to match the MMG sampling rate. The XS software was modified to process the two modalities in parallel in equivalent ways. The MMG and EMG were first directly sonified, and then used as control data to enable the user to drive the mapping of 3 gestures.

Arm bands with EMG and MMG sensors were placed on the forearm. One MMG channel and one EMG channel each were acquired from the users' dominant arm over the wrist flexors, a muscle group close to the elbow joint that controls finger movement (Fig. 2).

3.2 Gesture-sound mapping

In order to let non-expert players train with our musical interface, we designed 3 mappings that linked a vocabulary of physical gesture with the production of sound. The gesture vocabulary is described in Table 1. The mapping allowed the production of two different and independent sounds with one gesture. We conceived the mapping by

[1]http://res.marcodonnarumma.com/projects/xth-sense/
[2]http://infusionsystems.com/catalog/product_info.php/products_id/199
[3]http://www.musicsensorsemotion.com/2010/03/08/sarcduino/

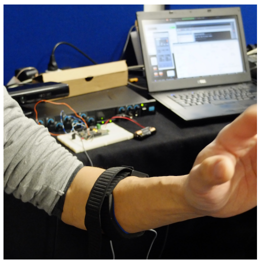

Figure 2: The EMG/MMG armbands.

Gesture 1	EMG	MMG
extend arm outward		
strongly clench fist for constant tension	X	
move clenched fist upward/downward		X
Gesture 2		
place elbow on a desk		
slowly rotate horizontally forearm		X
repeat rotation increasing speed	X	
repeat rotation increasing force	X	X
Gesture 3		
lift elbow at shoulder level		
slightly contract wrist upward/downward	+	X
slowly move elbow upward/downward	-	X
repeatedly contract fingertips	X	X

Table 1: The training gesture vocabulary.

extracting from the medical literature information on the biosignals produced by a varied range of physical gestures.

The EMG was translate into sound and processed into a high pitch musical sound; the MMG was processed into a low pitch one. This aimed to facilitate users in distinguishing the two sounds. The raw EMG data was first normalised, and then converted into audio rate signal. The resulting sound was a cluster of high-pitched, sparse sound grains. In order to give the EMG sound identifiable timbre characteristics, it was further processed. The processing chain included a single side band pitch shifter to lower the frequency, a fuzz distortion to produce a more homogeneous signal, a resonant filter to outline the midrange spectrum partials, and reverberation to widen the stereo field. A similar processing chain using different parameters was used to process the raw MMG sound. The pitch-shifter was used to increase the MMG frequency and thus make it more easily audible through headphones, the fuzz distortion to add textural grains, the resonant filter to make more evident the higher partials (35 Hz and 40 Hz), and the reverberation to simulate a dry room environment.

Gesture 1 exploited the different *activation* mechanisms of EMG and MMG during sustained isometric (i.e. static) contraction [8]. During isometric contractions the EMG is continuously activated, whereas the MMG is a discrete event triggered at the contraction onset and outset. In the sound mapping associated with Gesture 1, the participant could produce a sustained high-pitch sound by clenching continuously the fist, and trigger low frequency reverberated pulses by flicking the clenched fist upward and downward.

Gesture 2 was based on the *localisation* of EMG sensors [1], and the *propagation* feature of MMG [13]. By executing a gentle forearm rotation, the amplitude of the EMG activated at the anterior forearm muscle is too low to be detected by the sensor at the back of the arm (*relaxation*).

To produce a higher EMG amplitude and detect the signal, rotation speed and force need to be increased. The MMG meanwhile propagates from the anterior contracting muscle through the surrounding tissues, and is detected by the sensor even when the muscle is contracted gently. The mapping programmed for this gesture enabled the participant to produce low frequency sounds by delicately rotating the forearm, and add high-pitched sounds by increasing speed and force of the rotary contraction.

Gesture 3 exploited the lack of EMG activity during forward arm *acceleration* [7] and the MMG *propagation* feature. By lifting the elbow to shoulder level and executing a gentle acceleration on two axis (forward/backward, upward/downward) without tensing the hand, only the MMG is activated in the deltoid and biceps. From there, it propagates to the sensor location, where it is detected. At this stage, there is no EMG activation. Iterated finger grasping causes tension in the forearm, and EMG activity is triggered. The participants could use this gesture to produce a continuous low frequency sound by waving the elevated arm, and high-pitched crackles by repeatedly grasping with their fingers. Audio samples produced by the participants for each mapping have been provided for reference[4].

4. EVALUATION

We invited 5 volunteer novices (4 male, 1 female) to take part in a short, individual training session with the instrument. The sound of the EMG and MMG were diffused through headphones on two independent audio channels to facilitate the user understanding when they were controlling one modality independently of the other. The sound created by the EMG was diffused on the left channel, and the MMG sound on the right.

We verbally explained the interactive principle of the instrument by saying that two different sounds could be produced; explaining that one sound would appear on the left, and a second sound on the right. We purposely avoided mentioning the use of EMG and MMG and did not refer to two modalities, only referring to our sensor system as activated by the body.

Exploration First, the participants were allowed to explore the mapping using their own gestures for 1m30s without being given specific information on the gesture mapping. We set a three-step challenge for the participants: *a*) produce sound only from the left channel for 30 seconds; *b*) produce sound only from the right channel for 30 sec.; *c*) produce sound from both channels simultaneously for 30 sec. Timing was kept by the researcher, who signalled the end of the 30s period, so as to help the participants concentrate on the training. We refer to this phase as *exploration.* At the end of the exploration phase, we asked the participants four questions pointing to the type of gesture they performed and its outcome.

1. The type of gesture done to control the left sound
2. Its outcome
3. The type of gesture done to control the right sound
4. Its outcome

Practice Following the interview, we explained to them how to play with the mapping by using the intended designed gesture. We then asked them to perform the same 3 steps from Phase 1 with this knowledge, using the designed gesture for 1m30s . We refer to this phase as *practice.* At the end of the practice phase, we performed a second interview. We asked the participant 3 questions:

1. Difficulty of independently producing the two sounds
2. Difficulty of playing only the left channel sound (EMG)
3. Difficulty of playing only the right channel sound (MMG)
4. Enjoyment of performing these gestures

The protocol was repeated 3 times, once for each gesture-mapping pair. The goal was to understand whether this step-by-step training would help the participants to successfully play the instrument.

5. RESULTS AND DISCUSSION

In this section, we present the results of the training session, looking first at the exploration phase, and then at the practice. The results we report were extracted from the participants' interviews, and validated by analysing the related data from audio, video, and EMG/MMG recordings.

5.1 Exploration

Generally users were not able to independently control EMG or MMG signal with their own gestures. A relevant exception consisted of two participants who were able to produce an isolated MMG signals using Mapping 1. Their gestures were similar in that they executed gentle forearm horizontal movements without tensing their limbs. In this case, they unawarely exploited the propagation feature of MMG signal: by executing light forearm movement the MMG produced by the bicep propagated to the sensor location where it was captured. Given that there was no direct tension in the forearm, the EMG was not activated.

With Mapping 2 there was no user who was able to control the two signals independently. With Mapping 3 only one user was able to isolate the EMG signal for about 10 seconds. He produced strong tension in the muscle proximal to the sensor by opening the palm and contracting his fingers upward. This gesture did not produce MMG as it requires almost no force production by the posterior arm muscles (where the sensors were located), yet demands a strong and continuous tension of the whole arm, which results from continuous EMG firing.

5.2 Practice

Following the gesture instructions, most participants (4 out of 5) were able to produce isolated MMG signals with at least one of the three mappings. In Mapping 1, two users successfully produced an isolated MMG signal. In Mapping 2, in contrast with the exploration phase, two users were able to produce isolated MMG signals. In order to successfully isolate an MMG signal with this mapping one had to perform a very gentle rotation of the forearm, while keeping the elbow and the fingers in a static position; interestingly, during the exploration, most users (4 out of 5) were contracting their fingers without realising that this would trigger EMG and MMG simultaneously. In Mapping 3, only one participant could isolate the MMG. This mapping was based on the most complex gesture, for it required the separate control of two body parts (arm and shoulder). This points to a specific skill level and "bodily awareness" (as one of the participant stated) that cannot be developed in the short time provided, but requires longer training. None of the participants managed to activate isolated EMG signals in any of the mappings.

5.3 Experienced use

Although not formally studied, it is worth mentioning that, while designing the system, two of the co-authors, one having long experience with EMG-based interface, and the other having an extended practice with MMG-based interface,

[4] `http://bit.ly/11IHUDc`

managed to separate EMG with Mapping 1. This may suggest that although it is generally difficult to produce continuous arm tension without vibrating the muscles, there are factors, such as training and gesture-mapping design, that can facilitate the improvement of this skill. This indicates that the ability of controlling independently the EMG and the MMG signals is not a natural skill in non-expert players, but a skill acquired by training. Indeed, several participants remarked that they might have possibly been able to find strategies for successfully playing the sounds given more time to explore the interaction with the instrument.

5.4 Discussion

The results from the Practice phase indicate that a novice player can learn how to master independently two interrelated modalities and use therefore, a wider range of control variables than those provided by a single modality. This validates the musical adaptation we made of EMG/MMG differences noted in the biomedical literature. By refining the control over specific motor unit, a player could engage in musically compelling ways with a NIME instrument based on bi-modal muscle sensing.

Gestures based on neat contraction onset/outset (as in Mapping 1), and speed of supination/pronation gesture (as in Mapping 2) seem to be easier to understand by novice users and thus more quickly learned. More complex gestures that involve the control of multiple limbs at the same time (as in Mapping 3) proved difficult to perform for first-time users, and might be used only by players with a background in gestural performance. It might also be interesting to design gestures and mappings that invoke and exploit the simultaneous activation of EMG and MMG. If with a single gesture a performer activates two separate sonic events, then the skill to mediate between the intensities of the two modalities could represent a valuable musical and physical challenge from the viewpoint of corporeal music performance.

Finally, it should be noted that EMG and MMG sensors are subject to noisiness in the respective signals. EMG sensing is affected by several issues, including capacitance build up between the dry electrode and the skin, as well as sensor location and analog signal amplification [6]. MMG sensing suffers in turn, of a too high sensitivity that might result in the capture of other bodily sounds, such as blood flow pulsations. The filtering of the raw EMG and MMG data is therefore often needed, and choosing a given balance between raw and filtered signal is a technical and musical choice [14].

6. CONCLUSIONS

EMG and MMG signals provide a rich bandwidth of information that congruently represents a physical gesture. This information can be used to design musically compelling gestures and sound producing mappings. We created a bi-modal EMG/MMG music interface using biomedical information on the distinctions between the two signals. Experienced users and designers of the system, were able to distinguish the two modalities. We evaluated the system with novice users who initially were not able to distinguish them without instructions. After brief guided training, our users were successful in controlling the two modes of muscle sensing.

The further development of gesture-sound mappings could benefit of a quantitative analysis of gesture and audio data collected during trials. The mapping used for this training was purposely limited to facilitate distinguishing one modality with respect to the other. Future work towards a more complex musical experience could include deriving mappings from different EMG and MMG gesture representations through the use of machine learning methods.

7. ACKNOWLEDGMENTS

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Understanding Gesture Expressivity through Muscle Sensing

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Expressivity is a visceral capacity of the human body. To understand what makes a gesture expressive, we need to consider not only its spatial placement and orientation but also its dynamics and the mechanisms enacting them. We start by defining gesture and gesture expressivity, and then we present fundamental aspects of muscle activity and ways to capture information through electromyography and mechanomyography. We present pilot studies that inspect the ability of users to control spatial and temporal variations of 2D shapes and that use muscle sensing to assess expressive information in gesture execution beyond space and time. This leads us to the design of a study that explores the notion of gesture power in terms of control and sensing. Results give insights to interaction designers to go beyond simplistic gestural interaction, towards the design of interactions that draw on nuances of expressive gesture.

Categories and Subject Descriptors: [**Human-Centered Computing**]: Gestural Input

General Terms: Human Factors

Additional Key Words and Phrases: Gesture, expressivity, muscle sensing, electromyogram, mechanomyogram, feature extraction, experimental study

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1. INTRODUCTION

Body movements are a powerful medium for nonverbal interaction, particularly through gesture. Gestures are increasingly exploited in human-machine interaction for workplace, leisure, and creative interfaces. Whereas human-human interaction involves rich and complex gesticulation, gestures captured for human-computer interaction (HCI) on consumer devices such as touchscreens, depth camera video controllers, and smartphone rotation sensors remain relatively simplistic, consisting mostly of simple postures, 2D shapes, and movement primitives. Similarly, whereas human interaction relies on gestural nuance, gestures in HCI often discard or avoid nuance through techniques of invariance for the sake of intertrial consistency and interuser generalisability. We present an approach that conceives of variation in gesture as a way of understating expression and expressivity, describing techniques using physiological interfaces to explore the use of gesture variation in HCI. In this way, we present techniques to extend simple gesture interaction towards more expressive, continuous interaction.

Human limb gesture is nuanced in a number of different ways. One can change how fast one performs a gesture, how much space the gesture takes, or how tense the body is while executing the gesture. These variations combine and contribute to

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convey the expressive content of a gesture. There exists a significant challenge to capture gestural nuance through sensors and interactive systems. Position-based representation of motion has been used in most prior work; however, one promising approach is to capture dynamic gesture through physiological signals that are rich in information on qualitative aspects of a gesture. Movement qualities as a new paradigm for interaction has been of interest to recent works in the HCI community [Fdili Alaoui et al. 2012; Fdili Alaoui 2012; Mentis and Johansson 2013], yet these qualities have not yet been broached through physiological sensing. Physiological sensors, ranging from brain-computer interfaces to biometric readers to muscle sensors, have become increasingly accessible with low-cost electronics, creating the potential for broad consumer applications [Fairclough 2009; Silva et al. 2014]. Muscle biosensing has certain advantages to nonphysiological motion sensing, such as fiducial-based motion capture or accelerometer sensing. Rather than report on the resulting physical output of a gesture, physiological sensing of muscle activity reports on the intention and activation of the body to create a gesture.

Muscle sensing has been used in a range of application areas, such as biomedical engineering, HCI, and computer music. In the field of biomedical engineering, muscle activation and articulation have been exploited to control prosthetic limb systems [Saridis and Gootee 1982; Silva et al. 2005; Castellini and van der Smagt 2009; Farina et al. 2014]. Because muscle sensing provides insights not only on volitional control but also on sensorimotor control strategies, it has been applied to the monitoring of muscle fatigue [Barry et al. 1992; Tarata 2003], the evaluation of muscle functions and responses to stimuli [Beck et al. 2004; Kuriki and Azevedo 2012], and neurophysiological assessment [Orizio et al. 1992, 1997].

In the field of HCI, the use of muscle-based interfaces has been motivated by the need to interact with a nonphysical interface [Putnam and Knapp 1993], a strategy that has been shown to be relevant in the case of users with disabilities [Barreto et al. 2000], or in the context of pervasive computing where wearable devices are too small to embed physical interfaces such as joysticks or keyboards [Wheeler and Jorgensen 2003]. Other interesting use cases include enabling interaction without any visible or audible user actions [Costanza et al. 2005, 2007; Schultz and Wand 2010], or while the hands are busy in other tasks, allowing forms of always-available interaction [Saponas et al. 2009, 2010].

Finally, muscle interfaces have been used in the field of computer music to allow for the control of sound synthesis directly from muscle tension [Tanaka and Knapp 2002] and to sonify the subtle variations in the articulation of a performer's body kinetic energy [Donnarumma 2012].

In this article, we present ways in which gesture expressivity is suitable for the design of gesture-based interaction. Looking at gesture expressivity as deliberate variation of gesture, our goal is to understand if such an approach is possible as a motor task. In particular, the emphasis will be put on dynamic aspects of a gesture detected by muscle sensing. This insight is fundamental to interaction designers in imagining scenarios to make expressive use of limb gesture.

The article is structured as follows. First we give working definitions of gesture and expressivity in gesture performance, introducing *dimensions of expressivity* to represent gesture variations. We then present different muscle activation mechanisms to arrive a bimodal approach using electromyogram (EMG) and mechanomyogram (MMG) signals, focusing on the gestural dimension *power* in the activation of forearm muscles. We then present a series of studies that explore (1) the use of gesture temporal and spatial variations for control and (2) the use of muscle sensing as an interface for musical interaction. This leads to an experiment in which we explore the deliberate control of power variations of gesture. We analyse the results and discuss their implications for interaction design.

2. GESTURE EXPRESSIVITY

In this section, we establish working definitions of gesture and the notion of gesture expressivity. We present a number of dimensions including temporal, geometrical, and dynamical variations in gesture execution. Among these dimensions, we focus on a dynamic dimension called *power*, which involves variation of the intensity of gesture.

2.1. Gesture: A Working Definition

Gesture is an intricate notion used across many different research fields. In social psychology, Efron [1941], in his seminal work, relates gesture style to a cultural basis. Gesture in HCI can refer to something as simple as a shape drawn on a tactile surface, whereas gesture as used in character animation of embodied conversational agents (ECAs) might refer to body movement accompanying speech and utterances. In music composition, a musical gesture can refer to the melodic progression in a score, whereas in musical performance, it can designate deliberate and nondeliberate movements of an instrumentalist [Jensenius 2014]. Finally, Mulder [1996] differentiates posture and gesture, where posture is seen as static and gesture is dynamic.

One generic definition of gesture in the HCI context comes from Kurtenbach and Hulteen [1990], who define *gesture* as "a movement of the body that contains information". In psychological study of nonverbal communication, Kendon [2004] writes: "Gesture [. . .] is a label for actions that have the features of manifest deliberate expressiveness". (It should be noted that here Kendon does not intend deliberateness as in the control of the expression but rather as in the voluntary act of expressing a meaning.)

From those different definitions, we extract a series of keywords that characterise our understanding of gesture: *movement*, *dynamic*, *information*, and *deliberate expressivity*. A recomposed definition of gesture can be stated as "a gesture is a dynamic movement of the body (or part of the body) that contains information in the sense of deliberate expression." We can unwrap this definition as follows. Deliberateness in the movement differentiates gesture from simple movement by inducing an intentional will of expressing thought, feeling, or meaning. Interestingly, deliberate expressivity refers to the capacity of varying the gesture execution intentionally. We now define gesture expressivity and its constitutive components.

2.2. Gesture Expressivity

Expressivity is a notion used to describe the articulation of information in genetics and computer science. In genetics, it refers to the variations in the observable characteristics and traits among individuals with the same genotype [Miko 2008]. In computer science, expressivity (or expressive power) has been used in programming language theory and refers to a measure of the range of ideas expressible in a given programming language [Felleisen 1991]. Thus, expressivity involves the idea of potential variation instantiated by the consistent constitutive structure.

In HCI-related fields, examining and designing medium for allowing expressivity is part of the core research in music technology, and more precisely in the New Interfaces for Musical Expression (NIME)[1] community (e.g., see the works by Jordà [2005] and Dobrian and Koppelman [2006]). Expression in interactive music is understood to be musical expression, connecting it to the art of all musical performance. For example, in instrumental performance of classical music, musical expression is related directly to variation as reinterpretation of an existing piece. One pianist may interpret an established repertoire composition differently than another pianist: we can think of this

[1]http://www.nime.org.

as interuser variation [Palmer 1997]. Or, a single performer may interpret the same composition differently in different performances: this may depend on the performer's emotional or psychological state at the moment of a concert, the feedback the performer gets back from the audience, or through changes of context such as the size of the performance venue. To accommodate these contextual changes, an instrumentalist may vary the dynamics (soft and loud moments) or tempo (speed) of the music and performs different gesture to execute these musical changes. A fast passage may work better in a smaller, intimate recital hall, whereas the reverberant nature of a large concert hall may require more emphatic playing with broader gestures to communicate musical phrasing to an audience farther away from the stage. In this way, musical performance serves as a useful example of understanding expressive gestural interaction, not just as an intuitive and emotional but as volitional, contextual input to interactive systems that may facilitate human-human communication.

Another active field in the investigation of gesture expressivity concerns ECAs. Gesture expressivity is seen as *how* a gesture is performed [Pelachaud 2009]—in other words, the potential variations in its execution. Variation in gesture performance can exist across different users or within a single user in multiple iterations recreating the same gesture primitive. The artefact of variability can occur due to a lack of skill to perform it or due to noise in the motor system. This differs from variation as the deliberate intention to nuance gesture execution to modulate its meaning. Hence, we propose the term *gesture expressivity* as deliberate and meaningful variation in the execution of a gesture.

2.3. Dimensions of Expressivity

Expressivity varies across different users of an interactive system or within a single user in multiple iterations of the same gesture primitive. The dimensions across which expressivity varies have been initially studied in fields such as experimental psychology, then applied in computer graphics animation, computer-mediated communication, and the performing arts.

Wallbott [1998] proposes that expressiveness can be characterised by movement qualities: *movement activity*, *expansiveness*, and *movement dynamic*. These movement qualities can be the source of expressiveness in "the type of emotion encoded, the specific ability of the encoder, and specific, discriminative movement indicators for certain emotions versus indicators of the general intensity of the emotional experience" (p. 892). These ideas have been applied in design, digital media performance, and the generation of expressive animated characters using ECA [Cassell 2000].

Camurri et al. [2004] have used overall activation (quantity of motion) to define interaction between a performer and digital media. Laban Movement Analysis (LMA) [Laban 1963], originally used as a method for observing, describing, notating, and interpreting human movement to enhance communication and expression in everyday and workaday life, has also been applied to understand movement qualities in terms of physical effort. Chi et al. [2000] use LMA to derive dimensions of expressiveness to be applied in the synthesis of expressive movements for animated characters.

Discussing the generation of expressive ECAs, Pelachaud [2009] maintains that when analysing expressiveness, it is important to consider that "behaviours encode content information (the 'What' is being communicated) and expressive information (the 'How' it is being communicated)." Thus, to characterise movement expressiveness, Pelachaud developed a model for the generation of ECA based on six dimensions:

—*Spatial extent*: Quantity of space occupied by the arm
—*Temporal extent*: Movement velocity
—*Fluidity*: Continuity in successive movements (jerky vs. smooth movements)

—*Power*: Dynamism (weak vs. strong)
—*Overall activation*: quantity of movement on a channel
—*Repetition*: Repetition of the stroke of a movement.

Among these dimensions, gesture power offers a novel way to consider expressive interaction going beyond geometrical and temporal descriptions of gesture, following recent studies on movement qualities in interaction [Fdili Alaoui et al. 2012]. According to Pelachaud [2009], power is related to "the degree of acceleration of body parts and corresponds to the dimension movement dynamics/energy/power defined by Wallbott" (p. 4). The hypothesis underpinning the research presented here is that gesture intensity, or power, is an expressive dimension that is suitable for tracking through physiological sensing, particularly muscle sensing. The study described in this article looks at users' ability to vary different aspects of gesture power captured by muscle sensors. The emphasis is not on the dynamic aspects of the final limb movement but on the dynamic muscular aspects of user intention that result in gesture that can be expressively modulated through variation of exertion, tension, and force.

3. DESCRIBING GESTURE THROUGH MUSCLE SENSING

Human limb gesture is initiated by the activation of muscle groups to generate limb movement. Sensing muscle activity allows us to detect the intention of the subject to create a gesture and glean its dynamic varying characteristics. In this section, we describe the physiological mechanisms involved in muscle activation and the related biosignals: the electromyogram (EMG)_ and the mechanomyogram (MMG). The characteristics of both biosignals are illustrated later in Table I. This section draws on biomedical literature [Kaniusas 2012] with the aim to help the reader better understand the further choices in sensors and data analysis.

Voluntary muscle control is part of the somatic nervous system (SNS), which is part of the peripheral nervous system. The SNS operates through two different kinds of nerves: the *afferent* nerves, which handle the transport of signals from sensory receptors to the central nervous system (CNS), and *efferent* nerves, which transport signals from the CNS to the muscles. It is through the efferent nerves that muscle activation takes place (Figure 1).

At the onset of stimulus integration, the SNS sends an electrical voltage, an *action potential*, to the motor neurons. When the action potential reaches the end plate of a neuron, it is passed to the muscles by the neuromuscular synapse. The neuromuscular synapse is a junction that innervates the skeletal muscle cells and is able to send the electrical potential throughout the muscle to reach all muscle fibres. A network of neuromuscular synapse and muscle fibres is known as a *motor unit* (MU). At this point, the motor unit action potential (MUAP) causes an all-or-none contraction of the muscle fibres. A gradation in muscle contraction is achieved by a changing number of MUAPs firing and differing, stochastic, frequencies.

By positioning surface electrodes on the skin above a muscle group, it is possible to register the MUAP as an electrical voltage. The resulting signal is recorded as an EMG. This is the algebraic sum of all the motor unit action potentials (MUAPs) at a specific point in time. It is a stochastic signal because any number of MUAP pulses is triggered asynchronously.

Muscle contraction is the product of a bioelectrical effect but also results in a biomechanical effect. When the muscle cells contract, they produce a mechanical vibration, known as muscle twitch, which lasts about 10 to 100 ms. The mechanical vibration of the muscle cells causes a subsequent mechanical contraction of the whole muscle that, by means of its oscillation, can be picked up as an acoustic signal. Using a microphone on the skin above a muscle group, it is possible to record a mechanical signal produced

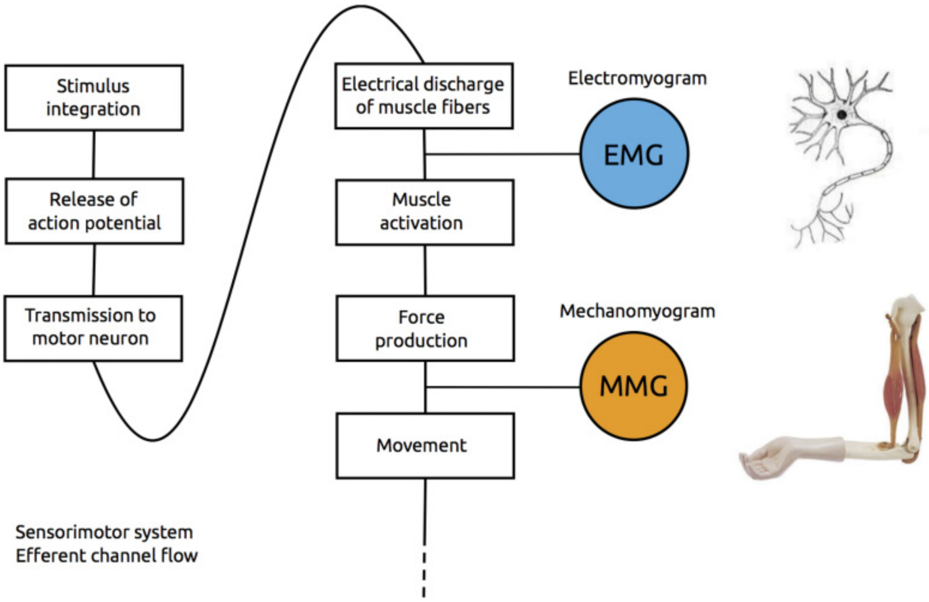

Fig. 1. The SNS. Detail of the efferent nerve information flow illustrating the muscle activation process. The blue and orange circles indicate the EMG and MMG signals, respectively. The location of the circles illustrates the different stages of the activation process at which the signals are captured (assuming noninvasive recording methods using on-the-person stationary or ambulatory sensors [Silva et al. 2013]).

Table I. EMG and MMG Description

	EMG	MMG
Type	Electrical	Mechanical
Origin	Neurons firing	Muscle tissue vibration
Description of	Muscle activation	Muscle contraction force
Frequency range	0–500Hz	0–45Hz
Sensor	Wet/dry electrodes	Wideband microphones
Skin contact	Yes	No
Sensitivity area	Local	Broad (due to propagation)

by the perturbation of the limb surface. This signal is known as an MMG. Table I reports a summarized description of both sensing modalities.

Whereas the EMG carries information on the neural trigger that activates muscle contraction (i.e., it informs us of the deliberate intention of performing a gesture), the MMG bears information on the mechanical contraction of the muscle tissues, giving access to the physical effort that shapes the gesture. In this way, the two signals provide complementary information on muscle activity [Tarata 2009], potentially providing important information on the expressive articulation of a gesture.

4. CONTROL AND SENSING IN GESTURE EXPRESSIVITY: PILOT STUDIES

In this section, we report two pilot studies that deal with the control and sensing of gesture expressivity. The first study presents the control of variations applied to surface gestures. The second looks at gesture expressivity using muscle sensing.

4.1. Pilot 1: Control of Gesture Spatial and Temporal Extent

First, we conducted a pilot experiment to study gesture variation as an expressive vector for interaction independent of physiological sensing. We looked at the execution of 2D finger gestures on a tactile interface to study whether they can be consciously controlled by users and to validate our adaptation-based machine learning algorithm as a means to track gesture variation [Caramiaux et al. 2013].

The study was divided into two parts. Part 1 aimed to understand whether users can control certain temporal and spatial gestural characteristics and if that control depends on the vocabulary of gesture primitives. Variation of gesture characteristics includes changes in speed (slower and faster) and in size or orientation (geometric changes in space). The gesture vocabulary was comprised of 12 2D shapes based on Wobbrock's work on tactile interaction [Wobbrock et al. 2009]. In part 2, we used a machine learning technique based on particle filtering previously used in musical control [Caramiaux et al. 2014] to simultaneously recognise and measure gesture variation in time and space. Gesture variation as tracked by the machine learning algorithm was exploited directly in an end-user graphics effects programme, validating the potential of expressive input to an interactive software system. Meanwhile, results from part 1 on the control of the gesture temporal and spatial variations provide important insight on users' ability to control gesture that can be applied to physiological interfaces:

(1) Multiple gesture characteristics can be varied independently in slower gestures (change in size and speed).
(2) This is independent of the gesture considered.
(3) When performing the gesture faster, there is a cognitive shift in motor planning from nonballistic to ballistic motion.

These findings provide insights useful to interaction designers wishing to create continuous interaction scenarios based on variation of gesture characteristics. However, the 2D gestures, while varying in time and space, offered an oversimplified model for expressivity based on gesture variation. First, the gesture vocabulary, based on shapes, constrained interaction potential. Second, the touchscreen interaction limited variation to size, speed, and rotation, and did not allow dimensions of expressivity such as power (as defined by Pelachaud [2009]).

Let us illustrate this statement by an example. A gesture such as clenching a fist can be articulated with greatly different power while looking apparently static. The deliberate variations of a gesture like this invoking changes in speed or intensity are likely characterised by physiological mechanisms that would not be picked up by position or motion sensing.

4.2. Pilot 2: Sensing Expressive Gestures

We next conducted a study looking at dimensions of gesture expressivity using muscle sensing. In part 1, we introduced MMG sensing alongside spatial motion capture and inertial accelerometer sensing in a multimodal configuration. In part 2, we used EMG and MMG in a bimodal configuration to look at the ways in which complementarities of these signals could be exploited in end-user interaction scenarios.

4.2.1. Part 1. In the first part, we aimed at examining the complementary information about gesture expressivity where the gesture was captured through different sensing modalities. To do so, we defined a set of gestures drawing on movements of a performer in a piece of contemporary music (the set of gestures is reported in Appendix). Each gesture was captured by MMG muscle sensors (placed on the forearms), accelerometers (also placed on the forearms), and full-body motion capture [Donnarumma et al. 2013a].

By looking at both physiological and spatial data recorded from the gestures executed with high and low force, we found the following:

(1) Physiological and spatial modalities complemented one another.
(2) The physiological modality only could sense the preparatory activity taking place before the actual gesture.
(3) Variation of gesture characteristics (such as power and speed) were detected by modulation of signal in different modalities.

These findings showed that the ability of users to independently vary different dimensions of expressivity in the simple gestures from Pilot 1 also applied to free space gestures and a range of more sophisticated sensing modalities including muscle sensing.

4.2.2. Part 2. In part 2, we introduced EMG sensing in combination with MMG and used them together as bimodal input to an interactive sonification system [Donnarumma et al. 2013b]. We looked at the ability of nonexperts to activate and articulate MMG and EMG separately using a given gesture vocabulary. The gesture vocabulary was designed by drawing on complementarity of MMG and EMG described in the biomedical literature [Jobe et al. 1983; Madeleine et al. 2001; Day 2002; Silva et al. 2004]. We sonified in real time the MMG and EMG signals as a form of feedback to the user, enabling them to understand when each signal was produced. Offline data analysis of the recorded EMG and MMG signals enabled us to understand the physical dynamics behind the users' control of different aspects of their muscle activity. The results showed the following:

(1) After a short training session, nonexpert users were able to deliberately vary the degree of activation of EMG and MMG signals independently.
(2) User-specific variations on the gesture articulation yielded different activity at the physiological level.

5. STUDY ON THE CONTROL AND SENSING OF GESTURE POWER

We built on the insight gained from the two pilot studies to design an experiment looking at the elements underlying variations of gesture power and its characterization in bimodal EMG/MMG signal data. The methodology consists of asking participants to perform several trials of a gesture, taken from a predefined vocabulary, and variations of this gesture in power, size, and speed. As such, we aim to understand variations in power as a motor task. A set of signal features are computed to elucidate the effect of variations and gestures on the potential control of power. The quantitative analysis is complemented by a questionnaire collecting subjective measures of users' notion of power.

5.1. Gesture Vocabulary

The gesture vocabulary comprises six gestures involving two types of interactions (surface and free space) and an increasing level of complexity (Figure 2):

—Gesture 1 (*Surface Rotation*): Two fingers on a flat surface, 180 degrees rotation, counterclockwise (clockwise for left-handed). *Example*: Rotate an image on a touchscreen.
—Gesture 2 (*Surface Line*): One finger on a flat surface, move along an horizontal, straight line from point A to point B, outward. *Example*: Drag a picture on a touchscreen.

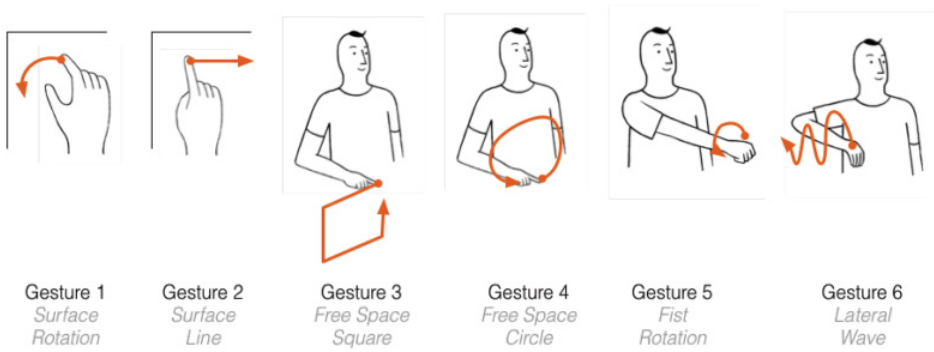

Fig. 2. Gesture vocabulary considered in the study.

—Gesture 3 (*Free Space Square*): Raise arm perpendicular to the body and draw a square with the index finger, start from the up/left corner, move right, clockwise (counterclockwise for left-handed). *Example*: Next track.
—Gesture 4 (*Free Space Circle*): Rise the arm perpendicular to the body and draw a circle with the index finger, start from the bottom/center point, move counterclockwise (clockwise for left-handed). *Example*: Fast forward shuffle.
—Gesture 5 (*Fist Rotation*): Rise the arm straight perpendicular to the body, close the fist, move the fist in a circle three times, start left, move counterclockwise, (clockwise for left-handed). *Example*: Play higher notes.
—Gesture 6 (*Lateral Wave*): Rise the elbow at the shoulder level, bend the forearm at 90 degrees, move wrist and forearm downward and upward three times while opening the arm outwards. *Example*: Play louder.

5.2. Gesture Variations

Using the preceding gesture vocabulary, we defined a set of variations to be applied to each gesture. We sought to design tasks whereby participants would be invoked to vary the intensity, or power, of each gesture on its own or in combination with related dimensions of expressivity such as gesture size. In doing so, we wanted to inspect the relationship, in spatial and temporal extent, between power and other dimensions of expressivity (as defined in Section 2.3). We thus devised a set of seven variations using combinations of dimensions as follows:

—Variation 1: Bigger
—Variation 2: Faster
—Variation 3: More Powerful
—Variation 4: Bigger and Faster
—Variation 5: Bigger and More Powerful
—Variation 6: Faster and More Powerful
—Variation 7: Bigger, Faster and More Powerful

We chose to constrain the variation in one direction (i.e., increasing speed, power, or size) to avoid variability due to the participant's choice of variation direction.

5.3. Procedure

The experiment was conducted according to the following procedure. The experimenter positions the EMG and MMG sensors on the participant's dominant arm. The sensors are positioned at the lower interior part of the forearm, at the midpoint of the muscle, as illustrated in Figure 3.

Fig. 3. Experimental setup. Left: EMG and MMG sensors placed on the forearm. Middle: EMG and MMG sensors placed on the forearm (close view). Right: The EMG (left) and MMG (right) sensors.

At this point, the experimenter introduces the study protocol. A gesture from the vocabulary is chosen randomly. The experimenter gives a visual example of the gesture and describes the typical scenario in which the gesture might be performed. The participant is given the chance to rehearse the gesture until he or she feels ready.

The participant performs the gesture and records data by pressing a start button with his free arm. Three trials of the gesture are recorded. Following the three trials, the participant is asked to perform variations on that gesture (*bigger*, *faster*, *more power* and the combinations described in Section 5.2). The order of variations prompted is randomly selected by the software. Three trials are recorded for each variation.

The experimenter then asks the participant how easy was to perform the variation on size, speed, and power. The participant replies with a rate in the 1 to 5 range, where 5 is very easy. In addition, the participant is asked to briefly explain the answer. The procedure is then repeated for each gesture in the vocabulary.

At the end of the session, each participant is asked to fill out a questionnaire that includes demographic data, along with questions regarding the use of a gestural interface in her everyday routine, as well as her knowledge level on the topic. Further questions address the participant's experience during the execution of the gestures and the possible real-world applications that she could imagine of the gesture variations we propose.

For this study, we recruited 12 participants (8 women, 4 men) ranging in age between 21 and 43 years with a mean age of 29.9 years (standard deviation (SD) = 6.5). Each subject took an individual 45-minute session and was recompensed by a nominal fee for participation. For each participant, we collected 3 trials for each original gesture (i.e., without variations), leading to $12 \times 3 \times 6 = 216$ trials. Then 3 trials for each gesture were performed considering each variation, leading to $12 \times 3 \times 6 \times 7 = 1{,}512$ trials.

5.4. Acquisition

Gesture data was recorded by means of a bimodal sensing system with two input channels: one EMG input and one MMG input. We first describe the acquisition system for the EMG and then describe the system for the MMG. Given the HCI target application scenarios, we chose not to use high-end medical equipment but sought to create a robust configuration of off-the-shelf components. Criteria included a practical enough number of sensing channels, convenient and noninvasive sensor placement on the user, and modest size and cost to be able to imagine potential incorporation of such sensors into future consumer interactive products.

After initial trials using different wet gel and dry electrodes, and prompted by the fact that gel and dry electrodes have been shown to perform similarly [Silva et al. 2013], we used the Infusion Systems BioFlex with active dry electrode sensors[2] to

[2]http://infusionsystems.com/catalog/product_info.php/products_id/199.

capture the EMG signal. The BioFlex offers (1) an on-board hardware calibration system to increase trial-to-trial reliability and (2) low baseline noise of the sensor circuit and cable transmission. The EMG signal was transmitted from the BioFlex as an electrical voltage. The signal is acquired through an Olimex board,[3] a shield for the Arduino[4] circuit board, at a sampling rate of 100Hz. The Bioflex and Olimex both provide analogue preamplification and signal conditioning. The signal is initially amplified and filtered with a one-pole high-pass filter with frequency cutoff (*fc*) at 0.16Hz, then amplified again and passed through a third-order Besselworth filter with *fc* at 40Hz.

We used the Xth Sense system to capture the MMG signal. The Xth Sense is comprised of an armband embedded with a wideband electret condenser microphone. This is encased within a silicon mold the prevents contact with the skin. The silicon mold isolates the microphone from external noise and electrical interferences and amplifies the skin vibration before it reaches the microphone. The design is inspired by the work of Silva and Chau [2003] in the design of control systems for prosthetics. The MMG signal was transmitted from the Xth Sense as an analog sound signal through an audio cable. The signal was then acquired through an external sound card that digitised it at a sampling rate of 44,100Hz and sent it to the recording software. The signal was not amplified. A high-pass filter with an *fc* of 1Hz was used with both signals to bypass artefacts created by the movement of the whole arm [Day 2002].

5.5. Feature Extraction

We selected a set of features to be extracted and analysed from both the EMG and MMG signals. In the prosthesis control literature, the predominant signal feature is its amplitude. Here we propose to compute additional features, namely frequency-domain features. The features are computed according to the workflow illustrated in Figure 4. In the following, the features that will be used are signal amplitudes, signal temporal zero crossings, and spectral centroids.

Signal amplitudes (time-domain feature). One of the most important features to be computed on both muscle biosignals is the amplitude of the signal along time. Amplitude computed on the EMG and MMG signals has been shown to be related to the force exerted while executing the gesture (i.e., see Perry-Rana et al. [2002]).

Amplitude estimation of the EMG signal has received a great attention and has led to several studies in biomedical or bioengineering literature [Hofmann 2014]. As suggested by the author, we chose to use a Bayesian filter based on the previous work of Sanger [2007]. For amplitude estimation of the MMG signal, we used a common estimator used in audio analysis: the root mean square (RMS) estimator.

Zero crossings (time-domain feature). The number of zero crossings in the signal is linked to the frequency of the signal. For low-frequency components, where the Fourier transform might lack resolution, this feature can be more informative. On the other hand, the feature can be used to discriminate signal from noise [Peeters 2004].

Spectral centroid. The spectral centroid is the mean frequency value in a signal chunk. We use the same method for both signals. The signal is windowed by a Hann window of $\log 2(F_s)$ samples, where F_s is the sampling rate. In other words, the window has a temporal length of about 1sec. The overlap is 1% of the size of the window size—that is, about 10msec. We use a Fourier analysis with the same number of bins than the number of samples in the windowed signal. The centroid is computed then on the spectrum.

[3]https://www.olimex.com/Products/Duino/Shields/SHIELD-EKG-EMG/.
[4]http://arduino.cc.

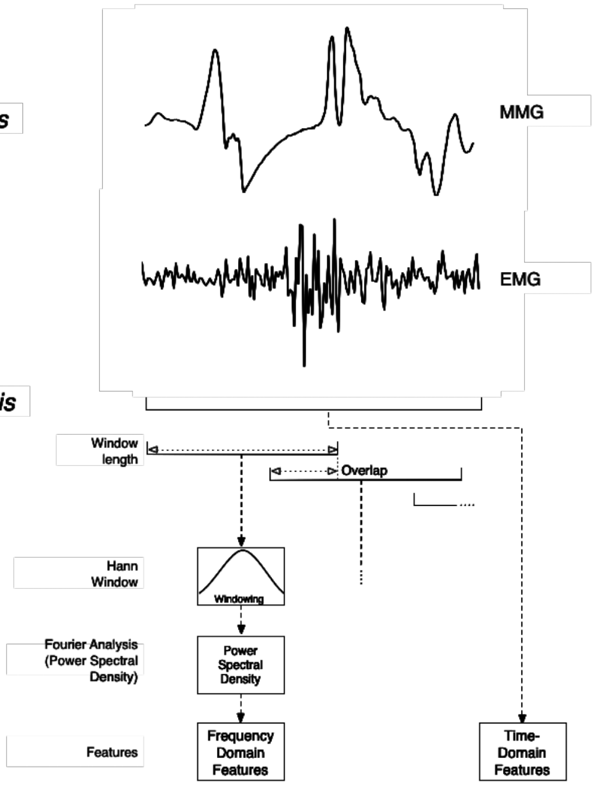

Fig. 4. The feature extraction dataflow.

6. RESULTS

In this section, we report on results from the study. First, we report on subjective measures assessing the subjects' understanding of the power dimension and the perceived difficulty of the tasks proposed. Then, we look at the data to understand how participants actually vary what they think of as power through objective measures on the signals' features. Finally, we use these measures to investigate relationships between power and the other two dimensions: size and speed.

6.1. Perceived Difficulty and Understanding of the Tasks

Participants were asked to rate between 1 and 5 the difficulty in performing variations in each dimension for each gesture (where 1 is very difficult and 5 is very easy). Results are reported in Figure 5. We analyse the difference between the mean scores across variations on gestures by using a Student's t-test between pairs of mean scores (α set to 0.05).

The test reveals that variations along each dimension have the same difficulty for gestures 1 and 2. The task of varying a dimension is globally easy for gesture 1 (mean score of 3.6, SD = 1.1) and very easy for gesture 2 (mean score of 4.7, SD = 0.5). The test shows that it is more difficult to perform gestures 3, 4, and 6 with more power than performing it bigger (or even faster for gestures 3 and 4). Participants explained

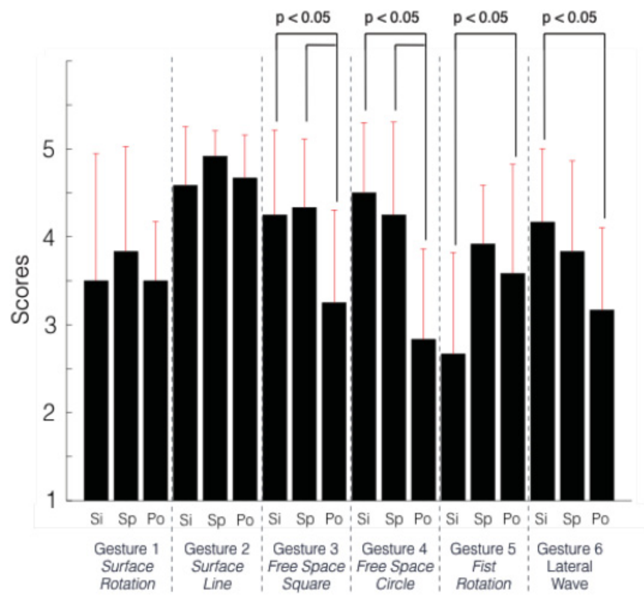

Fig. 5. Subjective ratings of the participants on the easiness of performing variations on each gesture. Scores are given between 1 and 5, where 5 is very easy and 1 is very difficult. Si (resp. Sp, Po) denotes the variation in size (resp., speed, power).

their ratings related to the task of varying power by mentioning aspects related to the following:

—the *feedback*, by mentioning the absence of haptic feedback ("there [was] no resistance," Participant 11);
—the *gesture* itself ("gesture [is] not fluid," Participant 10), whereas size and speed are easier since there is "less limit in space" (Participant 9) and it is "a bit easier because of the breakpoints" (Participant 8); and
—the *variation*, by observing that they had to be more focused on other variations, like the size to respect the task of performing the given gesture ("I had to keep control to make the shape," Participant 6).

Participants found it more difficult to perform gesture 5 bigger than faster. Here, the difficulty of applying a change in size is related to the gesture itself and its inherent biomechanical constraints ("too limited [in space]," Participant 7; "a more constraint movement, awkward," Participant 3; "limit in the movement itself," Participant 10) that impacts the relation with the gesture reference ("default gesture was already at the max," Participant 12).

The difficulty of the task seems to be related to the perceived notion of power. This brings us to analyse how participants understood this expressive dimension. Participants were asked to describe the power dimension of a physical gesture using their own words. From the questionnaire, we extract the words used by the participants to describe the characteristics of *Power*. We report the analysis in Table II.

The analysis shows that participants used descriptions that can be gathered into three main categories:

(1) Power intended as *pressure* or physical force exerted against a surface
(2) Power as physical *tension* or strain exerted in the absence of an object to manipulate

Table II. Subjective Descriptions of "Power" as Extracted from the Questionnaires

Description	Number of Participants	Quote Example
Pressure	6	"In the case of the tactile surface [I changed] pressure" (P1)
Tension	4	"Power [. . .] seemed to be tension in the arm or wrist" (P3)
Intensity	2	"[A] combination of intensity and intentionality" (P10)
Speed	2	"[W]asn't always sure what doing the gesture with more power meant, or if it just sped it up" (P09)
Effort	2	"[I]ncreased effort" (P11)
Energy	1	"I was using more energy to do the same movement" (P5)
More stress	1	"[M]ore stress in muscles" (P2)
Forceful	1	"More forceful" (P4)

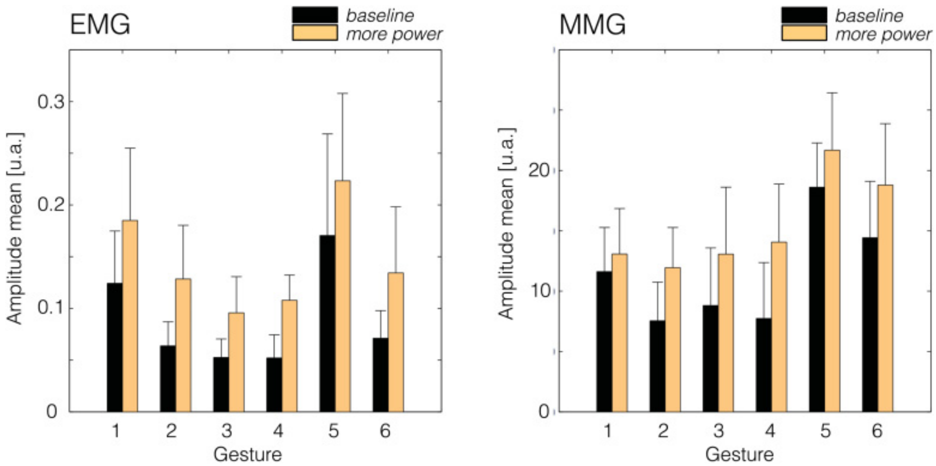

Fig. 6. Power estimations for both EMG (left) and MMG (right) averaged across participants and trials. Black bars show the mean amplitudes when no variation is applied (baseline), and orange bars report mean amplitudes when more power is exerted.

(3) Power as energy of the physical gesture, intended as *kinetic energy* resulting from motion.

In the following sections, we first inspect how these interpretations of power (pressure, tension, and kinetic energy) are illustrated through physiological features computed from the EMG and MMG signals. We then analyse how the extracted factors (feedback, gesture, and variation) affected the variations of power by the participants.

6.2. Objective Measure of Power as Tension, Pressure, and Kinetic Energy

We first inspect how the muscle signal amplitudes are linked to the variations of power in gesture execution, considering every gesture from the vocabulary. We compare the averaged amplitudes of both signals computed for each gesture under two conditions: baseline (gesture performed with no variation) and more power. Figure 6 illustrates the results by reporting both modalities (EMG on the left, MMG on the right) and the averaged amplitudes across participants and trials for both conditions "baseline" (black bars in the figure) and "more power" (orange bars).

A repeated-measure analysis of variance (ANOVA) is performed to investigate the effect of both factors GESTURE (the six gestures of the vocabulary) and VARIATION (two variations here: baseline and more power) on the signals' amplitudes. There is a significant

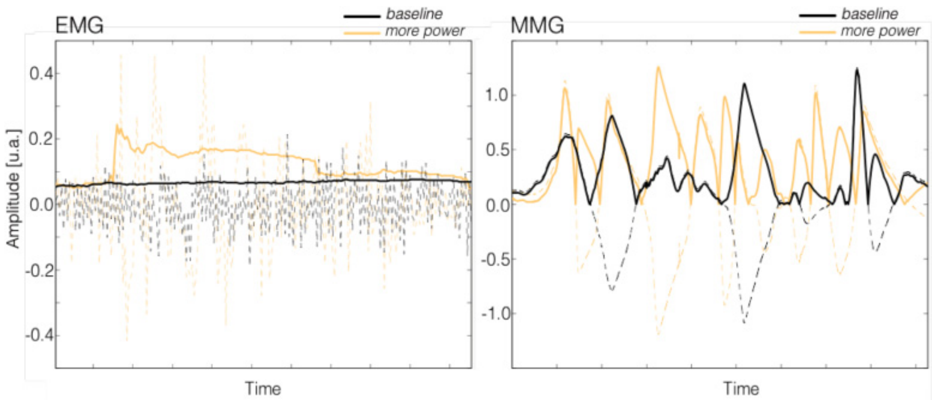

Fig. 7. Examples of EMG signals (left, dashed lines) and MMG signals (right, dashed lines) for gesture 3 (performed by Participant 5) are reported for two conditions: baseline (black) and more power (orange). The amplitude estimations are reported on top of the signals.

effect of Gesture on the EMG amplitudes, $F(5, 132) = 11.7$, $p = 0.0$ (partial η^2 is 0.30), and on the MMG amplitudes, $F(5, 132) = 10.3$, $p = 0.0$ (partial η^2 is 0.28). Moreover, there is a significant effect of Variation on EMG amplitudes, $F(1, 132) = 24.3$, $p = 0.0$ (partial η^2 is 0.16), and MMG amplitudes, $F(1, 132) = 14.7$, $p = 0.0$ (partial η^2 is 0.10). There is no interaction between the factors Gesture and Variation in both cases of EMG and MMG amplitudes.

A post hoc analysis using a Tukey's Honestly Significant Difference (HSD) performed for each gesture reveals that the EMG amplitudes significantly increase with the condition "more power" compared to the baseline ($p < 0.05$), except for gesture 5. Similarly, MMG amplitudes significantly increase, except for the gestures 1 and 5, if more power applied ($p < 0.05$).

Based on these results, performing gestures with more power leads to more muscle tension as shown in both EMG and MMG amplitude estimations. Gesture 5 (Fist Rotation) is a particular case, because the gesture itself, without variation, already requires tension in the forearm's muscles. MMG amplitudes, however, do not show significant change in amplitude for gesture 1 (surface rotation). For this gesture, participants considered power to be pressure exerted on this surface (see Section 6.1). Therefore, the EMG amplitude feature is a good candidate to capture pressure and force exerted on a surface.

Although average amplitudes of EMG and MMG both increase when applying more power, the amplitude increase is not of the same nature across the two modalities. Figure 7 illustrates this with an example.

On the left, two EMG signals are reported: the dashed black line is the signal for gesture 3 (free space square) when no variation is applied, and the dashed orange line is the EMG signal for the same gesture performed with more power. The solid lines are the amplitudes computed from the signals. On the right, two MMG signals are also reported with their computed amplitudes for the same gesture. One can observe that EMG amplitude increases globally, whereas the MMG amplitude has more transients. This illustrates that the EMG is a stochastic signal revealing the number of MUs solicited, whereas MMG refers to the resulting dynamics of muscles. This confirms that EMG amplitude is more suitable to capture pressure than MMG amplitude.

To analyse the change in dynamics related to the kinetic energy in the movement (changes in acceleration), we compute the number of zero crossings on the signals and

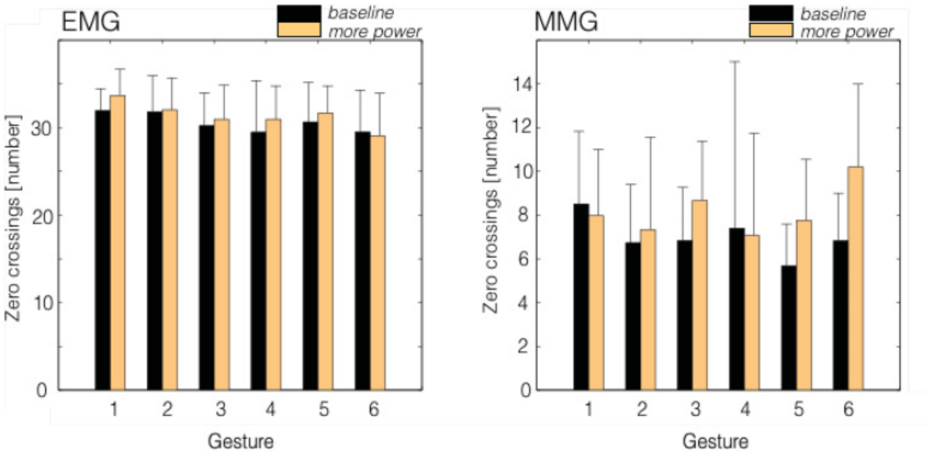

Fig. 8. Zero crossings for both EMG (left) and MMG (right) averaged across participants and trials. Black bars show the mean number of zero crossings when no variation is applied (baseline), and orange bars report mean number of zero crossings when more power is exerted.

inspect how this feature is affected by variations in power. Figure 8 reports the results. ANOVA is performed to investigate the effect of the two factors GESTURE (the six gestures of the vocabulary) and VARIATION (baseline and more power) on the signals' numbers of zero crossings. The analysis reveals that there is a significant effect of GESTURE on EMG zero crossings, $F(5, 132) = 37.7$, $p = 0.002$, but no effect of VARIATION, $F(1, 132) = 22.7$, $p = 0.13$. Regarding MMG, the analysis shows that there is a significant effect of VARIATION on MMG zero crossings, $F(1, 132) = 4.6$, $p = 0.02$, but no effect of GESTURE, $F(5, 132) = 1.1$, $p = 0.34$.

A post hoc analysis on the MMG zero crossings is then performed to examine the individual differences for each gesture between the two conditions "baseline" and "more power." The analysis reveals that the number of zero crossings significantly increase for gestures 3, 5, and 6 ($p < 0.05$).

Note that a similar analysis performed on the centroid frequency leads to an identical result for the MMG. However, for the EMG, the centroid frequency significantly decreases when applying more power (Figure 9).

Higher frequency in the MMG signal (more rapid oscillations) relates to higher power in the execution of the gesture. Let us inspect the time-frequency representation of the same gesture taken as example in Figure 7. Figure 10 reports the spectrogram of the signal with the centroid curve on top of it (white curve). The figure reports the specific case of gesture 3 performed by Participant 5 with no variation (on the left) and with more power (on the right). We observe that on the right side, higher frequencies have more energy when the power is applied. However, the peak (in white) of energy is almost the same in both cases.

6.3. Power Dependency on Gesture and Other Dimensions of Expressivity

In the previous section, we showed that the EMG amplitude feature significantly increases when participants varied the power of a gesture. This means that the haptic feedback does not affect the change in power measured as the variation of EMG amplitude (i.e., related to the tension exerted in the arm). However, the haptic feedback affects the spectral density in the MMG signal, as shown in Figure 9.

Figure 6 illustrates that the increase in amplitude depends on the gesture performed. To examine how each gesture affects the change in amplitude, we computed the

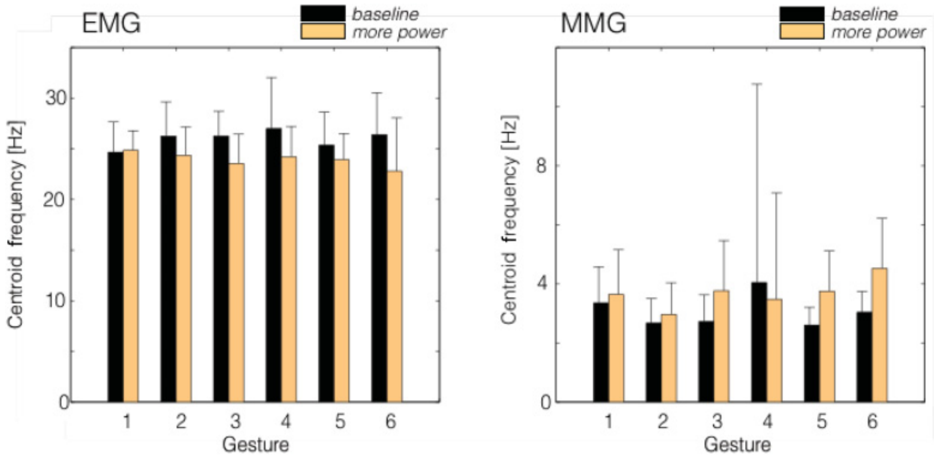

Fig. 9. Centroids for both EMG (left) and MMG (right) averaged across participants and trials. Black bars show the mean centroid frequency when no variation is applied (baseline), and orange bars report mean centroid frequency when more power is exerted.

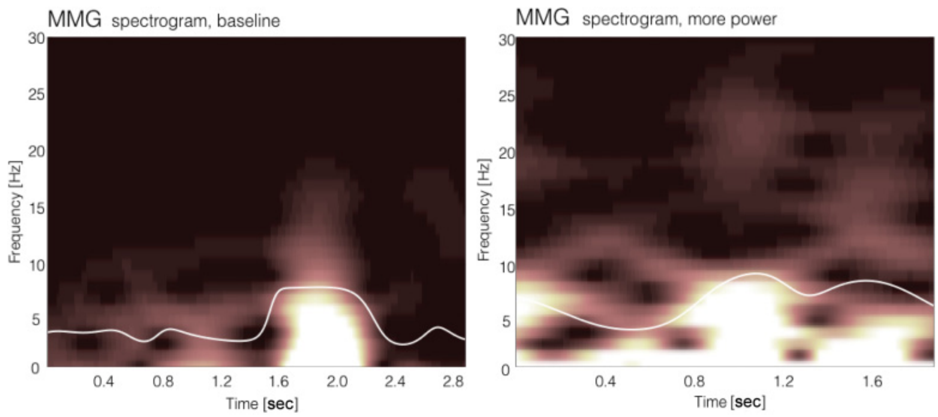

Fig. 10. Spectrogram of the MMG signals for an example trial of gesture 3 in the case of no variation (left) and more power (right). The white curve plotted on top of it illustrates the temporal evolution of the centroid.

percentage of amplitude increase between "no variation" and "more power." Figure 11 reports the results. We compute a pairwise Student's t-test with $\alpha = 0.05$ across gestures to compare amplitude increases. The test reveals that gesture 1 (Surface Rotation) has a significantly lower increase in either EMG or MMG amplitude compared to the other gestures ($p < 0.05$). Similarly, gesture 5 (Fist Rotation) shows a significantly lower increase in either EMG or MMG amplitude than gestures 2, 3, 4, and 6. In other words, the increase of tension when performing gestures 1 and 5 is more limited than for the other gestures.

Furthermore, we examine the link between power and the other dimensions: speed and size. We inspect if the global speed of the gestures (given by their relative duration) changes if one is performing the gesture with more power. Figure 12 reports the results. We compute a Student's t-test (with $\alpha = 0.05$) pairwise on the relative durations across variations (baseline, bigger, faster, and more power) for each gesture. First,

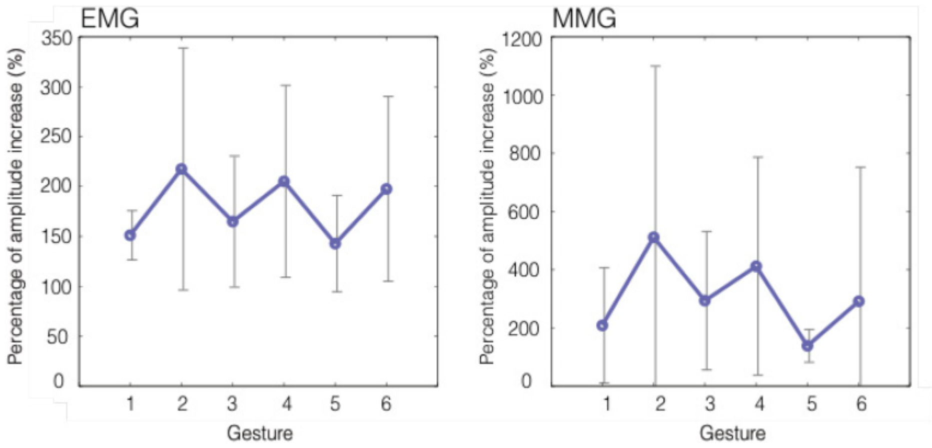

Fig. 11. Percentage of amplitude increase between the condition "more power" and the baseline. Percentages related to EMG are reported on the left, and those related to MMG are reported on the right.

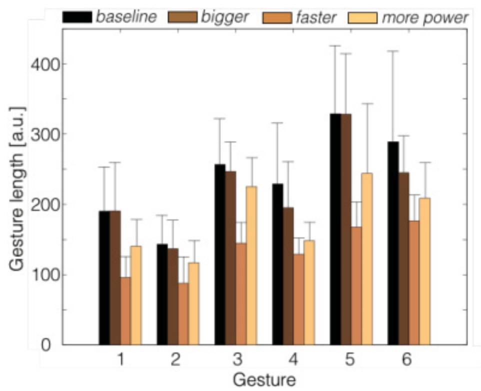

Fig. 12. Lengths of the gestures performed averaged across participants and trials. Four conditions are considered: baseline (black), bigger (brown), faster (orange), more power (yellow).

the test applied between the baseline and the condition "bigger" does not reveal any significant difference for every gesture. In other words, participants maintain that the global duration of a gesture equals the original duration of baseline performance even when varying gesture size. By consequence, this means that they also perform the gesture quicker. Second, the duration of gestures performed under the task "faster" are significantly shorter than the gesture durations under the conditions of baseline, bigger, or more power ($p < 0.05$) for every gesture. Finally, the test shows that gesture lengths decrease when performing gestures with more power compared to the baseline ($p < 0.05$). In other words, when asked to perform a gesture with more power, participants also performed it faster.

Finally, we inspect how variations in size affect variations in power in terms of EMG and MMG amplitudes. Figure 13 reports the results. We perform a statistical t-test between conditions for each gesture to inspect their relative differences. The analysis reveals that both EMG and MMG amplitudes significantly increase between bigger and more power ($p < 0.05$) but not between more power and the combination bigger

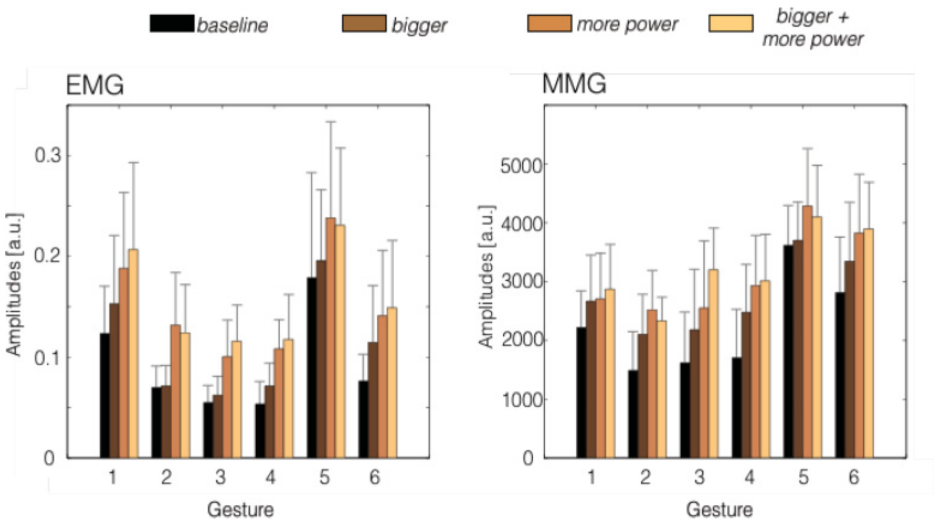

Fig. 13. Amplitudes for both EMG (left) and MMG (right) averaged across participants and trials. Four conditions are considered: baseline (black), bigger (brown), more power (orange), bigger + more power (yellow).

and more power. In addition, the EMG and MMG averaged amplitudes do not increase between the baseline and bigger. In other words, participants are able to modulate the size of the gesture while keeping muscle tension at the same level as in the baseline.

7. DISCUSSION

The studies presented in this article are a first attempt to understand if an approach considering gesture expressivity for HCI is possible as a motor task. This insight is critical to interaction designers in imagining scenarios that make expressive use of limb movement. A first pilot study reports on the ability for participants to control variations in size and speed separately and independently on the gesture performed. A second pilot study reports on the importance of considering muscle sensing in the capture of expressive movement to go beyond spatial and temporal variations. This led us to the design of the study presented in Section 5, where the notion of gesture power is explored in terms of control and sensing. In the results, we explore the role of the haptic feedback on user understanding and control of gesture power variation, the role of the gesture executed, and the interdimensional dependencies of expressivity. Here we discuss these aspects, report challenges for interaction design involving the proposed approach, and give some possible applications in HCI.

7.1. Haptic Feedback

The user's ability to understand the task of varying gesture power is linked to the presence of a haptic feedback. As we would expect, power variations carry with it more subjective ambiguity than size and speed.

When a gesture involved haptic feedback, like the resistance of a boundary object, participants associated gesture power to the notion of *Force* (understood as *Pressure*). When the gesture lacked haptic feedback, as in free space movement, participants associated power to the notion of *Tension* or *Intensity*. These three terms—*Force*, *Tension*, and *Intensity*—refer to three facets of the notion of power. We can think of them operating as "subdimensions" of the power dimension.

Tension, measured as EMG amplitude, was shown to be modulated independently to the presence of a haptic feedback. In other words, the variation in power in terms of tension is equally possible for a surface gesture as for a free space gesture. The motor capacity for varying tension is therefore decorrelated from the user's understanding of the variation of power.

On the other hand, the presence of haptic feedback affects the dynamics of the forearm muscles, as we have shown by inspecting spectral information in the MMG. The number of zero crossings inform on the activity of the muscle during gesture execution. We showed that the activity increases for free space movements, and mainly for those that involve wrist rotations or dynamic changes in the gesture execution itself, such as square corners. Therefore, moving in free space induces articulations between the forearm and the hand, dynamically activating the forearm muscles, whereas performing gestures on a surface mainly solicits movement of the whole arm to exercise pressure (better captured via EMG as discussed earlier).

7.2. Gesture Design

Another factor is the role of the gesture executed. Whereas the pilot study with 2D shape gestures indicates that the ability of users to execute variations are independent of the gesture performed, the results of the main study presented in Section 6 indicate that the gesture performed has an influence on the way in which users perform variations in the various dimensions. The gesture vocabulary has been designed to encompass gestures with various biomechanical characteristics like wrist torsion or arm articulation. Biomechanics have a direct influence on the power as captured by muscle sensors. From the study, we retain the following:

—Gestures involving limb torsion are more limited in the range of muscle tension that can be applied. The natural gesture (with no variation) already induces tension in the muscle. By consequence, the range of potential variations is limited compared to other gestures.
—Gestures in free space involve higher activity of the muscle, captured in the frequency domain of the MMG signal. Articulations of the forearm lead to higher partials in the frequency response of the muscle. The same is observed for gesture, including abrupt changes in shape (e.g., square).

Hence, gestures can be designed to take into account biomechanics and highlight user modulation of power. For instance, a surface gesture allowing modulation of the pressure over the widest range or a free space movement with punctuating changes may become part of the gesture typology that interaction designers might incorporate into future interactive products that track user gesture by way of muscle sensing.

7.3. Dependency Interdimensions of Expressivity

Whereas expressive gesture presupposes spontaneity and personal difference, exploiting expressive variation in HCI applications requires reproducibility and the ability of users to intuitively control the expressive dimension in gesture. Note that deliberateness refers to the capacity in motor control to perform a given task. We did not evaluate deliberateness in a task-driven study where error rate and time completion would allow assessment of accuracy.

In the first pilot study, we showed that varying size and speed is natural and can be executed deliberately in 2D gestures. Both can be controlled separately if the gesture is performed slower; otherwise, both are intrinsically coupled. The 2/3 power law states a strong correlation between instantaneous speed and curvature [Viviani and Flash 1995]. This means that the speed cannot possibly be constant over the pattern (even if the user perceives it as constant), with each gesture having a specific time/speed profile. The law of isochrony further establishes that the average speed of point-to-point movement tends to increases with the distance between the starting and ending point. In other words, we tend to keep constant the time required to perform a gesture if performed bigger. We show that the law also applies to free space gestures. For larger gestures, the total length remains constant, meaning that the average gesture speed increases.

This establishes that speed is not a parameter that we are used to controlling or varying in everyday motor task. On the contrary, size is a parameter that we often modulate. Note that these facts only hold for ballistic gestures performed sufficiently fast without feedback. When performed sufficiently slowly, the gestures can be controlled through a sensorimotor loop using, for example, visual feedback. In such a case, the human motion law that we mentioned earlier does not hold.

Power is an expressive dimension that takes advantage of the richness of information in physiological signals and can be modulated by varying the tension in the muscle. We demonstrated capturing such modulation through EMG amplitude analysis. Varying tension, however, seems to have an incident on the speed of execution of a gesture. Power and speed seem to be intricately linked, but it is not clear about the mechanisms that link speed and power, such as in the previously mentioned laws of motion. On the other hand, size and power are separable in the sense that they can be modulated independently.

7.4. Applications

Our findings provide insights for interaction designers wishing to enhance the expressivity of interaction using muscle sensing. Here we present some possible applications that could make use of the approach proposed.

The first application, Expressive Texting, has been imagined by Participant 12. In the scenario, a user types a text on her mobile phone while commuting on public transport at rush hour. High stress going to work makes her typing more vigorous, and she is eager to transmit her mood to the recipient. The messaging application understands the level of stress by analyzing the gesture power picked up by wireless muscle sensors and render the content of the text message in bold upper case or larger font sizes. This scenario is simple and useful to clearly illustrate the type of application that can be envisioned leveraging on our approach.

Another set of applications that could be imagined involves adaptive interfaces that respond to the rigidity of user gesture depending on his level of expertise. If the the user's gestures show high tension due to inexperience, the system could simplify its interface relative to a user who is more fluid and relaxed in their interaction. Or, if the user's gesture shows high force, the system could visually emphasize a specific part of the interface.

There are further potential applications in games. User engagement with a game is critical to the interactivity with the system and has been measured by brain-computer interfaces. Typically, a user has a limited set of controls to help in navigating complex virtual environments. An understanding of physiological aspects of the user's gesture could help gain insight on the user's level of engagement. Some games have recently implemented very basic physiological sensing,[5] but the use of different expressivity dimensions, as proposed in this work, could provide more subtle interaction or could even be used to alter the narrative of the video game in real time. High tension in the user's gesture could prompt the game to render a more quiet environment to encourage the user to rest, and high force could make the user's virtual character stronger during fights, with high intensity prompting the soundtrack tempo to increase.

A final set of potential applications relates to the performing arts and digital media art. In this context, the ability to provoke different and unexpected responses in the

[5] See a review of physiological sensing-based games at http://www.physiologicalcomputing.net/?tag=biofeedback-games.

audience is critical to the success of an artwork [Ouzounian et al. 2012]. A set of tools helping artists to leverage subtle variations of audience reaction while experiencing an artwork could advance new prospects for live digital music, interactive dance, virtual reality, media theatre, and interactive installations.

8. CONCLUSION AND FUTURE WORKS

In this article, we explored how limb gesture variation captured by physiological sensors can be suitable for the design of expressive interactions. Results from the first pilot study illustrate that users are able to reliably perform simple variations in size and speed of 2D shape gestures, and they do so independently of the gesture performed. The second pilot study introduced muscle sensing in a multimodal context alongside standard physical sensors and looked at two complementary modes of muscle sensing—the EMG and MMG—in a bimodal configuration. This study showed that muscle sensing gives an indication of the user intent in the execution of a gesture and that given auditory feedback, users are able to reliably perform gestures that highlight differences in complementary modes of the EMG and MMG. This points out that muscle sensing is suitable for detecting expressive input and that physiological sensing can be exploited by users in a voluntary manner in HCI settings. We implemented techniques from the biomedical literature on consumer-grade muscle sensing hardware. These physiological phenomena needed to be detected in real work setting with higher noise, lower sampling rate, and perturbation, similar to those in which we might imagine future interactive products to be used. The rapid democratisation of sophisticated physiological hardware in the e-health space means that the signal quality, number of input channels, and sampling frequencies will only improve, making techniques like those presented in this article increasingly robust in everyday settings.

The main study describes an experiment that focuses on expressive dimensions of gesture from a user-oriented qualitative and quantitative perspective. A questionnaire following task-based trials gauged the participants' perceived difficulty in performing gesture variations as well as their subjective understanding of the gesture dimension *Power*. For the user, power is an ambiguous, subjective dimension that can be understood differently according to the presence or absence of haptic feedback and can be assimilated to tension or kinematic energy. According to the participants, power also depends on the gesture performed and other dimensions to be manipulated (e.g., speed).

A quantitative analysis of EMG and MMG data provides signal features—amplitude and zero crossings—that are useful in measuring objectively the insights from the questionnaire. The analysis first shows that participants were able to modulate muscle tension in gestures, and this modulation can be captured through physiological sensing. Exertion by pressure is better explained via EMG signal amplitude, whereas dynamic variation of intensity is better captured through MMG, in the frequency domain. The ability to control variations in power, then, depends on the gesture performed. Finally, we showed that power and speed are dependent.

The proposed approach, using gesture variation as a medium of expressive human-machine interaction, leads to several potential applications for expressive interaction scenarios, addressing diverse fields such as personal devices, adaptive systems, video games, and the performing arts. We believe that this work has relevant impact for the HCI community, and we see current challenges that will drive our future work in the field.

A first challenge is to build on the results from these studies to create interaction scenarios involving dynamic gesture variations. Such scenarios would allow for evaluation of the approach from a task-oriented perspective and assessing aspects such as usability. As the task would require the deliberate activation of muscles, the effect of fatigue and stress would also need to be measured to shed light on usability issues for HCI.

The second challenge is the computational modeling of muscle-based variation and their real-time tracking. In the past, we developed a machine learning–based method that is able to recognize a gesture as soon as it starts and can adapt to spatial and temporal variations. The system has been assessed on gesture databases from the state of the art and successfully deployed in gesture-based sonic interaction [Caramiaux et al. 2014]. The study presented in this article gives insights to the challenges in adapting such a system to track power variations captured by bimodal muscle sensing. This machine learning technique would classify different muscle gestures and perform adaptation that would take into account variations in gestural power. A future work would be a system that considers bimodal muscle input and tracks variations in power, which would be an improvement over current position-based systems.

Finally, the investigation of gesture expressivity through muscle sensing would allow us to explore higher-level notions such as effort, which has been widely used in creative practice like dance but also in medical fields like stroke rehabilitation. We believe that the conceptual and methodological approaches presented offer insight for further research in using physiological interfaces to go beyond movement-based HCI.

APPENDIX

A.1. Additional Material of the Prior Work

Here we report the gestures used in our second pilot study, part 1 (Figure 14).

METAPHORICAL GESTURE	ARMS PHYSICAL GESTURE
Shaking bells	Right arm lifted up. Wrist bent forward. Multiple contractions of the right hand fingers.
Scattering sound grains 1	Right forearm lifted up. Distal phalanges bent forward. Fast multi-directional wrist contractions.
Stretch the sound 1	Right arm lifted up and extended frontally towards the right. Palm completely open. Closing rapidly the fist, while rotating and contracting the forearm towards the left.
Stretch the sound 2	Right arm lifted up, extended backwards behind the shoulder, and towards the right. Palm close. Fast wrist rotation, and faster flexion of the distal phalanges.
Dropping something small	Right arm lifted up. Wrist bent forward. Single, neat contractions of the right wrist, and fast flexion of the ring finger.
Rotating bells	Right arm extended backwards behind the shoulder, and towards the right. Palm half close. Very slow wrist rotation.
Grasping the void	Both arms lifted up. Elbows at the shoulder level. Forearms bent perpendicularly to the arm. Fast arms closing, and wrist upward/downward contraction.
Shaping a wave	Left forearm lifted up. Palm half open. Upward wrist contraction, and movement of the forearm from right to left.
Throwing a sound wave	Left forearm completely bent upward. Wrist bent forward. Palm half closed. Extension of the forearm, upward wrist contraction, and full opening of the palm.
Holding a growing force	Left arm lifted up. Wrist bent forward. Multiple contractions of the left hand fingers and wrist, and full tension exerted in the whole arm.
Scattering sound grains 2	Left arm resting along the body. Sudden, strong, upwards wrist contractions, and fingers flexion. Lifting left shoulder upwards.
Rotating a wheel	Left arm perpendicular to the body. Forearm slightly bent to the right. Palm half open. Sudden upward wrist contraction, and fast rotation of the forearm from right to left.

Fig. 14. Gesture vocabulary used in our pilot study [Donnarumma et al. 2013a]. The gestures are derived from an existing performance piece of contemporary interactive music.

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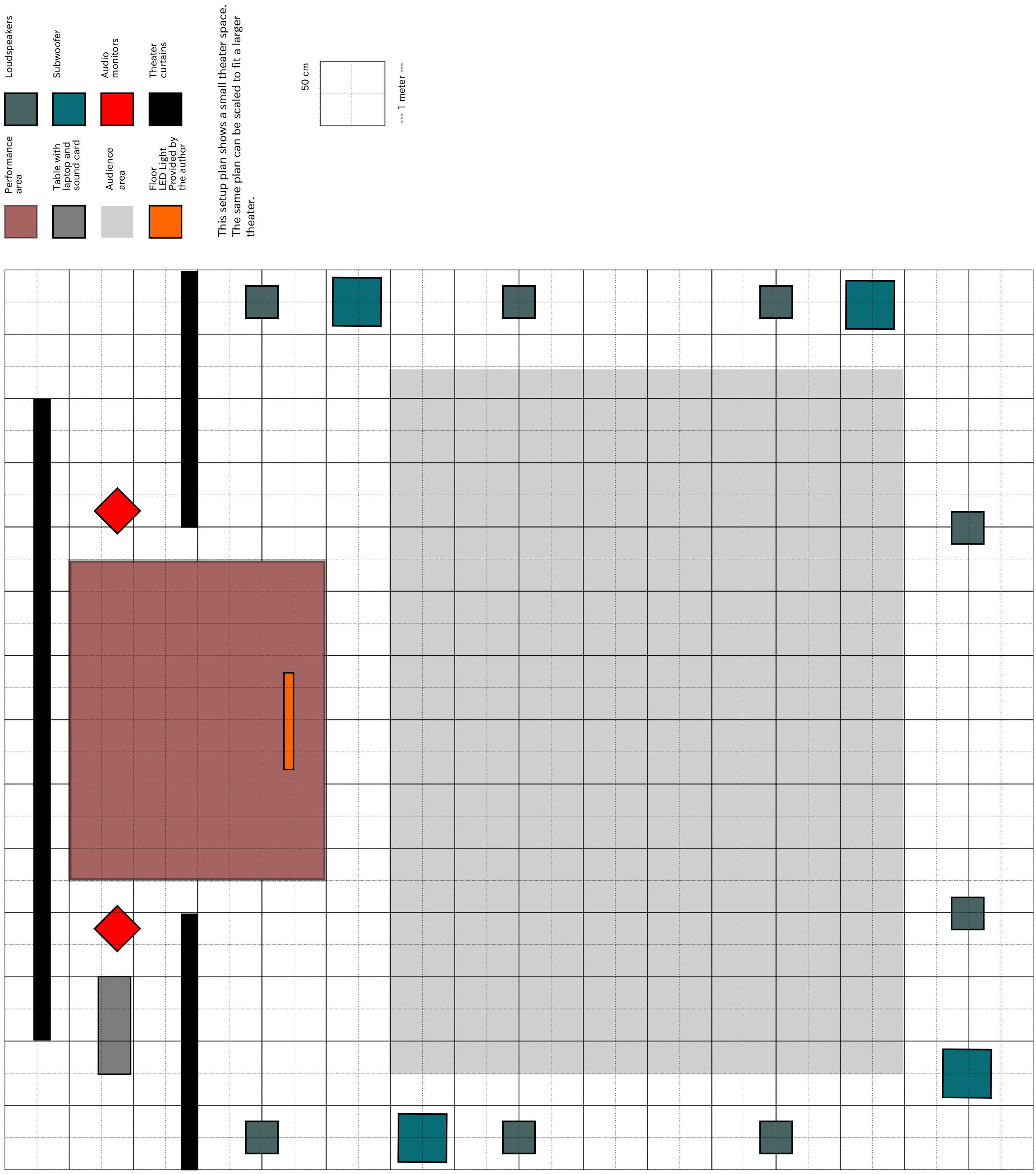
D.2 Corpus Nil Setup Documentation

Space Features

The work is to be performed in a traditional or black box theater. It can however, be adapted to venues of various size. It is necessary that the stage is elevated by at least 1 m in order to achieve the visual effect the performance relies upon. The piece requires an area of 20 square meters in which the performer will move. The stage should be completely empty. In case other artists are performing in the same event, the stage should be emptied completely before this performance.

Setup Notes

The performer's laptop and external soundcard shall be placed on a table covered with a black sheet and located in a corner of the stage, behind a black curtain. The equipment must not be visible to the audience. As for lighting, the venue should have black walls or be completely dark when lights are switched off. White walls, emergency lights, natural or artificial light from windows or ceiling must be avoided. During the performance, doors should be closed and air conditioning turned off, as its sound interferes with the piece. The setup plan for the piece follows on the next page.


Loudspeakers
Subwoofer
Audio monitors
Theater curtains
Performance area
Table with laptop and sound card
Audience area
Floor LED Light Provided by the author
This setup plan shows a small theater space. The same plan can be scaled to fit a larger theater.
50 cm
--- 1 meter ---

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