Designing From Listening: Embodied Experience and Sonic Interactions

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ABSTRACT

An understanding of the richness of people's sonic experience can lead to the creation of novel methods for informing design practices. One of the challenges in Sonic Interaction Design (SID) is to deal with the complexity of the "sonic": its phenomenon, the interactions it creates, its social and cultural contexts. To tackle this challenge, this thesis investigates how we can draw upon people's everyday sonic experience, particularly listening and remembering sound, to design interactions using body movement, digital sound processing and embodied technologies. Firstly, the research analyses how sound has been studied in its phenomenological, cultural and social aspects in fields such as Sound Studies and Embodied Sound Cognition. Secondly, it involves users in the process of designing sonic interactions, with a user study about gestural-sound relationships during active control of digital sound, and a series of participatory design workshops which draws upon people's sonic experience for imagining interactions with sound.

The thesis provides four main contributions. The first is Retro-Active Listening, a concept which draws attention to sounds heard in the past by remembering listening to them. The second is the Sonic Incident, a technique for SID workshops, which allows designers to explore participants' past experiences of listening. The third is the Gestural Sound Toolkit, which enables designers to rapidly prototype interactive sound mappings based on human movement. The final contribution is three models for designing embodied sonic interactions. These comprise (1) Substitution, in which users' movements substitute the cause of the sound, (2) Conduction, where users' movements have a semantic relationship with the sound, and (3) Manipulation, in which users' movements manipulate the sound. These contributions help to build a framework for design that addresses lesser-explored matters in SID, such as embodiment and contextual aspects of sound, which are potentially relevant for users.

Declaration of Authorship

I hereby declare that the work presented in this thesis is entirely my own. Where I have consulted the work of others, this is always clearly stated.

SIGNED

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1 INTRODUCTION

1.1 The Context of Sound

Sound is part of our everyday lives. Things around us produce sounds: car engines rumble, doors squeak, clocks tick and the wind howls. Sound is happening around us in this very precise moment. It also happens somewhere else, far from where we are now while reading this text. Sound is close to us and yet far away. It can be the sound of my fingers typing on this keyboard, or the person talking loudly at distance while I write this text.

Sound "tells" us that something has just happened, or that it is about to happen. It continuously appears and disappears to our ears. Sound for us is often the sound of something in the moment we notice it. Sound is around us when we think of its sources. When we hear the sound of a falling tree, we are prone to believe that a tree has fallen. Sound is also inside us. When we think of the sound of the falling tree, we can imagine hearing its sound, even if now we are reading this text. Sound is also elsewhere, where we cannot hear or imagine it, such as the sound of a dying starfish.

Sound is a mechanical vibration transmitted through a medium. Sound irradiates in the environment and it is reflected, refracted, amplified and absorbed by its surfaces and materials. We can perceive these vibrations with our ability to hear them through our ears and feel them through our body, as stimuli that we cannot easily block.

Hearing is our physiological predisposition to sound as this phenomenon happens to us. Hearing sound gathers our attention and we may begin to listen. Listening is a conscious action. It may involve giving our undivided attention to something we are interested in. On the other hand, listening can become unavoidable such as when we hear the conversation of our loud neighbours, or a song that we particularly like being played by our favourite internet radio station. Listening is our continuous repositioning to different sonic layers, delimited by our bodies and the surrounding environment.

As we are able to hear and therefore listen, sounds become meaningful to us. Sound can affect our emotions. We can remember previous experiences through thinking or hearing sounds that are associated with them, even if they are not coming from the same source. Hearing the horn of a ship signalling its entrance in a port of the Northern Sea may remind some of us of very distant places and experiences, such as being kids playing football near to the harbour of a small city on the Mediterranean Sea. It may remind others of something else, some other places and personal stories. It can also cause fear and panic, such as when we hear the sound of an explosion or somebody shouting in the street in the middle of the night. It can cause us discomfort, joy and emotional or physical pleasures.

Hearing sound can convey information to us. The sound of a crying baby can alert a parent of a newborn that he or she needs attention. We can also search for information through listening. The same parent could lean towards the door of the living room and attentively start to listen to any sounds coming from the newborn's room, to understand if their baby is sleeping or not. Sound can also be used to understand information about physical characteristics of our world. We can for example throw a rock in a well to understand if it is deep. We can knock on the wall of the flat that the estate agent is showing to us to hear if its thickness and material construction will protect us from possible noisy neighbours (or in some cases to protect them from us).

We produce sounds. There are many ways in which we can do this. We can use the innate abilities of our bodies. For example, we can use our voice and shout our friend's name walking down the street to call his or her attention towards us. We can also hit a resonating surface with our hand. We can use instruments built with the specific aim of producing sound. We can ring a doorbell to alert somebody that we are outside their door. We may want to play a musical keyboard and produce music. We can use a megaphone to make our voice louder than our physical abilities can permit and reach more distant people with our message. Our ability of playing is connected to our ability of hearing and our predisposition to listen. It is made possible by the nature of sound as a mechanical vibration, to the meaning we give to this vibration, how it is shared through cultural conventions and re-created through technological development.

1.1.1 Everyday interactions mediated by sound

Our ability to hear, listen to and produce sounds determines various types of interactions in the world. We usually understand that two people are communicating with each other by hearing them talking. This can suggest to us many different possibilities for action. We may want to listen to them to try to understand the content of their conversation. We can interrupt them and intervene in the communication. We might ignore them by concentrating again on our work or even walk away if we are not interested or disturbed, and so on.

The link between body and sound suggests us that it can help a group of people to coordinate their movements with other forms of interactions. During an army's march, the sound of hearing one another stepping rhythmically is one factor which enables a large group of people to synchronise their actions. In a dancehall, a group of people can dance together hearing music that they are not necessarily producing. These interactions are not dependent only on sound, but sound is an important aspect of them. Without hearing the steps or the music being played at such intensity we would lose the ingredient that connects people's action together.

The space and context of where sounds are produced, propagated and heard play an important role in our everyday interactions with the world. A large empty hall with a wooden floor and high ceiling will not be suitable for some forms of vocal communication as a large reverberation will create problems for the intelligibility of the speech. The same hall may be suitable for other activities, such as hearing a basketball bouncing. Replacing the wooden floor with carpets will cause the ball to bounce differently. We would also hear a different sound of the ball bouncing, which would make the same game more difficult to play, or perhaps transform it into a very different one.

1.2 The Use and Design of Sound

As sound is heard, listened to and produced, we can also design it. Sound Design is the process of imagining and creating sounds that can be suitable for specific situations and usages. We can see a few examples in cinema, video-games and product design. In cinema, sound designers use diverse tools and techniques - analogue and digital - to record, produce and compose sounds that can accompany the film. They are in charge of establishing links between the moving images we see on screen and what we hear played back from the cinema's loudspeakers. Sound designers craft and design sounds to modulate the affective and sensorial dimension of the spectator and to build a sense of temporal narrative that fits with the intentions of the director.

In videogame design, sound designers shape the sonic dimension of the game. They create the general atmosphere and mood of the game through the soundtrack, and imagine and design sounds for every aspect of the game, from virtual explosions to the rumble of a hungry alien frog. The work of a sound designer for games deals with aspects of simulation of virtual worlds and how players can perceive the designed environment of the videogame itself, taking into account factors such as speed of the element on screen, success or failure of players' actions. Sound designers exploit auditory feedback to help gamers to make sense of their own actions in the game and its goal.

Sound can also play an important aspect in product design. Matters of suitability between product usage and its sound are often considered. Product designers may want to think how to attenuate the sound of the electric blender they are producing. Sound in that case is something that needs to be reduced, but is not designed in the first place. In other cases, designers use additional, designed sound to communicate the state of the usage of the product or possible actions with it. For example, a microwave oven usually has an integrated loudspeaker that plays a sound to notify the user about the different phases of the cooking process. In other examples product designers can use sound to give a character to their product, such as speaking and sound-producing toys. The use and attention to sound in product design can facilitate and enrich our interaction with objects or create completely new forms of artefacts and interactions.

1.2.1 The Practice of Sound Art

In Sound Art, sound is considered as an aesthetic phenomenon, a material, a process, as well as an operation (LaBelle 2006). Artists use sound to evoke the action of listening in the physical or aesthetic aspects of the artwork itself. In many sound artworks, listening is one of the actions required in order for the sound artwork to be perceived as such, or to be categorised in this way. Approaches to sound often focus on its affective and vibrational aspects which escape the intentionality of listening and physically stimulate our senses. Artists can challenge, transform, refocus and create completely new experiences of sound for the audience. For example, we can imagine a sound art installation in which we can feel sound through our bones, and being immersed in a special situation of listening and exposure to sound which is very different from our everyday sonic experience. We could say that one of the aims of sound artists is to use sound as a material, process and strategy for creating contexts and experiences, which engage (or negate) the audience in different forms of interactions.

1.2.2 Designing Sonic Interactions

The recent emergence of ubiquitous computing and real-time sound producing technologies offers new opportunities for sound design in interactive contexts. The miniaturisation of motion sensors and sound computing technology provides design opportunities in which digital sound and human movement can be considered together. Sonic Interaction Design (SID) is a design field which triangulates sound design, interaction design and computing to exploit the opportunities given by the relationships between auditory perception and human movement. It provides focused ways in which sound is considered as a design medium, particularly meaningful for aiding a desired human-computer interaction.

Designers in this field combine sound design and interaction design techniques to explore how sound can enhance everyday interactions using digital technologies. The types of research that SID enables are various, from motor-rehabilitation through sonification of human movement (Avanzini et al. 2009; Tajadura-Jiménez et al. 2015), to product design and arts (Barrass 2013). Hybrid artefacts such as sonic knives (Polotti et al. 2008) and musical basketballs (Rasamimanana et al. 2012) are just a few examples of augmenting everyday objects with digital sound and sensor technologies. SID exploits our existing relationships between our use of artefacts and the sounds they produce, transforming them into something different – yet familiar – by using interactive technology and real-time sound processing.

1.3 My Practice: Designing Sonic Experience

In the previous section I introduced the subjects of sound, listening and sound design and their contribution to shaping forms of interactions. I have been fascinated by the multifaceted dimensions of sound and its experience. In my research and practice I explore sound and interactive technologies with the same fascination. I use sound as a material for creating situations of interactions between people and technology, focusing on exploring emerging actions. For example, I design activities that help an audience to build their particular sense of place through listening, through their attention towards the sonic aspect of the environment.

In previous works as a sound and media artist, I started to explore sound as a medium for everyday, embodied and situated interactions using mobile and computing technologies. In Osmosis (2011), I investigated the relationship between site specificity, symbolic and acoustic properties of the space, high power sound technology, real-time sound processing and sensorial exchange between acoustic and haptic sensation.[1] In The Flying Ear (2011) I augmented helium balloons with microphones and headphones and invited people to use them in walks in which they listened to the sound of the city from a higher, shifting perspective.[2] In The Quiet Walk (Altavilla & Tanaka 2012) an iPhone analyses the sounds of urban locations and diverts the user towards quieter spots.[3] In these artworks, the interaction was designed around the constraints and affordances of the technology and used to explore technologically mediated ways to listen to our everyday.

I collaborated with the artist Berit Greinke (Queen Mary, University of London) on a project that aimed to add a sonic quality to textile artefacts. In Twiddletone we used participatory workshops to develop music and sound interfaces based on e-textiles and interactive sound programming. In the Amplifying Textile workshop (KHB, Berlin, 2011) we taught textile design students how to augment their textile products with sound and use it to generate sound-textile prototypes.[4] In the workshop Chrome-Live (KHiB, Bergen, Norway, 2012), we used the process of colour chromatography on paper to build a real-time digital music composition with textile design and fine art students. This project helped us to investigate the idea of a synesthetic and algorithmic translation of colours and textiles into sound and how this could be explored by working with students who were not specialists

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[1] http://alessandroaltavilla.net/home/projects/osmosis/
[2] http://alessandroaltavilla.net/home/projects/the-flying-ear/
[3] http://alessandroaltavilla.net/home/projects/the-quiet-walk/
[4] https://twiddletone.wordpress.com/workshops/

in sound design. We finally applied these ideas for our artistic performances, in which we played e-textiles as musical instruments and produced an installation (Marrakech Biennale of Art, 2012).[5]

After obtaining an M.Res in Digital Media, I have contributed to research projects in digital interactive music and sound. In a collaborative research with Atau Tanaka (Goldsmiths, University of London) and Neil Spowage (De Montfort University) we used the concept of affordances, from ecological psychology, to investigate gestural control of digital musical sounds (Tanaka et al. 2012). We conducted a user study, in which we designed different gesture to musical sound mappings (drum kick, violin, voice) and applied them consistently on three different accelerometer-based devices (a smartphone, a game controller and a miniaturised accelerometer). We asked participants to play sounds by spontaneously moving the devices, and interviewed them about their experience. Participants' interactions were influenced consistently but not systematically by the form of the devices and by the cultural musical references, varying with device and sound despite constant underlying gestural mapping. This study formed part of my exploration of the complexity of sound design, interactive technologies and their possible usage. It presented me with new ideas regarding body movements, action-sound perception and cultural aspects of sound itself, to be further investigated in a new research project.

1.4 The Problem of Sonic Experience in Sonic Interaction Design

As we will see in Chapter 2, much of the research in Sonic Interaction Design focuses on the relationship between human action and sound feedback through the use of digital technology. Real-time digital sound feedback is often used as a strategy in which sound conveys continuous auditory information about the state of the interaction between users and artefacts.

Sound, according to Karmen Franinović, can be considered in SID as an "active medium that can enable novel phenomenological and social experience with and through interactive technology" (Franinović & Serafin 2013, vii). The previous

[5] http://alessandroaltavilla.net/home/projects/an-arbitrary-system-for-tuning-fabrics/

statement by Franinović opens up possibilities for research within SID to go beyond the use of sound feedback, unfolding ideas regarding how we can draw upon sonic experience itself for informing design practices. The focus on “phenomenological” and “social” experience posed by Franinović concerns not only interactive technologies; it can be taken as a starting point for questioning what is the consideration of “sonic” in SID.

An important challenge in SID research is the complexity of people’s experience with sound. To do so, we need to investigate the consideration of the “sonic” itself. Sound is a physical, material - yet invisible - felt event. At the same time sounds can be perceived as strong cultural and social signifiers (Bull & Back 2003). As humans, we listen to sound, but we also imagine it, remembering and imagining ourselves as listening. We also feel sound in our bodies, opening up the spectrum of our phenomenological experience to sound beyond audition. To tackle this complexity, research in Sonic Interaction Design needs to explore social, cultural and phenomenological perspectives of sound, for which it is necessary to draw upon concepts from research on Sound Studies. Can we expand the concept of the “sonic” in Sonic Interaction Design? This leads to the first core research question (Q1) which asks:

- Q1: What is the “sonic” in SID?

Another important challenge in SID research is the need to understand what it means to experience bodily interactions with sound based on embodied technology. We lack knowledge of what kinds of sonic experiences this particular condition creates for potential users. Without these considerations, we lose an understanding of how interactive sonic technologies can fit the complexity and variety of people’s everyday sonic experience and how these can inform the design of novel interaction scenarios. These considerations lead to the second core research question (Q2):

- Q2: How can we access and draw upon people’s sonic experience to inform a development of novel scenarios of embodied SID?

In this PhD, I focus on Sonic Interaction Design by starting from sound, rather than technology. I propose a specific focus on a “sound-centred” approach to explore the sonic experience of potential users. We can temporarily set aside, though we do not dismiss, the technological and functional approach to Sonic Interaction Design.

My research investigates how we can start from sound to design novel scenarios of everyday interactions using body movement and digital sound processing. The aim is to deepen and develop an understanding of sonic experience that can be useful for interaction designers who wish to work with sound and embodied interactive technologies.

In virtue of the above considerations a few methodological questions arise:

- MQ1: How can we draw upon sound as a starting point in designing embodied interactions?
- MQ2: How can an understanding of our sonic experience be useful for designing interactions with motion sensor technologies?
- MQ3: How can participatory activities help us to explore the diversity of people's everyday sonic experiences and inform our approach to designing interactions?

To start to investigate these questions, I divide the research in two stages. Firstly, I conduct an analysis of existing literature in Sonic Interaction Design, Sound Studies and Embodied Sound Cognition. I will look at aspects of embodied action-sound relationships through investigating the concept of sonic affordances and exploring the diversity of listening experience. In the second stage of the research, I rely on user-centric methods and qualitative research techniques to gather people's sonic experience through a user study and a series of participatory design workshops.

1.5 Thesis Outline

Chapter 1 has introduced the topic, the context and the problematics of this research, concluding with the core and methodological research questions.

Chapter 2 presents the literature review on the subject of the sonic in the field of Sonic Interaction Design, Sound Studies, Embodied Sound Cognition. Sonic Interaction Design exploits action-sound relationships to design possible interactions mediated by sound. Sound Studies helps us to understand sound from a cultural and social science perspective. Embodied Sound Cognition studies how our bodily actions are linked to sound perception. It follows a brief overview of the concept of affordances from Ecological Psychology and its application in Sonic

Interaction Design. The chapter continues with a discussion of experience of listening, in which I present an overview of listening modes and focus on the particular experience of imagining and remembering sound. The chapter concludes with a short discussion on the subject of the sonic.

Chapter 3 presents the research methodology adopted to investigate the research questions. It introduces the general approach based on what is defined here as “sound-centred”, which gives an important role to exploiting listening as the core methodological input of this research, and its basis on qualitative and user-centric methods. After a section which reviews methods and techniques applied in Sound Studies, Sound Art and Sonic Interaction Design, I present the research steps followed in this research, the methods and instruments used. The chapter concludes presenting a pilot user study in which I explore affordances evoked by listening to sound in a Sonic Interaction Design context. The pilot study focuses on understanding participants’ descriptions of sounds and gestures which they produced while playing pre-designed sonic interaction mappings using a miniaturised motion sensor connected to an interactive sound playback system, which constitute the basic technological component of this research.

Chapter 4 presents Form Follows Sound, a series of participatory workshops developed in this research in which we use sound as a starting point for designing interaction scenarios. It reviews existing methods and techniques used in Human-Computer Interaction and Sonic Interaction Design which inform the methodological approach for the workshops. The Form Follows Sound workshops present two novel methods to be used in early phases of design: the Sonic Incident and Embodying Sonic Imagination. The two methods are deployed in the ideation phase of the workshops, which is followed by a realisation phase in which participants design interactive sonic prototypes. The chapter describes the gestural-sound design toolkit, a hardware-software solution based on accelerometers and real-time sound playback used to help participants to realise interactive sound prototypes. The chapter ends with a presentation of results, discussion and contributions that Form Follows Sound gives to research in Sonic Interaction Design. A long paper on these workshops has been published in the proceedings of the ACM CHI Conference on Human Factors in Computing Systems, held in Seoul in 2015 (Caramiaux et al. 2015).

Chapter 5 presents the findings of this thesis and discusses it in view of the results of theoretical research undertaken and the data from the user experiment and workshops. It begins with answering the core research questions, followed by a discussion of the development of a “sound-centred” and answering the methodological questions outlined in Chapter 1. The chapter continues by presenting the research contributions. The first contribution is Retro-Active Listening, a listening mode which draws attention to sounds heard in the past by remembering listening to them. The second contribution is the Sonic Incident, a technique for SID workshops, which allows designers to explore participants’ past experiences of listening. The third contribution is the Gestural Sound Toolkit, which enables designers to rapidly prototype interactive sound mappings based on human movement. The fourth and final contribution is three models for designing embodied sonic interactions. These are (a) Substitution, in which users’ movements substitute the cause of the sound, (b) Conduction, where users’ movements are in a semantic relationship with the sound, and (c) Manipulation, in which users’ movements manipulate the sound. The chapter ends with a discussion of the emerging concept of Sonic Affordance and points towards future work which is needed on this topic.

Chapter 6 concludes presenting a summary of the thesis. It continues by summarising the core contributions of this research and concludes by outlining opportunities for future research and practice.

2 UNDERSTANDING THE SONIC

2.1 Chapter Introduction

This chapter presents a review of the research areas for the study and design of interactions mediated by sound and interactive sound technology. The aim of the chapter is to provide the contextual and theoretical background that informs this research. We look at the role sound plays in processes of knowledge, experience and interactions. To do so, I first discuss how sound is treated in design practices, followed by an analysis of sonic experience in theoretical fields, spanning from Sound Studies to Embodied Music and Sound Cognition.

The first section reports on the field of Sonic Interaction Design (SID), a field which exploits the use of sound and interactive technologies to design interactions with artefacts and systems. After providing a brief overview of the field, I focus on what can be considered to be an "embodied approach" to SID, reflecting on the work of SID researchers and designers who focus on models and techniques of mapping between human movement and digital sound feedback. I then present the methodological paradigms currently in use in SID that can aid the design of embodied sonic interactions.

The chapter continues with a review of research fields that can help to expand the understanding of the “sonic” in SID, and which could feed methodological outcomes into qualitative research for the discipline. I review important theoretical and field work in Sound Studies, a multidisciplinary field that helps us to frame the phenomenological, cultural, social and political effects of sound in the everyday and throughout history. This review proceeds by looking at cognitive approaches which study embodied aspects of music and sound, unveiling relationships between human movement, sound and listening. A section on sound-related affordances helps to uncover a concept from psychology and interaction design which can be helpful for discussing interactions mediated by sound. This can help us to identify aspects of embodied motor-kinetic binding which may be useful for designing bodily interactions in SID.

The chapter continues with a presentation of theories about listening, to expand our knowledge of sonic experience. It analyses different forms of listening involved not only with the presence of sound stimuli, but also imagining and remembering sound. The chapter concludes with a discussion of the topics emerging from the literature review, tracing back their possible usefulness for this research.

2.2 Sonic Interaction Design

Sound has a long history in Human-Computer Interaction (HCI), often having a supporting function in the user interface as a way to notify users about their actions. An early example is the SonicFinder (Gaver 1989), which introduced auditory icons defined as "everyday sounds meant to convey information about computer events by analogy with everyday event". The use of sound in the user interface arises from the need to transmit information through a medium other than the visual. Sound HCI research has resulted in techniques such as sonification (translation of data into sounds), earcons (audio messages made of short rhythmic sequences of pitched tones with variable timbre) and auditory icons (sounds from everyday conveying information about events).

As a physical property, sound can contribute to the perceived possible actions afforded by the manipulation of an object (Gaver 1991). The idea of linking sound and event perception to action possibilities has been used to design different synthesis algorithms to produce and manipulate sounds according to the physical attributes of the sources. For example, a physical modelling synthesiser, designed to simulate how different materials (e.g. wood, metal) resonate when they are struck. This framework has guided recent designs of technologies for sound and interaction design, focusing on the model of interaction itself, rather than sound engines based on conventional sound synthesis techniques (Delle Monache et al. 2010).

Sonic Interaction Design (SID) is a research field which has emerged in the last 10 years, which investigates sound as the means for designing interactions between humans, digital systems and the environment. SID derives from an interdisciplinary dialogue between research in sound and music computing, sound design, auditory display and interaction design (Rocchesso 2011; Franinović & Serafin 2013; Pauletto 2014). Sound is considered in SID as an "active medium that can enable novel phenomenological and social experience with and through interactive technology" (Franinović & Salter 2013). According to Rocchesso and Serafin, Sonic Interaction Design is "the activity of shaping the relation between humans and objects by means of sound" (Rocchesso & Serafin 2009, p.905).

Analysing the ways humans perceive, understand and interact through sound, SID practitioners and researchers study how the auditory domain is linked to possibilities of interactions, and how this knowledge can be actively used to design interactive systems. The possible applications of research deployed in SID are various and range from auditory and tactile interfaces for Human-Computer Interaction (Lemaitre et al. 2009; Polotti et al. 2008), product and game design (Barrass 2013; Baldan et al. 2013; Polotti et al. 2008), motor-rehabilitation and medical research (Rosati et al. 2012; Avanzini et al. 2009; Avanzini et al. 2013; Tajadura-Jiménez et al. 2015), to interactive sonification (Pauletto & Hunt 2009; Grond et al. 2010).

2.2.1 Embodied Sonic Interaction Design

A core element in SID is the role that "embodied action and perception plays, or how action can be guided by sound in a concrete, lived manner" (Franinović & Salter 2013, p.43) based on theories of embodiment in cognitive sciences (Varela et al. 1991) and HCI/interaction design (Dourish 2004; 2013). In a chapter on understanding the experience of Sonic Interactions, in the book Sonic Interaction Design, Franinović and Salter consider the importance of the enactive quality of sound, as a catalyst for possible action. According to them the phenomenon of sound offers different possibilities of interactions and affordances compared to vision, due to sound's "vibratory, unstable and malleable character" (Franinović & Salter 2013, p.43). The contextual framework provided by Franinović has been explored in SID, focusing on understanding action-sound couplings and types of interactions.

Technologies used in SID, such as audio sensors, actuators, processing and sound synthesis techniques, make the field a "privileged framework for experimental design of continuous interactions in embodied interfaces" (Rocchesso & Serafin

2009, Rocchesso et. al. 2009). Rocchesso and Serafin also argue that designing sound to help continuous interactions poses problems other than finding appropriate sounds for defined gestures. The main sound-design concerns are appropriately designed relationships between interaction primitives and dynamic parameters of sound models, based on perceptual effects. The relationship between continuous interaction and dynamic sound feedback has been studied by Lemaitre et al. (2009). They designed The Spinotron, an interface to allow continuous interaction based on pumping and rotation. The pumping motion of The Spinotron drives a sound synthesis model based on a ratcheted wheel. Lemaitre and collaborators conducted a user study based on three experiments, in which participants were asked to describe the causal relationships between materials, interactions in the production of sound heard and to learn how to maintain a constant speed of the ratchet. The results showed that participants describe causality between their actions and sound heard while manipulating the artefact, in contrast to the sole listening of the sound without manipulation. Sound feedback helped participants to accomplish a rotary manipulation of the object at a constant speed, whereas without sound feedback this caused a lower success rate. Based on these results Lemaitre et al. argue that dynamic and continuous sound feedback helps users to control tangible interfaces. The link between manipulation of objects and the design of interactive sound can therefore indicate the value of continuous and embodied sonic interaction explored in the context of everyday objects.

2.2.2 Augmenting Everyday Objects with Sound

Object manipulation assisted by auditory feedback is one of the central topics explored in Sonic Interaction Design. Research in this field also extends to investigate how sound enhances usability, responds to user desire and sets contexts for interaction. Several authors have explored interactions emerging from the augmentation of everyday objects with sound interactive technologies. From sonically responsive cocktail glasses, to musical basketballs and affective couches, SID designers explore how sound can reconfigure everyday habitual interactions. In Franinović's Flo)(ps, purposely-designed cocktail glasses are augmented with sensor technology to retrieve information about the usual gestures associated with the act of drinking. Interactive sound technology is then used to generate synthetic sounds played back from speakers placed inside the bar table (Franinović 2011). The sound synthesis engine, running on a computer, is programmed to generate different sounds reacting to users' gestures. The specific research goal in Flo)(ps is to explore how sound can create novel or unusual gestures within habitual settings and afford new forms of interpersonal interactions.

Everyday dining actions such as cutting, piercing, sticking, drinking, pouring, grasping and stirring have been explored sonically with an augmented dining table project (Polotti et al. 2008). Polotti and his collaborators chose the dining scenario because of the strong familiarity of embodied links between everyday objects, actions and social interactions in that particular everyday context. In their project the actions produced using augmented knives, decanters and salad bowls are mapped to produce sound using physical modelling sound synthesis. The particularity of this project is that the sound design is based on the principle of "contradiction" between action and sound produced, a sort of sonic feedback that Polotti calls "circuit-bended" (Polotti et al. 2008, p. 2884). To give an example, the action of pouring liquid from a decanter is sonified using a continuous friction sound to transmit an impression of resistance of the liquid. This offers the possibility to study everyday action-sound relationships by adopting sound design strategies that deliberately contradict these relationships. Polotti's research explores how sound feedback contributes to the action produced in order to envision new ways of manipulating artefacts.

Another notable feature of augmenting pre-existing everyday artefacts with sensors and interactive sound technologies is that the affective dimension of both sound and artefact can be explored, manipulated and designed. ZIZI is an "affectionate" couch created by Stephen Barrass, Linda Davy, Kerry Richens and Robert Davy (Barrass 2013). Originally imagined as a designer's answer to the imagination of a domestic situation of the future, Barrass et al. aimed to give ZIZI a personality with physical and emotional states, such as "boredom, excitement and pleasure" and to communicate this to users through sound and vibration.[6] They use an interactive affect design diagram (IADD) which is based on the previously existing models for the classification of sound and the affective and emotional response produced in humans (Bradley & Lang 1999). Barrass and his colleagues designed four different sounds to encourage specific actions from the users. These included actions such as sitting, patting, stroking, and also simply nothing, which are captured with a motion sensor installed inside the couch. This kind of interactive

[6] *Experimenta House of Tomorrow* Exhibition, Black Box Gallery, Melbourne, 2003.

design aims to give rise to different scenarios in which sound (and vibration) is designed as a medium to give identity to an artefact and encourage or discourage certain forms of interactions through affecting the users' emotions.

Another approach to the sonic reconfiguration of everyday objects is augmentation through musical interaction, a theme emerging in the NIME field (New Interfaces for Musical Expression). The designer Nicolas Rasamimanama, in collaboration with the music composer Andrea Cera, developed Urban Games, a musically augmented ball to explore playing strategies. A wireless inertial measurement unit is embedded inside the ball in order to retrieve movement data, which is sent in real time to a computer running the sound engine. The different possible movements of the ball (roll, spin, shake, dance, dribble, throw and hit) are processed by a gesture recognition system in order to achieve a stable mapping between pre-composed musical material, additional real-time audio rendering processes and movement carried out while playing. Different games such as basketball or volleyball are played to explore the "potential of musical interaction based on playing techniques" (Rasamimanana et al. 2012).

Mogees, by Bruno Zamborlin, is a mobile application for smartphone equipped with contact microphones, which allows non-specialist users to "transform everyday objects into musical instruments" (Zamborlin 2015). The application is designed to capture the acoustic response of any object that the user may desire to play by hitting, striking or simply touching. This information is then processed by the mobile application to generate synthetic musical sounds using a physical modelling engine. The sounds played back through headphones give the user an intimate way to musically explore everyday objects. Mogees and Urban Games are examples of how music can inform interaction design by imagining new ways of physical interaction with everyday objects.

2.3 Sound Studies

Researching sound unveils a plethora of possible definitions and perspectives that need to be taken into account. Sound has been analysed and defined in disciplines such as acoustics (Beranek 1954), which studies the propagation of mechanical waves and vibrations, and psychoacoustics (Fastl & Zwicker 2007) which describes and measures how humans perceive sounds physiologically and psychologically. On the other hand, as sound is pervasive to the environment, listening to it can provide an indicator or an "object" of study to understand human activities, as in the case of Sound Studies (Sterne 2012), Auditory Culture (Bull & Back 2003) and Acoustic Ecology (Schafer 1994; Truax 1984). The following review will focus on these latter approaches of studying sound, and informs my approach to it in this thesis.

In October 2013, the first conference on Sound Studies organised by The European Sound Studies Association took place at Humboltdt-Univerzität in Berlin. The aim of the conference organisers was to collect the current research on "functional sounds" in everyday life, focusing on different approaches including sound design, sonification, auditory culture, everyday soundscapes, art practices and popular culture. Importantly, the conference disclosed a variety of contemporary theoretical and practical research which the organisers aimed to "addresses everyday context within which sound - in its relation to media, technology, and the arts – is constitutive for new ways of thinking, listening and becoming (Michelsen & Schulze 2013).

Sound Studies is a multidisciplinary field, in which ecological, social, political and technological dimension of sound are considered to inform new knowledge about research practices. This provides us with a way to discuss how sound has been studied in humanities and how it operates as a medium for everyday interactions. Jonathan Sterne proposes a definition of Sound Studies in his volume The Sound Studies Reader. He describes this as "a name for the interdisciplinary ferment in the human sciences that takes sound as its analytical point of departure or arrival […] It 'redescribes' what sound does in the human world, and what humans do in the sonic world" (Sterne 2012). For Sterne, Auditory Culture (Bull & Back 2003) is part of what a "sound student" should be aware of, together with other critical approaches such as the study of vibrations and their "ontological" existence as described by Steve Goodman (Goodman 2012) and sound art practices (LaBelle 2006; 2010). Also of significance is the study of listening technologies, from stethoscopes to microphones and recording devices, and their relationship with the construction of the sense of the audition itself (Sterne 2003).

Sound can be considered as a way to understand the different social and cultural dimensions of the world. For Jacques Attali, western culture constructs its understanding of the world mainly through visual metaphors, failing to acknowledge that the world is for "hearing and not just for beholding'' (Attali 1985). Exploring an interdisciplinary interest on the subject of sound, one of the early collections of writings on Sound Studies is Bull and Back's "The Auditory Culture Reader" (Bull & Back 2003). Here, they seek to overcome the historical visualist framework to knowledge, in order to move towards what the two authors call a "democracy of senses" that also includes hearing and listening. This collection of essays presents selected writings and original contributions from the fields of sociology, cultural and media studies, anthropology, urban geography and musicology, to disclose the expanding contemporary discourse on "the social nature and meaning of sound" (Bull & Back 2003, p. 3). According to Bull and Back, the study of auditory culture aims to provide an integrated, multidisciplinary and academically diverse framework for studying the importance of sound and listening in social sciences. The focus is not only how sound is perceived or what it describes in terms of information, but also how it constitutes, shapes and continuously re-shapes culture and society. The social nature and meaning of sound is analysed by Bull and Back through a shift in "thinking with and through sound" (Bull & Back 2003, p.16), which allows a reconsideration of sound and listening as epistemological tools for sociological analysis.

2.3.1 Sound as knowledge

According to Bull and Back, to understand the social world, it is important to start to listen, rather than just to see. It is useful to consider how sound can be considered epistemologically, involved in modalities of knowing the world. Bull and Back consider acoustemology to be one of the theoretical frameworks involved in this process. Acoustemology is a concept developed by the ethnomusicologist and anthropologist Steven Feld, who describes it as the union of acoustics and epistemology that investigates the "primacy of sound as modality of knowing and being in the world" (Feld 1996). This dual relationship between knowing and being is for Feld indissoluble and embodied, as sound both "emanates from and penetrates bodies", and it is reciprocal to the "reflexive and historical relationship between hearing and speaking, listening and sounding". Acoustemology therefore considers the subject's constant sounding potential, of being both listener and producer of sound, which, according to Feld, shapes the relationships between bodies, places and time.

2.3.2 Sound as corporeal interaction

The permeability of the body to sound is at the core of the phenomenological approach of the American philosopher Don Ihde. According to him, a subject is constantly intertwined with the external world through sound. External sounds, such as sudden intense noise or non-constant loud sounds "disrupt" and "penetrate" the inner speech of the subject, which constitutes its continuous sense of "self-presence" (or thinking). At the same time, we can be "seduced" by sound, in particular by music, which temporarily "dissolves" our self-presence; one is "out of the self" (Ihde 1976). Continuing with Ihde's terminology, this happens because thought is embodied through language, and language itself is embodied in the auditory dimension and "hidden" in inner speech. Finally, Ihde underlines the bodily nature of sound as "felt and experienced in the body", transmitted through the bones and cavities in our bodies. The body itself therefore becomes a space of self-resonance for internal and external sounds.

Sound entails an experience, a form of participation, defined by media theorist Julian Henriques as "sounding" (Henriques 2011), which negotiates between the experience of immersion and resistance of the body to the sonic medium. As sound penetrates and resonates through bodies, it assumes a material connotation, exploring particular sound intensities affecting not only the human body but also the social sphere. He proposes the concept of Sonic Dominance to describe situations in which the overload of sound, such as the one experienced in Jamaican sound systems, creates situations in which "the sonic medium displaces the usual dominance of the visual medium" (Henriques 2003, p. 452). The word dominance is used by Henriques to underline the affective physical power of sound through vibration, suggesting the "material substance and imminence of the sound" which allows us to block out rational processes (Henriques 2003, p.457). It is a visceral experience that involves the skin and the bones. It is both an experience of "power" and an experience of "pleasure" mediated by sound and by the particular sound system. This not only evokes, but also creates temporary conditions of power and pleasure based on "connection, combination and synthesis" which is collectively shared. Sound is finally considered here as a full medium of affect and felt knowing, determined by its aspects of technical production and its infra-auditory and corporeal dimensions, such as vibrations and patterning (Henriques 2010).

Similarly to Henriques, Steve Goodman focuses on this corporeal and non-cochlear dimension of hearing, describing a materiality of sound created by contemporary sound technologies. This affects the whole body as pure vibrational force, controlled by policy makers, capitalised by political and military forces and subverted by emerging communities (Goodman 2009). For Goodman, the use of sound entails issues of power, which can be deployed with negative physical effects towards a “receiver”. Goodman describes the danger of acoustic weapons such as Long Acoustic Range Devices, developed in military engineering. These devices are designed to play highly concentrated beams of sound which are directed towards human individuals. The high sound pressure acts as an invisible bullet that can cause permanent damage. Goodman also describes other sonic weapons that use high power infra-sounds to discourage protesters by provoking a feeling of sickness due to the effect of low vibrations that cause internal organs to resonate. This shows how corporeal and affective aspects of sound have great importance in our experiences, considering not only how we think about sound but also what we feel through it.

2.3.3 Sound as social interaction

The anthropologist Steven Connor describes the participatory and bodily experience of sound created by collective hand clapping, which relates both to the sensorial and the social. Firstly clapping "makes you aware of yourself and the other in yourself" as it is both a sounding act and a touching act, revealing the fact that the person who claps is at the same time a subject and an object. He or she is the "doer and a done to" who creates an acoustic outcome. Listening to yourself and others clapping at the same time, creates an "energetic feedback loop" (Connor 2003, p.73). When crowds clap together the process is amplified and self-sustained because of the multiplicity of the bodies involved. Collective clapping is related to specific social situations, with appropriate codes and meanings shared by their actors and described by their rhythms, intensities and durations. However this is hard to control by the individual. In this sense, for Connor clapping is "pure multiplicity" such as swarms or storms, an assemblage of multiple entities into a morphing and ephemeral organism. Finally, clapping acts upon time and place by occupying it, by being one whole, or as Connor writes an "energy that tries to solidify itself as a substance" (Connor, p.75). This helps us to understand how sound can be an embodied and collectively sustained phenomenon.

The sociologist Paul Filmer explores how the relationship between time and culture is mediated by rhythmic actions. The act of producing music in particular is involved in the "social process of human being itself" where social structure is crystallised in musical structures. The practice of music and its "rhythmic muscular bonding" is not technologically based and does not disappear with mechanical reproduction of music as argued by Barthes (1977). Instead music itself contains and affords "rhythmic impulse for the articulation and enactment of human sociality" (Filmer 2003, p.110). The view that Filmer offers is the one in which music and sound are non-technologically or mediated processes, rather they entail some physical processes connected to the nature of repetitive action. We can see Filmer's view as an extension of the embodied aspects of sound, similar to the socially sustained sensorial activity observed in Connor, and applied to understand music's influence on social ways of being.

2.3.4 Sound as politics of everyday interactions

Historians and media theorists Corbin, Bijsterveld and Bull focus on how sound determines the everyday politics of space. For the French historian Alain Corbin, sound involves both geographical and social spaces, building territories and communities. In his essay on village bells in 19th century France, he considers the bells as markers of the social life of the villages' communities. Usually situated in the centre of villages, bells define the rhythm of the everyday activities of their communities. Examples of these activities are religious functions, the passing of time and warnings for collective danger, such in the case of fire. At the same time, their sound also defines physical boundaries of a territory by limiting space with their acoustic 'readily perceptible limits' (Corbin 1998). Sound can be perceived as an acoustic sign of social and geographical borders.

If sound acts as a "marker" for community, it also holds the potential to be used for social discrimination by constantly redefining the thresholds between "sound", "silence" and "noise". The historian Karin Bijsterveld argues that the mass-diffusion of cars started to fill cities with mechanical and electrical noises in the beginning of the 20th century (Bijsterveld 2001). This became a form of noise pollution. Rather than discussing matters of natural against the artificial, Blisterveld focuses on questions of power and politics of sound policing. She observes that the overproduction of sound was considered a problem of "education" rather than one caused by technological development. Therefore, policies for noise-abatement began to arise in Europe, mainly from rich elites, with the formation of an "Anti-Noise Society" founded in Germany by Theodor Lessing in 1908. Bijsterveld notices that the Anti-Noise Society suggestions against noise pollution were only made in consideration of the city streets. New pavements were installed to reduce the sound of the increasingly economically accessible cars. Conversely, no noise abatement was considered for the factories, usually owned by some of the richest members of the society who lived and worked elsewhere, illustrating what Bijsterveld considers an "elitist approach" to sound control. Finally, she claims that the "sound of technology is an aspect of technological culture". Noise becomes a handy label used by power structures to address the acquired ability of producing sound by lower classes. The same sounds that in an earlier technological development, such as in the first industrial revolution, were positively associated with the symbols of power, strength, progress, prosperity, energy, dynamics, masculinity and control, had now become a matter of concern and discrimination.

In his essay on the particular sonic environment of cars, Michael Bull describes the car interiors as a unique ecology built on a mediated sound space. This came with the introduction of the radio and recorded sound played back in the vehicle. By conducting a series of interviews with car drivers, Bull describes what constitutes a "privatized aural space" which is a 'safe and intimate environment inhabited by the mediated presence of consumer culture'. In this sense, for many individuals the car becomes a free and private space of listening that is not shared with the normal inhabitants of a house. For the drivers this becomes a way of "re-inscribing the ritual of everyday practices with the driver's own chosen, more meaningful set of rituals" (Bull 2003, p. 371).

Considered together, these writers focus on the borders between private and public, territories and social classes. Sound is considered as an important environmental and social aspect of the everyday, in both its acoustic and cultural dimensions: it is always a matter of public concern. It can be used to drive some social behaviours and at the same time to build a sense of local belonging in villages, as observed by Corbin. In other cases, its control in terms of noise reduction and the access to silencing technologies is appropriated by economically advantaged classes as a privilege and commodity over others, as discussed by Bijsterveld. For similar reasons, the acoustic dimension of sound, ways in which to control it, can help to build a private and intimate space for the individual, as noted by Bull. For these authors, sound has both a political and ecological dimension that determines the environment and the actions possible within it.

2.3.5 Sound as indicator of place: Acoustic Ecology

The focus on culture and society provides us with a way to understand how sound is important for humans. Sound can be analysed as a way to understand activities that take place in a particular environment or a geographic place. Acoustic Ecology, a discipline which emerged in the late 1960s with the work of Raymond Murray Schafer and his team at Simon Fraser University, Canada, investigates "the study of sounds in relationship to life and society" (Wrightson 2000). Schafer, a music composer and professor of Communication Studies, urges us to study the environment through listening to its sounds. This is because, according to Schafer, the contemporary environment suffers from an overpopulation of sounds causing noise pollution. He identified that the industrial revolution introduced a whole set of new sounds to the world, such as the ones produced by machines and cars.

The following electric revolution added its own sounds and the introduction of devices that can record sounds and re-transmit them separately from their natural sources. Schafer defines this phenomenon as "Schizophonia" (Schafer 1994). This makes the "natural" and human sounds less audible, causing effects that can be harmful for humans and animals. For this reason, he makes a call to listen to the environment and to take responsibility for an "acoustic design" of the world. This can help people to reduce noise pollution and to prevent the disappearance of "endangered sounds", such as "natural" sounds, which are increasingly being masked by louder industrial and electronic sounds. Acoustic design is here a relevant concept which helps us to think about the larger implications of design practices using sound. This does not concern sound design itself, but thinking about its modes of reproduction and transmission, its context and its local and global ecology.

Schafer proposes a few key concepts in order to understand the sounds in our environment. One of the key concepts is the "soundscape''; this term has been defined several times in the history of Sound Studies. For Schafer this is "the sonic environment", an object to study, which may be the actual environment or any abstract construction of it, such as a musical composition or electronic sound works (Schafer 1994). Barry Truax defines it as the basic term for acoustic communication, as "how the individual and society as a whole understand the acoustic environment through listening" (Truax 1984). For Paul Rodaway this is "the sonic environment which surrounds the sentient. […] The hearer, or listener, is at the centre of the soundscape. It is a context, it surrounds and it generally consists of many sounds coming from different directions and of differing characteristics" (Rodaway 1994). We can say that a soundscape is the equivalent of a pictorial image of place in terms of characterising audible events.

Schafer distinguishes three elements of a soundscape: (1) keynote sounds, (2) sound signals and (3) soundmarks. Keynote sounds are those which are part of an acoustic image and are always or very often present in a place. They can be consciously or unconsciously heard but their presence defines the general tonality of the sonic image. Sound signals are sonic events that disrupt the normal soundscape and which gain an immediate meaning, for example alarms or people shouting. In general these are the sounds that grab the attention of the listener. Finally, soundmarks are sounds that belong exclusively to a specific place or area (Schafer 1994). This terminology provides us with a lexicon for describing a sonic image related not only to a place but also to aspects of everyday life.

One of the greatest merits of Schafer's approach is the creation of a framework and tools to listen to the sonic environment consciously, including listening exercises (Schafer 1992) and classification grids. However, the idea of soundscape and Schafer's approach to acoustic ecology has been criticised. One issue has been raised by the French philosopher, urban planner and musicologist Jean-Françoise Augoyard. He proposes to study "sonic effect" rather than soundscapes, referring to the latter as a "miraculous, qualitative and hedonistic concept" (Augoyard et al. 2006). Augoyard's approach focuses on the effect that sound has on other agents, describing not a blurred static image but a dynamic complex scene of actions, causes and effects between all the agents within the environment. Another criticism comes from Redström who argues that acoustic ecology is not ecological enough (Redström 1998) as it is still too human-centric. This incomplete approach to ecology also poses ethical problems caused by aesthetic moralism, especially dealing with topics such as conservation based mainly on rejection of the urban modern world. The French composer and writer Michel Chion argues that Schafer's concept of soundscape is particularly problematic when listening in situ, as opposed to listening to a recording made in a particular area (Chion 2010). It imposes a way to listen that Chion defines as temporary and not precise enough because influenced by the sensorial and material context surrounding the listener and the impossibility of an accurate differentiation of different planes of sound in a single act of listening. We can see that Chion and Augoyard have in common the same criticism of Schafer's soundscape as being fundamentally imprecise, particularly on an experiential level.

Another strong objection to the concept of soundscape comes from the anthropologist Tim Ingold. In his collection of essays "Being Alive: Essays on Movement, Knowledge and Description" Ingold argues that the idea of soundscape is based on an incorrect visual metaphor (Ingold 2011), and that sound should not be compared to vision but rather to light. He observes that Schafer's soundscape is built on the equivalent of an aural landscape, similarly to photography or painting. This does not represent our sonic experience in the environment, our immersion, a condition that Ingold calls "ensounded". For Ingold we do not hear sounds but we hear *in* sound. His view places sound as neither material nor immaterial, but as a phenomenon of experience, requiring an emphasis on aspects of embodiment and mediation.

Acoustic Ecology offers ways to understand activities taking place in the environment by listening to its sounds. It helps us to obtain "sonic" images of particular contexts, a way to notice things happening within them by using listening. This can be helpful, for example, to researchers who want to use listening to understand contextual and environmental factors. However, it may not be sufficient as a model to understand our interactions mediated by sound. We have seen that sound is a more complex and embodied phenomenon than only what we can listen to. We cannot always be the "observers" of sounds. To better understand our sonic experience, we now need to look at other strategies and contexts, such as those that are specifically designed to invite our participation through sound.

2.4 Embodied Sound Perception and Cognition

2.4.1 Embodied and Situated Cognition

If acoustemology (Feld 1996) offered us a view of sound as a fundamental aspect of being and knowing the world in which we live, a phenomenology of sound (Ihde

1976) suggests how it penetrates our bodies and our reasoning. Concepts such as Sonic Dominance (Henriques) and being ensounded (Ingold 2011) focus on questions of the body in relation to immersion in the sonic medium. We can see these as forms of embodiment which are connected to cognition.

Recent developments in cognitive science and artificial intelligence consider the body as actively involved in the process of knowledge and perception of the world (Varela et al. 1991; Noë 2004; Wilson 2002; Anderson 2003; Clark & Chalmers 2010; Lakoff & Johnson 1999). This approach to cognition is rooted in embodiment and phenomenology of perception, foregrounded by the work of the philosophers Heidegger (1927) and Merleau-Ponty (1945). This view overcomes the Cartesian subordination of the body to the mind, which historically framed perception and the motor system as separate, functioning through sequential input-output relationships, which has been contested by several authors in the field (Varela et al. 1991; Noë 2004; Wilson 2002; Anderson 2003; Clark & Chalmers 2010; Lakoff & Johnson 1999). By relating together linguistics, phenomenology and neuroscience, Lakoff and Johnson (1999) advocate for an embodied approach in philosophy and cognitive science. In their book Philosophy in the Flesh, the authors argue that all the cognitive aspects of human life, from language, to the sense of reality and the construction of meaning, "begins with and depends crucially upon our bodies, especially our sensorimotor apparatus, which enables us to perceive, move, and manipulate, and the detailed structures of our brains, which have been shaped by both evolution and experience" (Lakoff & Johnson 1999, p.17). The interdependence between environment, perception, mind and sensorimotor apparatus impacts on our understanding of sound in its phenomenological and embodied aspects, as already seen in Ihde (1976).

ENACTION

In an embodied-mind thesis, the link between action and perception through bodily experience is fundamental to an understanding of how cognitive tasks take place. In the field of developmental psychology, Jerome Bruner argues that in the early stage of infancy, physical actions performed by babies, such as object manipulation and tasting, constitute a way to build knowledge of the world in which they are situated. This happens through continuous sensory feedback and adjustments. This concept is defined by Bruner as "enactive representation" (Bruner 1964). The concept of enaction is further explored by the neuroscientists and philosophers, Varela and Thompson and the psychologist Rosch in their book The Embodied Mind. The authors extend the definition of enaction, focusing on perceptually guided action, stating that "cognitive structures emerge from the kinds of recurrent sensorimotor patterns that enable action to be perceptually guided" (Varela et al. 1991, p.176).

The philosopher Alva Noë further claims that perception is practically action, it is "something we do" (Noë 2004). According to Noë and similarly to Bruner, experiences and explorations help to build our knowledge of the world, and the possession of bodily skills determine what is possible to perceive. In this sense, Noë suggests a strong relationship between perception, sensorimotor system and movement as "What we perceive is determined by what we do (or what we know how to do); it is determined by what we are ready to do" (Noë 2004, p.1). Comparing auditory experience to visual experience, Noë argues that sound perception fulfils these principles as we experience sound from the perspective of a moving body, continuously adjusting our head towards sound sources based on sensorimotor patterns. Noë's discussion of sound perception helps us to think about patterns and movement as a fundamental component of listening. Noë's focus on enaction can help us to think about sound and movement, and it links to Ingold's ensounded (2013), in which movement is a constitutive part of experiencing sound.

EXTERNALISM

As not all the cognitive tasks take place exclusively in the mind, the same can be said of the body's boundaries. The "Active Externalism" thesis of Clark and Chalmers considers the role of environment in driving cognitive processes (Clark & Chalmers 2010). Clark proposes the concept of "extended cognition" to include the world as part of the cognitive process and not separated from it. Indeed, "the mere fact that external processes are external where consciousness is internal is no reason to deny that those processes are cognitive" (Clark & Chalmers 2010, p.30). This happens through the formation of coupled-systems, such as the ones formed between the human bodies and tools and technologies. We use some artefacts to help us think, make calculations, measure and so on, therefore easing the cognitive load "outside" the brain and the immediate body. For Clark and Chalmers this constitutes a cognitive system based on a multiple, constantly emerging coupled interaction between the human organism and the external entity. This entails a process of inferences based on negotiation and extension of the sensing and acting body through multiple historical, technological and environmental layers described by embodied cognition.

2.4.2 Embodied Music and Sound Cognition

Studies in cognitive neuroscience have found links between the auditory and motor systems. In an experiment with primates, Kohler et al. demonstrate that mirror neurons in macaques are activated not only when they perform an action, but also when they see others doing the same action, and importantly, when they hear the sound of an action (Kohler et al. 2002). Similar results for humans have been shown by Zatorre et al. (Zatorre et al. 2007) in the study of music perception from the point of view of music performers. They explain that aspects of perception and production in music performers depend upon the interactions between the posterior auditory and premotor cortices of the brain. They also claim that this interaction is present, in different levels, between participants with different degrees of musical expertise, from non-musicians to professionals.

Questions of embodiment in music have been examined in the field of Embodied Music Cognition (Leman 2008), which originated in musicology and music performance studies. One of the principal concepts in Embodied Music Cognition is that music perception is related to mental simulation of physical action. For the musicologist Marc Leman, musical experience is a process rooted both in material, energetic qualities of playing and listening to music, as well to more ecological and social considerations. His approach considers the constant "mutual relationship" between natural phenomena, such as acoustic energy, and cultural constraints such as significations, attributions, meanings, norms and social conventions. Considering the example of making a musical instrument, Leman argues that this "involves action and perception in relation to the natural and cultural environments" (Leman 2008, p.53). The development of music itself is constantly linked to a co-evolution with the development of musical instruments and practices. This includes the acoustic resonances of the instrument, the sensorimotor apparatus of the performer and the listener, the cultural context of the music produced and socio-technological developments.

For Leman this forms an "Ecological Resonance Model" between the subject and the environment, in which "constraints of different types (physical, biological, cultural) interact on the basis of mutual exchange of energy", an energy that is both acoustic and physical. Leman's ecological model is closer to an ecological approach to perception (Gibson 1979) rather than acoustic ecology. It shares a more embodied perspective to music than the one of a distant observer. A subject is directly involved in a contemporary process of sound production and perception, similarly to Ihde's understanding of the phenomenology of sound. This constitutes a sort of interaction loop, between internal and external states mediated by sound, which is acted out by the body, afforded by the environment and reinforced by culture. Leman adds that "the dynamic model of the subject/environment relationship holds that action and perception can turn natural constraints into cultural constraints, which in turn have an effect on action and perception" (Leman 2008, p.59). It also involves an understanding of the action-relevant value of sounds, the judgement of these sounds in view of musical ideals, and shaping the physical environment that produces sound. All this proceeds within the confines of a cultural goal. Finally, it follows that through action, humans are able to turn physical energy into action-relevant concepts and cultural artefacts, such as in the case of music and musical instruments.

Rolf Godøy argues for a motor-mimetic theory of sound perception (Godøy 2003) in which he claims that "perceiving sound is closely linked with mentally simulating the gestures that we believe have been made in the production of sound" (Godøy 2006, p.70). Inspired by electroacoustic composer Pierre Schaeffer's reduced listening (Chion 1983), Godøy investigated the link between gestures and "raw sonorous objects" arguing for an intimate, corporeal and felt link between energy aspects and morphologies of both gestures and sound. These sound objects are for Godøy, embodied as co-articulated gestural-sonic objects (Godøy 2010a), which are based on chunks of perceptual auditory groupings from psychoacoustics (Bregman 1990). These are linked to the perception of acoustic energy which is mentally simulated as motion, causal descriptions of sound events and representations of sound sources (Godøy 2010b). He goes further by proposing a link between musical sounds and their affordance for gestural renderings, as being part of "ecologically founded energy schemata" (Godøy 2010b, p. 112). These schemata comprise renderings of movement perceived in terms of trajectory of sound over time that can be represented by gestures. This is finally used by Godøy to propose gestural affordances of musical sound as affording gestures which follow shapes and trajectories evoked by musical sound. This suggests a need for research into sound-related affordances, because of the intimate link between sound perception and movement production, which could be exploited in the design of interactive systems.

2.5 Affordances

In "The Ecological Approach to Visual Perception", Gibson (1979) considers the environment and animals as complementary to each other. The environment determines what animals can do, what it affords them for life, such as nutrition and locomotion. The environment consists of three main components, the substances, the medium and the surfaces. These components, together with animal sensorimotor abilities, are important for the animal's life, laying specifications for what that creature can do.

According to Gibson, information is present in the environment in ambient light. One of the main points in Gibson's understanding of visual perception is the configuration of optic arrays. An array is a stable and fixed arrangement between the perceiver and environment. The movement of the perceiver changes the perspective of viewing in a proportional way related to the configuration of the array, disclosing or hiding available information already present in the environment. Static objects can be seen as invariants, while moving objects are perceived as changes. We are able to pick-up information about events, or things that happen around us because of the local disturbances of the configuration of the optical array and the new configurations resulting from them.

Gibson's hypothesis is that animals perceive information regarding possible actions. Affordances are all the possibilities of actions that are latent in the environment which are available to a capable animal. These are dependent on the environment and by the specific sensorial and physical characteristics and capabilities of the animal. A bridge affords humans to easily cross a river underneath it. A bird would not need the bridge to cross the same river, however the bridge may provide it with different affordances. For example, the bird may use the bridge's handrails to rest and spot fishes, therefore saving energy for hunting, and subsequently adapting its hunting technique. Human intervention in the environment (such as the example of the bridge), through creating changes to its substances and materials, creates new affordances shaped by human needs.

2.5.1 Affordances in Interaction Design

The concept of affordance has been applied in Human Computer Interaction and Design in order to understand and improve users' interactions with systems and designs. Affordances have a close relationship with usability: affordances can be understood as immediately readable information, without the need of instruction for the user about how to use an interface. Gaver extends the discussion on affordances by discussing their possible perception, as they can be visible, hidden or even false. The concept of affordance for Gaver

> *"points to a rather special configuration of properties, which implies that the physical attributes of the thing to be acted upon are compatible with those of the actor, that information about those attributes is available in a form compatible with a perceptual system, and (implicitly) that these attributes and the action they make possible are relevant to a culture and a perceiver." (Gaver 1991, p.81).*

Affordances can be complex and hierarchical, as they can reveal other affordances. They are sequential when they are revealed by exploration over time, while they are nested when they are based on spatial relationships. Gaver gives an example of a sequential affordance, entailing the opening of a door by pulling down the handle and hearing the click of the latch. By hearing the click the subject can understand that the door can be opened. A nested affordance is, for example, using a stick to recover a ball that is stuck over an otherwise unreachable tree branch. The concept of affordance finds practical application when designing graphic user interfaces. Gaver provides the example of the scrolling bar. This is designed to afford to the user the action of dragging up and down the bar with the mouse to show files that otherwise could not be seen in the graphical interface (Gaver 1991). By designing a scrolling bar that invites the user to drag it up and down with a mouse, rather than writing a textual instruction or typing a command on the, designers can place the information for action as embedded in the object and facilitate the interaction between the user and the system.

Norman argues that users need to perceive affordances to have a successful interaction (Norman 1998). A perceived affordance constitutes what he considers as a social signifier shared by people (Norman 2008). For Norman placing a button on the graphical user interface of a mobile is not placing an affordance. It is using an already known signifier that is social because of the familiarity that users have gained through years of usage of graphic interfaces based on metaphors of buttons, sliders and icons. In this sense a signifier reveals how information is perceived and shared, indicating possible action, often by relying on metaphors. This is based not only on physical constraints, such as Gibson's affordances, but also on behavioural constraints, which are based on physical (based on intuition due to physical compatibility between the agent and the environment), logical (based on reasoning and deduction) and cultural (based on conventions and cultural aspects) (Norman 2008) Norman's model offers us a way to think about the relation between affordances, signifiers and the social. Thinking about these three levels of behavioural constraints to understand implications for sound design and interactions is important, as sound is inherently an ecological event we can perceive in the environment and that defines particular socio-cultural settings.

McGrenere and Ho (McGrenere & Ho 2000) make an attempt to clarify the notion of affordances by comparing the ecological approach from Gibson and Gaver to Norman's one. Agreeing with an ecological perspective, they move away from dualistic views which argue for or against the existence of affordances. McGrenere and Ho propose the concept of the degree of affordances, which considers complex hierarchical aspects. Importantly for design, they argue for a separation between affordances and their perception as both useful in separating the utility (the function) of an object from their usability (how easy is to use it to achieve its main function).

Still and Dark (Still & Dark 2013) discuss that a more cognitive approach to affordances can be useful to understand the step between perception and "automatization" of actions. By reducing the scope of attention to perceived affordances only, they argue that these can arise when the cognitive effort is minimal, but they may be influenced by the consistency of previous designs that users may have already experienced. For example, a current smartphone shares the same numeric pad layout for its phone calling functions with a first-generation mobile phone equipped with a physical numeric keyboard, although in the smartphone the buttons are drawn digitally on the screen and hidden in a sub menu, while in the old phone they are physical. The cognitive effort to make a call using the numeric layout is very minimal and being automated not only by the supposedly intuitiveness of the layout, but also from the experiences that users have gained with the same layout over the years. Still and Dark offer a view of affordances in which the tension between elements of “direct perception” from ecological psychology are considered at the same time of the history of the subjects in their everyday, relating for example cultural aspects and the context of interaction.

2.5.2 Affordances in Sonic Interaction Design

Sound as a physical phenomenon can contribute to the perception of information about affordances provided by an object. We can hear the click of the door opening after we pull the handle and understand we can open it. Studies of auditory aspects of affordances have been proposed for medical contexts and for the study of perception. Stanton and Edworthy (Stanton & Edworthy 1998) apply Gibson’s affordance to inform the design of auditory warnings for medical treatment units in order to communicate the potential for specific actions, rather than generic warnings. Rosenblum et al., (Rosenblum et al. 1996) studied how listeners evaluate sound as information for the evaluation of proximal distance between a subject and a sound source. Their findings show how sound perception helps perceivers to gather information about the reachability of a sounding object.

As we have seen in earlier, object manipulation by auditory feedback is explored in Sonic Interaction Design (SID). Franinović explored how everyday actions may change within sonically augmented everyday objects, such as sonic drinking glasses, which affects the way users drink (Franinović & Visell 2007; Franinović et al. 2008). Lemaitre et al. (2009) showed that continuous sound feedback helps users in manipulating tangible interfaces. These previous works investigated the contribution of auditory feedback on physical and social aspects of manipulating and using an object, however we need more research in SID that focuses on sonic interaction, related to bodily actions and gestures, without the intermediate presence of a device or an object.

2.5.3 An ecological approach to sound perception

A consideration of an ecological approach to perception is important at this point in order to understand our sonic experience, and how sound contributes to the perception of action possibilities. This section builds upon my review of approaches in Sound Studies and Acoustic Ecology through an exploration of the understanding of embodied action sound relationships and their link to psychological and ecological aspects of sound. Gibson helps us to understand how information may be placed in the environment and our perception, and how it is configured in optic arrays. Following a similar shift from a visual-centred approach to considering sound, it is useful to consider how an ecological approach to sound perception may deepen our understanding of how sound reveals information to us about interactions in the world and possibilities for action.

Gaver's work in sound perception analyses ecological aspects of what we hear (Gaver 1993b) and how we hear (Gaver 1993a). He argues that hearing sound in our everyday conveys meaningful information about events happening in the environment around us. His research into everyday listening involves mappings between physics of events and the attributes of the sounds that convey information to a listener. Gaver's focus on everyday listening is helpful for defining a framework for describing sound in terms of audible source attributes.[7] Changes in frequency and the temporal aspects of sounds are determined by interactions between materials and substances, and their specific physical attributes, including the medium of propagation of sounds.

2.6 The Experience of Listening

Discussing the many facets that listening unveils about our everyday sonic experience is significant within Sonic Interaction Design. Listening can be conceived of as a modality in which we dispose ourselves as receptors of something outside ourselves, through sound and our hearing abilities. We actively decide to listen when we want to hear a conversation between two people, with a specific focus on grasping the meaning of words spoken by the others. We also

[7] As opposed to *musical listening*. This is as a different way of listening to sounds and implies the perception of energetic and physical aspects of sound, such as its spectral energy, pitch, timbre and other "musical" properties of sound.

find ourselves listening, rather than deciding to listen. For example, it can be difficult to stop listening to the conductor's announcements when we are travelling on a train, even if we are absorbed in reading a book. At the same time, listening comprises a tension between the different signifiers and affordances of sound. An attention to the topic of listening can potentially help us to understand unconsidered aspects of sonic experience, envisioning and improving the design of interactions that fit in already rich multi-sensory dimensions of our everyday. It may also help us to understand our different dispositions to sound.

2.6.1 From Hearing to Listening

Hearing and Listening are two modes in which we experience sound as we slip between presence and attention. Hearing sounds conveys possible information about events happening around us, or something that just happened around us in a very close and immediate past. It helps us to locate ourselves in space and time through the presence of sound. However, hearing is never enough in itself, but points us to activate listening, which can be seen as a form of temporal attention which prepares us to perceive events in the immediate future.

Hearing can be considered as the ability to perceive mechanical vibrations as sound. It differs from listening, as it does not involve an attentive focus. We can hear sounds without the specific intention of doing so. For example, a writer can hear the clicking sounds produced by typing on the keyboard and intentionally ignore them. Listening is an activity we carry out. It can bring our attention towards unnoticed sound.

2.6.2 Listening as a bodily disposition to information

Gibson (1966) gives to listening an important active role in the auditory system. He identifies sound waves as potential stimuli, as existing in the environment with or without our presence as perceivers. Sound becomes an actual stimulus when it reaches our ears. Listening is something that we do to orientate our bodies towards the sound source and to pick up possible information about it, which may be helpful or even of vital importance to us. We can see listening as a way in which - as animals - we perceive events in the world as being afforded by the coupling between our innate sensorial apparatus, the sound waves produced by the physical and chemical interactions in the environment between the different materials, substances, and propagated through different mediums. Perceiving events by hearing and listening to sound means to potentially perceive information that is available over time and out of the reach of our eyesight - beyond the static arrangement of surfaces and moving objects gathered through vision.

Gibson further explains that listening to sounds involves two different categories of processes: (1) orientation and localisation of the event, (2) identification of the event. This difference is dependent on our sensorial apparatus - the ears, the head and the motor system - the physics of the sound waves and their propagations through the medium we encounter. Listening is therefore connected to the way we dispose ourselves towards picking up possible information. Gibson rightly specifies that the environment does not transmit any code or message, but it is the coupling between the animal and the environment that affords this (Gibson 1968). This information is not available per se; it is not encoded by a medium and then decoded by us. It is afforded by the events happening in the environment and their resultant by-products in terms of energy patterns that can be picked up by our sensorial apparatus, and their relation to our needs. Listening is afforded by sound, by our sensorial apparatus and by our needs for surviving and living. It is a bodily disposition towards sounds that is linked to the awareness of the external environment and our own presence.

2.6.3 Listening as formation of the self

Listening is also linked to the process of forming the self and identity. Sound can be understood as a form of exteriority and listening is something we do to understand the world, on various levels of consciousness. The philosopher David Michael Levin describes the experience of listening as a stage of formation of consciousness in the growth of the individual, which is for him as a Sonorous Being. He describes four stages of listening: (1) Zugeôrigketi, or primordial attunement, (2) everyday listening, (3) skilfully developed listening and (4) harkening. Levin's categorisation draws parallels between other categorisations of the individual to include complex processes such as social interactions. These stages are not a straightforward and linear progression, rather they are carried forward by preserving elements of the previous ones (Levin 1989). The primordial attunement relates to an initial perceptual awareness of the self because of the ability of hearing. This ability then becomes specialised to decode events as information about possible actions, as in the case of everyday listening, but it is never lost in the following phases. The experience of listening is inherently complex and dynamic and it occurs not only during the temporality of the sonorous event itself, but also within the lifetime of the individual.

The philosopher Jean-Luc Nancy analyses listening to understand our physical and conscious presence in the world (Nancy 2007). By analysing the nuances in the French language regarding our encounters with sound, Nancy focuses on understanding processes in which the intentionality of the listening subject is not central and determined by the subject's willingness, but rather by a process of resonances between the self and the sonorous phenomena. Listening defines a threshold, an edge between ourselves, the acoustic phenomenon, the sound producing object and the possible creation of meaning through a resonance. This resonance does not affect only the physical level, but it is also based on symbolic and cultural dimensions. The self is simultaneously resonating with the sonorous thing itself and outside of the self through listening. In Nancy's words:

> *"To be listening is always to be on the edge of meaning, or in an edgy meaning of extremity, and as if the sound were precisely nothing else than this edge, this fringe, this margin—at least the sound that is musically listened to, that is gathered and scrutinised for itself, not, however, as an acoustic phenomenon (or not merely as one) but as a resonant meaning, a meaning whose sense is supposed to be found in resonance, and only in resonance."* (Nancy 2007, p.7)

Nancy's theorisation of listening offers us a different way in which listening is not necessarily described only in terms of intentionality of the subject. It liberates sounds from the linguistically bound component of the thinking subject, through processes of resonance of affect and becoming through listening, as we have seen with Henriques' concept of sonic dominance and Ingold's idea of ensounding, describing sound as something we do not listen to but we listen in.

2.6.4 Listening Modes

It is important to note that the act of listening can assume different connotations according to the specific needs of listeners or their situations. There have been numerous attempts to categorise the range of listening experiences. The musicologist David Huron describes listening modes as the "distinctive attitude or approach that can be brought to bear on a listening experience" (Huron 2002). It is worth investigating some of these distinctive ways of listening in order to understand what we listen for and how we find ourselves as listening. The following sections describe a few typologies of listening that focuses on meaning making of the world, deep listening, listening to our own actions, corporeal forms of listening, phenomenological and experiential forms of listening.

MEANING-MAKING AND CONTEXT

In one of the most important works on the phenomenology of sound, the composer Pierre Schaeffer describes four types of experiences of sound (Chion 1983). We can perceive sound (Ouir), we can listen to it (Ecouter), we can hear it (Entendre) and understand through it (Comprende). Schaeffer's description unfolds the complexity of hearing and listening as processes that relates together perception, sound, consciousness and meaning.[8] It involves us as listening subjects, the sound as an object outside us and ways in which we make sense of the world through our listening capabilities.

Barry Truax relates cognitive processing and meaning-making to our ability of listening. He declares that "a general characteristic of cognitive processing that seems to lie at the basis of listening is the detection of difference" (Truax 1984, p.19). Listening is therefore positioned as an orientation in which we dispose ourselves attentively to gather possible information that is retrievable because of this detection of a sonorous difference. He describes three kinds of listening. The first is "listening-in-search", as an attentive, conscious focus in the environment for gathering sonic cues, which provides the "difference" that can be discerned by the listening subject, facilitating a conscious process of meaning making. The second, "Listening-in-readiness", describes a state in which we are ready to receive information through sound even if our attention is directed elsewhere. The third, "background listening", indicates the general inattentive type of listening and the realm of unnoticed sounds that we can physically hear but we temporally ignore because other cognitive tasks are taking place.

Michel Chion draws upon Schaffer's typologies to identify objective and subjective relationships with sound and their relative modes of listening (Chion 1994). These are Causal, Semantic, and Reduced. Causal listening involves the

[8] Terms in French language in the original text.

listener focusing their understanding on which source produces the sound. In Semantic listening, the purpose of a listener is to understand the code that a series of sound can represent. For example, a listener can understand spoken language because of the phoneme produced by the speaker and the grammar and syntax of the language itself which he/she is able to comprehend. Reduced listening is the mode in which a listener focuses on the acoustic attributes of sound itself, independently by its cause or meaning. Pierre Schaeffer also proposes the concept of "reduced listening". For both Schaeffer and Chion, reduced listening can be considered as a specific way in which we listen to sound looking for its acoustic, spectro-morphological, and musically relevant characteristics. This is a form of analytical listening based on categorisations of the acoustic phenomenon, commonly used in specialised practices such as music theory, composition and psychoacoustics. Listening for intentional reduction is useful for music composers who may use everyday sounds in their compositions. This is particularly relevant for cases in which the sound is not reproduced by its natural sound source, such as in acousmatic sounds, technologically mediated reproduction of sound, for example a digital sound played back by a computer. Reduced listening is a very strong intentional mode of listening which focuses on defining characteristics of sound which require substantial effort in terms of concentration, as well as the skill of the listener to build categories in which a sonic phenomenon can be differentiated. To give an example, discriminating the sound of a magpie from one of a robin requires both an analysis of certain features of sounds, such as pitch, phrasing, rhythm, and a knowledge of how other birds sound. These skills are not immediately available to a listener who is not a trained ornithologist.

It is important to observe that Chion's work is based on understanding complex relationships between perception, sound, image, and movement in the context of cinema. His most famous text, "Audio-Vision" (Chion 1994), discusses this link as a form of "contract" between the perceiver and the perceived and how artists, composers, and directors can use it to in the service of the audio-visual experience of cinema. Understanding listening for Chion is therefore instrumental to manipulate what is felt as a very embodied tie by perceiver, between the image seen and the sound heard. Understanding listening is instrumental to designing a continuous sense of logic that involves their affective (as pre-emotion) and conscious dimensions. It states that action-sound relationships can be continuously manipulated as they need to be believable and meaningful, and not necessarily realistic. The meaning-making power of listening is therefore a useful process for understanding the design of novel interactions mediated by sound.

On a macro-level, listening can give us a sense of place. We have already seen in acoustic ecology that listening can help us to distinguish the acoustic balance of a particular place, by analysing its most recurrent and characterising sounds ("keynote sounds"), place-specific sounds ("sound marks") and functional sounds with an immediate meaning ("sound signals") (Schafer 1994). Augoyard extends the possibility of listening to the sonic effect of a place, focusing on process of transformation and propagation of sound rather than just the presence of the sound sources. Discussing a phenomenological approach to sound, Brandon LaBelle regards listening acts as a multisensory reconfiguration and negotiation between different senses. In his words "listening became more fully an act of imaginary projection and transference, often occupying a temporal zone where a visual source was suspended and reconfigured according to auditory association." (LaBelle 2010, xx). In this way we shift towards temporal present moments and contexts. Within listening it becomes possible for the invisible to become noticeable, not only to ourselves as individual beings, but also to others. Listening is, according to LaBelle, a form of participation towards the sound event. By participating in the sound event we also participate to its context, making sense of the situation in which we are. When we listen to sound we listen to the context of established relationships, negotiations and interactions between ourselves as listening subjects, as individuals and as part of the social. We listen to sounds as physical phenomena, to their physical reverberation through surfaces and materials, as constitutive elements of space, and to cultural resonances propagated through auditoriums, hospitals, churches dance halls, websites and many other everyday places.

DEEP LISTENING

The late American composer Pauline Oliveros described a holistic process of listening which brings together different levels of awareness of sound, which may be external or internal to the listener. In her Sonic Meditations pieces she introduces a praxis of listening as an active process for spontaneous sound making and self-awareness (Oliveros 1974). Usually performed within groups of people with various degrees of musical preparations - including non-musicians - these pieces require concentration through four main activities: (1) Actually Making a sound, (2) Actively Imagining Sound, (3) Listening to present sounds, (4) Remembering sounds. These activities help listeners to bring to their awareness the whole dimension of sounds around them, external and internal. In particular, imagining sound and remembering sound points the listeners towards their own ability to evoke a lived sonic experience which is rendered internally, similarly to a form of listening without sound.

Oliveros' strategies for activating listening processes are part of what she considers the practice of deep listening, which she describes as

> *"listening in every possible way to everything possible to hear no matter what you are doing. Such intense listening includes the sounds of daily life, of nature, or one's own thoughts as well as musical sounds. Deep Listening represents a heightened state of awareness and connects to all that there is. As a composer I make my music through Deep Listening."* (Oliveros 2000, p. 37)

For Oliveros this is a composition strategy - encompassing very important aspects of a spiritual and holistic view of human existence - as a way of producing music based on an immersion in what is perceived to be the sonic world, the one around, inside and outside the listener, not only spatially, but also temporally. Deep listening is a practice that needs to be cultivated to raise a developed and new form of awareness of sonic experience. Importantly it provides methods to shift a listener's attention towards not only the world of sound, but also to themselves as listeners.

ERGO-AUDITION

The link between our moving body, sounding and ability to hear is another factor to consider when we analyse listening. In "Le Son", Michel Chion describes "ergo-audition" (Chion 2010), a modality in which listening reveals our sense of agency in the production of sound as a direct consequence of our own bodily actions. For example, we may be suddenly aware of our footsteps on a cracking wooden floor. By hearing sounds we produce with our actions, we become aware of our sounding potential, which can lead us to move differently. For example, we can walk slower if we want to avoid being loud and disturb another person that may be in the same space as us.

We have previously seen the anthropologist Steven Connor describing how clapping in public constitutes a form of collective sounding actions sustained by an energetic feedback loop. This can be seen as a form of collective ergo-audition that resonates with the affective position described by Nancy, affording an embodied resonance. Ergo-audition is therefore a complex mechanism in which we listen to our agency in the world and therefore an important mode of listening, especially in the case of listening to our interactions in the world.

EMBODIED LISTENING

Research in embodied music and sound cognition focuses on enactive aspects of sound perception, describing how gestural and bodily movement can be used to articulate descriptions of sound. The gestural tracing of a sound can provide both kinaesthetic and associative, extra-auditory information. By rendering sound as movement we can study the relation between the temporal aspect of sound and what we identify as action. This gestural rendering helps us to highlight not only matters of bodily response to sound. It also offers us ways in which we can try to frame bodily enaction as a form of communicating a visual impression of a sound heard.

We can see this as a form of embodied listening, which combines aspects of built and enacted relationships between the temporal/energetic profiles of sound and bodily response of the listeners. As we have seen earlier, Godøy and Leman focus on evoked corporeal response of musical stimuli and listening focusing on an imitational aspects of spectro-morphological and time-based profiles of sound in one case, or gestural association with playing a musical instrument or conducting music on the other. In addition to their accounts of embodied listening, listeners may draw upon other non-sonic elements of associative process with sound, such as those rooted in their cultural baggage, or in their memory. This can form a repertoire of action-sound relationships, gestures and movements, conscious and unconscious, that may go beyond pure musical or sonic aspects, instead drawing upon other experiential aspects.

In embodied listening we pre-consciously use the body as part of the listening process, as a way to relate to both the temporal pattern-based aspects of sound and to its symbolic everyday dimension, which affords our bodily participation in the sonorous event. In the complex scenarios of everyday interactions that exploit our bodily movements and sound feedback, embodied listening is another type of listening, mainly preconscious that needs to be carefully considered and exploited.

Baptiste Caramiaux, Jules Françoise et al. (Caramiaux, Françoise, et al. 2014) use the concept of embodied listening as a way to design gestural-sound mappings. They claim that by looking at action-sound relationships arising from analysing different listening modes, such as Causal, based on sound-source, and Acoustic, based on sound features, designers can implement instantaneous, temporal and metaphorical mappings which are intuitive for the users. Embodied listening refers to action-sound relationships that are revealed through bodily movement of the listener, such as gestural rendering of sound.

AFFECTED LISTENING AND FELT SOUND

Claire Petitmengin's research focuses on phenomenology of experience which she investigates using first-person and introspective methods to gather people's experience from their own perspectives. In a specific research article on sound, Petitmengin et al. (Petitmengin et al. 2009) use experiments, interviews and discourse analysis to find out how participants describe their experience of listening. They ask participants to describe the different sounds heard as stimuli. They perform this task in various iterations, to retrieve various levels of experience from participants. Petitmengin et al. identify three categories of listening: (1) Listening to the source of sound, (2) Listening the sound object, (3) Listening to the felt sound. All these categories are characterised by elements of perceived results, multi-modality of experience, "attentional disposition" and the "experienced space" between the sound and listeners.

The first of these categories (1), describes the processes in which we tend to identify possible sound sources. According to Petitmengin this can be characterised by the evocation in our memory of similar sound producing events and objects, which may or may not be the actual ones involved in the sound heard. This implies that we actually imagine what we think is the related "sound source". For example, the sound of bouncing ball can either evoke the image of a basketball bouncing to some people, or the image of a tennis ball to others. In this case the focus of attention is completely directed to the source of sound. The perceived experience of space between the sound sources and us becomes invisible, as the sound source occupies our attention. In the second category of listening we listen to the sound object. We tend to focus our attention towards acoustic features of sound, independently from its source. We are not interested in recognising sound as information for a cause, rather to hear the "sound in itself". Petitmengin gives us the example of listening to the timbre of voice without paying attention to the words spoken by the voice heard. When we listen to sound we are more focused on an attentive listening to identify temporal changes of sound per se. It requires an effort from us as listeners that is not present while we listen to sounds as sources. Petitmengin argues that the perceived experienced space is more "dense" between the ear and the sound source, which makes the latter "invisible" to us. The third mode of listening is "felt sound", which describes what sound does to the perceiver. Here the listener focuses his or her attention on the experience in itself. A felt sound has a tight relation with the body or the emotional state of the perceiver, as a matter of resonances, intensities and feelings. Our whole body, rather than only our ears, constitutes a very active part of the listening experience. The sensorial experience of sound is transmodal, involving visual, tactile, olfactory, kinaesthetic and somaesthaetic resonances. Sound is experienced as a threshold, direction and attentional disposition, which synchronises, extends or collapses inner and outer spaces of the listener.

EXPERIENTIAL LISTENING

Kai Tuuri's research on listening considers aspects of action, meaning-creation and experience informed by theory of embodied cognition (Tuuri & Eerola 2012; Tuuri & Peltola 2014). His research focuses on extending the taxonomy of possible listening modes to achieve a better understanding of the complexity of the subject, by extending previous literature on listening modes. One of their major contributions is the concept of "embodied resonator" as a way in which perception of sound, listening, sensorimotor abilities and experience are connected to the creation of mental images of action-relevant clues in the world. In Tuuri and Eerola's words the "embodied resonator functions as a mediator which permits patterns of sensation to be inferred in terms of mental imagery being projected from the structured nature of experiences" (Tuuri & Eerola 2012, p.145). This means that listening affords the creation of meaning-making for possible actions, even in the case of imagining "patterns of sonorous sensations", such as remembering a particular musical phrase. By looking at this embodied and ecological approach to sound, Tuuri and Eerola distinguish three hierarchical levels of listening, each one consisting of three sub-levels. These macro-levels of listening are (1) Reflective, (2) Denotative and (3) Experiential.

The first macro level of listening is the "Reflective", which involves listening as a strongly analytical process. This level includes reduced and critical listening as discussed earlier. Reduced listening, as already identified by Schaeffer and Chion, is here considered as a modality in which our sonic experience is voluntarily turned towards a process of analysis in which "listening is a self-reflective analysis of one's listening experience and, by resisting any denotations, also intentional manipulation of that experience" (Tuuri & Eerola 2012, p.149). The critical listening focuses on an analysis of the appropriateness of a sound to its situation and to the perceived intentions of sound-producing agents, taking into account experience and context.

A second main level of listening is the "Denotative". It encompasses a spectrum of modes in which individuals build meaning through listening. These spread from a more source-oriented focus, such as identifying the causation of sound, towards more context-based aspects that span from subjective and empathetic relationships with sound, to functional and semantic characteristics of sound heard.

The "Experiential" mode takes into account different levels of action-sound couplings and their relative mental images which we build, some of these in a pre-attentive way. Tuuri and Eerola include reflexive and connotative modes of listening, as already discussed by Huron, and importantly adds the kinaesthetic mode. This mode is based on a mentally built association between sound and quality of movement, denoting a gestural quality of sound perception. The experiential modes of listening are important in this discussion on modes, as it considers unconscious, pre-reflective aspects of experience, which go beyond the established views of listening as a purely matter of intentionality.

2.7 Imagining, Remembering and Re-Evoking Sonic Experience

So far I have reviewed modes of listening in which sound was heard, identifying three main typologies. However, this list is not exhaustive and many authors have worked towards an expansion, rather than a reduction of the listening modes, to include the complex nuances of listening experiences (Huron 2002; Petitmengin et al. 2009). The listening subject, through the resonances between sound, consciousness and the external world, points the attention towards aspects of causality between action and sound produced by the others. An action-sound relationship can be understood as a sensorial coupling that is perceived as meaningful by the subject. This coupling occurs on several levels, forming an "ecological resonance" as described by Leman, earlier in section 2.4.2. It is a familiar, embodied, cultural relationship that is perceived as authentic, in which sources and events are linked through sounding and contribute to the meaning-making of the listening subject's world.

The account of experiential listening based on auditory experience unfolds a phenomenological account of sound from the perspective of the listener. This helps us to conceive of listening as a way to understand our embodied experience with sound. Sounds cannot only be heard, but felt and evoked from memory. This can contribute to an expansion of our understanding of listening as an activity that goes beyond hearing sound in a given moment and rooted in our everyday lived experience.

Taking into account this complexity, I now want to consider listening experience without sound. We have seen how different types of listening unveil conscious and unconscious relationships with sound. By thinking about listening without sound, as a stimulus not present at the time of listening, we may able to access other unconscious, introspective, affective and embodied encounters with sound and deepen our knowledge about sonic experience.

In the following sections, I describe three modes of listening without sound. The first is to imagine sound, the second is to remember one sound from the past, and the third is to remember a sonic experience, which focuses specifically on extra-auditory information.

2.7.1 Imagining Sound

Imagination is the mental activity of thinking about something that is not present to our perception at that moment. It may be an experience lived in the past or yet to be lived in the future. Imagination can go beyond what is necessarily real, yet it requires the perspective of the imaginer and their capacity to build a mental "rendering" of the imagined thing. It is a process that relies on a potential embodiment - as a process, as appropriative projection towards the thing itself - of the imaginer with the imagined thing, structuring a form of experience. For Ihde it “presentifies” external experience to the inner self, as an image. I present the following example to try to explain this process. Reading the sentence “A blue butterfly flew over the dirty boots before turning itself into a red caterpillar” implies the creation of an image in our head. This image is temporal – it changes over the time - because I chose the verbs “flying”, “turn”, the adjective “blue” and “red” for the same subject (the butterfly/caterpillar), and the temporal adverb “before”. This indicates a link between imagination, language and our experience, even in the case of a non-realistic situation, such as the butterfly turning back into a caterpillar. According to neuroscientists and cognitivists Vittorio Gallese and George Lakoff, imagining is a form of mental simulation that frames understanding as perceiving and doing, because it is deeply embodied. This embodied link may rely on the fact that imagination and perception involve the activation of many of the same neurons (Gallese & Lakoff 2005). Imagination requires a full embodiment in a temporal and contextual shift, encompassing lived past and possible future.

Imagining sound can be seen as an internal simulation of listening to a sound that is not present to us as an external auditory stimulus. It can be a previously heard or non-existent sound. It consists of an equivalent shift towards a sound that is not physically propagated and heard in the moment in which we are thinking about it. According to Mark Grimshaw et al., imagining sound is similar to hearing it, “much as sound perceived in the presence of sound waves” (Grimshaw & Garner 2014). Hubbard (2010) reviewed an exhaustive literature of psychological and clinical experiments on the subject of auditory imagery. These experiments strongly suggest that many of the mirror neurons activated while imagining a sound are the same as those involved when one hears an auditory stimulus. Thus the auditory imagery shares elements of the perceptual-experience of hearing sound. Sound is re-heard by an internal simulation that involves different parts of the brain and motor system. Similarly to the butterfly example I used to discuss imagination, we can imagine the sound that the butterfly made. Even if we may not know how a butterfly sounds because we may have never heard it, we can imagine the movement of butterfly’s wings to produce a “flapping” sound. This flapping sound is now internally simulated while we read this sentence, even if it may be a different sound to the real one. We combine an everyday experience of listening to a flapping action, such as the one of a pigeon flying, by imagining the butterfly taking off the ground and scaling down the size and organic material of the butterfly's wings, to make it sound softer.

Imagining sound can be seen as a powerful way to think about processes of sounding and listening in our approach to designing sonic interactions. It can help to expand the concept of the "sonic" in SID by considering sound not only in its presence as an external stimulus, but as part of an experience designers can draw upon and incorporate on more imaginative levels.

2.7.2 Remembering sound

When we remember sound we access our memory. We re-imagine and re-hear a particular sound internally. This particular sound is the one we remember. We heard this sound in the past and it was specific to an experience we personally lived out. Imagining sound can be linked to an internal simulation of the auditory stimulus that is similar to perceiving the stimulus itself. Remembering sound can be subject to a similar process, but driven from an actual lived experience. When we remember sound we remember more than sound itself; we remember sound sources, events, feelings, places, content of the information we decoded from sound. We remember the causal, semantic and reduced aspects of listening, together with extra-auditory information. We access imagery that is specific, but not exclusive to sound.

The subtle difference between imagery and memory is striking as it is also their interdependence. As an example, when I remember the sound of a stream of water, I recall the sound by simulating it inside my mind. To do so, I use different observing and listening perspectives at the same time. I imagine myself listening to the stream very closely, hearing fast drops of water hitting the rocks quickly, as I see this image in my mind. Then I "zoom" out and I see the trees from above, looking down to the dark blue stream flowing. I hear the sound of the water stream as a continuous slow hiss, rather than the particular sound I heard when I imagined it before. If I now access my own personal memory to remember the sound of the small stream of Bosco Caggione (Taranto, Italy), flowing down on a bed of yellow sand to the light blue water of the Ionian Sea, I do not remember the same sound. The materials involved in the interaction have changed. I am not sure I can remember the exact sound of that specific stream but it is different from the "archetypal" imagery of the stream I evoked before. What I cannot evoke from the archetypal imagery of the stream flowing in the archetypal wood, is my personal experience of it. I remember instead the feeling of the stream Caggione on my feet as cold as ice when I went to visit it last December. We cannot remember the sound of a butterfly flying as the example of imagining sound I made before, although we can imagine it. The point here is that remembering sound is often accompanied with a negotiation of an "archetypal" imagery. Only a refinement and focused act of recalling the memory itself helps to find specific aspects of personal experience, which we access because we were trying to remember its sound. This tension is fascinating.

Memory is a very complex and heterogeneous topic and it constitutes an important part of our lived experience. Its complexity goes beyond the scope of this thesis, but it is important to briefly discuss it at this point. There are different types of memory, based on types of time. Short-term and long-term memory describe the level of persistency over time of the thing remembered. An important aspect of memory is the act of remembering or recalling it. The act of recalling something from our own memory means to bring back an experience we lived in a past time. It describes a movement of information as being available between different types of time, from the past to the present. Sutton (2012) describes different varieties of remembering, according to the different typologies of memories. Memory can be "recollective", concerning remembering what or regarding a "habit" or "procedure", concerning remembering how. Recollective memory can be personal or general. We span from remembering facts (events we lived through) we lived to collective notions of culture and history. For example we can remember the episodic moment of when our shopping bag broke while we were walking back home yesterday afternoon, as we can remember the exact date of the "discovery" of the Americas.[9] Memory is involved in many processes, from learning action-information relationships in the everyday, to the formation of individual and collective identities. Memory traces back while imagination pushes forward.

[9] The word "discovery" here reflects one of the dangers of claiming and re-presenting memory associated with history. In Italy, children at primary schools are taught to remember the date of October 12th 1492 to celebrate the Italian Cristoforo Colombo (Christopher Columbus). I remember myself completely indoctrinated by this pseudo-patriotic celebration. Yet, this was the beginning of a very violent process of colonisation of a vast part of the world. I voluntarily kept this term, even I am conscious of the problematic of it to underline the danger of when memory becomes selected by structure of power. It is also interesting to notice that people in Portugal think that Columbus was Portuguese, while in Spain people believe he was Spanish.

Other than giving us access to past information, memory enables us to "to revive perceptions, which it has once had, with this additional perception annexed to them, that it has had them before" (Locke 1998; p.97 as cited in Sutton 2012). Psychologist and anthropologist Andrew Stevenson argues that the function of memory is not necessarily the one of an archive, rather the one of an "emplaced phenomenon", which brings us back to the perceived event. Stevenson links memory to aspects of living thinking and practice (Ingold 2011). He argues for the multi-sensorial, lived, practical element of memory, by saying that "Remembering can be regarded as a function of everyday practice rather than encoding. It can be seen as an embodied, multi-sensory phenomenon that is inseparable from emplaced enactments" (Stevenson 2014). In this process we form a moving image inside our head, a simulation of the lived event. The connection between memory and imagery seems to be evident at this point. As we are able to imagine things that we are not experiencing at the present moment, we can simulate things we lived in the past. The exact correspondence of what we perceived as actual stimuli and what we imagined and remember is still debatable, but the specific interest here is the ability to dispose ourselves to "perceive back", to access a "past" in function of the present moment and the future actions. By reviving perceptions we re-immerse ourselves in a sort of sensorial travel machine that goes between our present lived moment and the past, including non-informational aspects such as feelings, emotions, movements, gestures, causes and effects, situations that have been ignored during the lived moment, or have even been completely forgotten. By exercising memory, as Stevenson proposed, we can access strategies for emplacing enactments. These emplaced enactments are connected to the personal, episodic aspects of memory. These contain an important element of lived experience from an "autobiographical" point of view (Sutton 2012). This type of memory goes beyond recollecting information, and rather it provides access to a more phenomenological quality. Importantly, the autobiographical memory can bring out elements of significant experience from the perspective of the beholder (Nelson 1993). The matter of personal, autobiographical memory is relevant in this thesis as it focuses on the phenomenological aspect of sonic experience.

Remembering sound is not necessarily an easy or intuitive way of recollecting a memory. If we are asked to remember a sound we heard in the last three days, we may have to make an initial effort to leave the present and concentrate ourselves on recalling an experience we lived. We may then "find" a sound that we can describe, a sound that is not completely forgotten, even if we may not have noticed it when we actually heard it. Raymond Schafer developed a series of exercises for educating students to listen to sounds more attentively. Only a very small minority of the 100 exercises proposed in his method were intended to stimulate the remembering of the sound, as most aimed to evidence the discovery of sounds that no longer exist due to technological progress. Exercise number 78 asks the following: "The soundscape is constantly changing. Old sounds are constantly disappearing (Where are the museums for them?). How many sounds can you remember hearing from your youth that are no longer heard today?" (Schafer 1992). Even though the relationship between technological and sociological landscape and its influence on soundscapes is not central to this thesis, the technique of remembering sound is important for the evocation of both sound and extra-auditory information from listeners. However, we have to be careful to avoid an excessive idealisation of what Barry Truax calls the "sound romance" (1984, p.25), the sound that disappeared from the past, subject of adoration and nostalgia. For this reason, one of the most interesting challenges is to access the non-idealised dimension of sonic memories.

2.7.3 Re-evoking sonic experience

Petitmengin and Tuuri used evocation as a mode to understand sonic experience. They both explored qualitative methods to investigate evocation through listening to sound. Tuuri et al. (2014) distinguish ordinary listening from evocative listening, which refers to more experiential, subjective modes of listening in which kinaesthetic and affective elements of sound are considered. In their studies they chose sound stimuli to be played to their participants. This creates an effect Augoyard and Torque define as "anamnesis", in which "an evocation of the past, refers to situations in which a sound or a sonic context revives a situation or an atmosphere of the past" (Augoyard et al. 2006).

This is undoubtedly valuable but other strategies may be adopted to study sonic experience. We can investigate evocative dimensions of listening without choosing the auditory stimuli to play back to a listener. One of my previous artworks explored the construction of memory and sense of place in urban walking through creating technologically mediated listening opportunities (Altavilla & Tanaka 2012). Transferring this artistic "operation" into methods to enquire about sonic experience can help to avoid the need to choose the sonic stimuli to play back to listeners. In this way we may find diverse qualities of sonic experiences as described by the participants. Re-evoking sonic experience from listeners' past may help us to identify personal, embodied, affective and problematic qualities of their encounters with sound. It may reveal an extra-auditory context, which may have been forgotten, together with an evocation of the sound itself.

2.8 Discussing the Sonic

So far, Sonic Interaction Design has been shown to be a discipline that focuses primarily on sound as the principal element for designing interactions, as the addition of the word "Sonic" to Interaction Design suggests. This does not necessarily represent a desire to create a sub-field. Rather it is a statement, an approach to research and practice that exploits sound – in its phenomenological and cultural aspects – as a starting point of the design process. The examples I have reviewed reveal a common characteristic: they are not based on aiding an interaction with the screen of a computer or a graphical interface. They are instead based on the idea that our actions with objects can be augmented with real-time sound feedback, based on manipulation with the artefacts. This can be seen as a different condition of being ensounded, which originates from Ingold's concept. Functioning differently to theoretical understandings, this condition is actualised - by design - using interactive technology, and moving towards the view proposed by Franinović of sound as an "active medium" that can shape novel, phenomenological and social interactions through digital technologies.

Working towards an understanding of sound presented questions about knowledge and embodiment. Acoustemology offered us a view of sound as a fundamental aspect of knowing and being in the world. Ihde described a phenomenology of sound and how it penetrates our bodies and our reasoning. Henriques and Ingold focused on questions of the body in relation to the immersion in the sonic medium. Henriques' sonic dominance describes the situation in which we operate when fully surrounded by sound, in its production and perception. Ingold described this condition as "ensounded", which we can see as a form of embodiment into the whole flow of life. Acoustic ecology on the other hand, showed us the attention towards processes of listening and analysis of sound in particular environments, and how we can understand these activities. These processes temporarily disembody us from the environment in which sound is heard, giving us the scope to understand environmental and social interactions from a different point of observation.

The insights offered by cognitive studies of music and sound and the analysis of listening can be used in design practice. We have seen the importance of links between sound perception and the actions we imagine as being associated with sound sources, and their acoustic energy for cognitive processes of music and sound. The muscular binding between humans and sound as described by Filmer and Connor sets what Leman described as an "ecological resonance", in which social practices are tied together in the processes of sound feedback, listening and gestures. This binding between bodily action and sound has been explored by designers in the field of Sonic Interaction Design to think about possible scenarios for designing everyday interactions mediated by sound, which are embodied, situated and meaningful. Sonic Interaction Design raises a new element for discussion: the very possibility of digital sound production connected to body movement aided by interactive technologies.

Listening comprises a tension between different signifiers and affordances, shifting temporalities, multiple perspectives, evocation of past experience and imagination of bodily gestures and actions yet to happen. Discussing the many facets that listening unveils about our everyday sonic experience is significant within the field of Sonic Interaction Design (SID) and Sound Studies. Analysing the various forms and modes of listening helped us to navigate the complexity of sonic experience. We have seen how listening is involved in processes of human identity and how it helps a person in their sense-making of the world. The corporeal and experiential dimension of listening help us to frame listening as an activity that we do with the whole body and which opens up new scenarios of design. An attention to the topic of temporality of listening experience, such as imagining and remembering sound, can potentially help us to understand unconsidered aspects of sonic experience, envisioning novel and improving existing design of interactions that fit into already rich multi-sensory dimensions of our everyday. Listening itself can be further investigated as a generative method for design. If some of the conscious elements of listening have been widely explored, more affective, evocative and embodied aspects of listening have yet to be systematically incorporated and assimilated into the design process. As the landscape of interactive technologies expands towards object-free interaction, muscle and gesture sensing, we need to think what a broader consideration of listening has to teach us and inspire in this regard.

One of the challenges faced by research in SID is to find approaches in which everyday sonic experience can be studied and used in practice. Sounds belong to and define contexts, give us a sense of place and notify us of events happening around us. The everyday experience of sound, including listening to, thinking and remembering sound is rich and complex. One of the difficulties of designing interactions mediated by sound is to co-exist with this already rich sounding world we live in. This concerns not only a “purely” sonic level, but also the way that we think about sound, the way we love or are annoyed by sounds according to their qualities, as well as the particular contexts, situations and cultural significations associated with them. This richness can and needs to be exploited in SID research.

In SID, real-time sound feedback based on body movement and interactive technology becomes a condition which is used to reveal potential applications, especially for functional aspects. An understanding of the contexts that we can explore with sound and embodied interactive technologies can be beneficial to research in SID. We have seen that interactive technology and sound perception play an important role in this field. The literature reviewed in Sound Studies can enhance our understanding of processes of embodied sonic interactions. This will help us to understand other possible paradigms for designing interactions that are not based exclusively on the control of digital sound and real-time sound feedback, but which exploit sonic experience in its embodied, social and cultural complexity.

2.9 Chapter Summary

The literature reviewed in this chapter helps us to trace the study of sound considered as a medium for embodied interaction. We have seen that sound is a complex social, cultural and embodied phenomenon. Sound is public and social. It is familiar and embodied. It allows different forms of interactions, such as hearing, listening and playing. Sound is often a matter of public concern and at the same time it is something that can dominate our sensorial sphere, offering ways in which we can act through sound. Sound is meaningful for us, through its cultural signification or in its embodied, physical and visceral qualities.

We have first seen the use of sound as a design medium, by presenting research in the field of Sonic Interaction Design. We have then seen theoretical aspects of sound in Sound Studies, and how it has been used to study cultural, phenomenological, social and political aspects of our everyday. Then we saw how acoustic ecology can help us to use listening as a technique to understand environmental activities. I then reviewed embodied sound and music cognition, and found links between sound perception and body actions. The chapter concluded with a discussion of processes of knowledge through sound, comparing theories and practices to see the emergence of phenomenological, embodied aspects of sound.

3 METHODOLOGY

3.1 Chapter Introduction

This chapter presents the methodological approach undertaken for this research to investigate users' sonic experience, embodied sound cognition and their role in the design of sonic interactions. This research introduces a series of methods for implementing a participatory approach to the design of sonic interactions. Conducted in collaborative settings within the EAVI (Embodied Audio-Visual Interaction) research group at Goldsmiths, University of London and as member of the ERC funded project "MetaGesture Music", my specific contribution to this research lies in designing and developing methods for interaction design that exploit users' embodied sonic and listening experience.

The research questions as formulated in Chapter 1 have been divided into two categories. The first category (Q) presents the core research questions, while the second category (MQ) addresses particular methodological issues that could arise. The questions are restated here as follows:

- Q1: What is the "sonic" in SID?
- Q2: How can we access and draw upon people's sonic experience to inform a development of novel scenarios of embodied SID?
- MQ1: How can we draw upon sound as a starting point in designing interactions?
- MQ2: How can an understanding of our sonic experience be useful for designing interactions with motion sensor technologies?
- MQ3: How can participatory activities help us to explore the diversity of people's everyday sonic experiences and inform our approach to designing interactions?

The following sections of this chapter present the research aims, the research design, the procedure and methods planned in order to investigate these questions.

It concludes by presenting a pilot user study which serves as an exploratory first step in this research.

3.1.1 Research Aims

The current panorama of embodied sensory technology and interactive computational sonic objects poses new ways to understand how people listen, not only using their ears, but also through their bodies. By analysing the complexity and variety of within listening, we can enrich our knowledge of sonic experience - beyond simple sound feedback - and envision novel scenarios of bodily sonic interactions.

The principal aim of this research is to investigate ways in which we can draw upon people's sonic experience to inform research into embodied Sonic Interaction Design. As we have seen in Chapter 2, the topic of human sonic experience is complex, spanning different fields of research, subjects and communities. Analysing sonic experience and listening bring us to realise how it comprises a tension between different signifiers and affordances, shifting temporalities, multiple perspectives, evocation of past experience and imagination of bodily gestures and actions yet to happen. This tension constitutes a richness that can be beneficial to investigate for designing embodied interactions mediated by sound, particularly in the field of Sonic Interaction Design.

The second aim of this research is to develop methods and techniques that exploit human sonic experience for SID research. A specific focus on embodiment and human motion will be the basis for defining and developing such methods. The focus on embodiment will allow us to devise and envision methods to investigate sonic experience, considering an intertwinement between motor system, perceptual system, environment and cultural assumptions. The attention on human motion for articulating specific methods addresses the problem of relating sonic experience and interactive sonification of human movement, which is the basis for the specific place of my research in SID.

The third aim is to explore embodied interaction with sound involving users, to better understand how the diversity and richness of everyday sonic experience can inform our research on embodied sonic interaction. Users are considered in this research not exclusively as end-users, rather as collaborators in the research process. With their involvement I hope to gather an enriched knowledge of their needs, experience and perspectives on embodied interaction with sound.

The final objective is to provide specific tools to designers, sound designers and artists wishing to work with motion sensors and interactive sound systems. Researchers in SID and sound design have reported on some pedagogical issues about involving designers - but not specialists in sound - working with interactive sound, particularly regarding aspects of "sensitisation" to sound (Rocchesso et al. 2013). Beside the difficulties of teaching non-specialists techniques and methods for thinking and working with sound, there is also a shortage of toolkits options for designing gesture-to-sound mappings that are intuitive and easy to use, and that can be integrated in design workshops and research projects.

3.1.2 Research Development

This research follows three stages of development. In the first stage, already presented in Chapter 2, I have analysed the state of the art in the chosen research field and literature relevant to the subject of this research. I started reviewing sonic experience and embodied interaction with sound, listening and sonic affordances across the fields of Sound Studies, Acoustic Ecology, Embodied Sound Cognition and Interaction Design. This analysis helps us to orientate our methodological approach and gather themes and methods to be deployed in this research. This serves to set the context of the research supported by surrounding knowledge of sonic experience, defining the development of the methods used in the following stage of research.

The core of the second stage consists of studying methods deployed in the field and to outline the set of methods and techniques I will use in this research. In this stage I will design the methods for collecting and evaluating data of this research project. Data will be gathered through a pilot user study and a subsequent series of participatory workshops. The pilot study serves as a preliminary step that aims to gather descriptions of participants' experience when interacting with sound through body movement and sound feedback. The insights from the pilot study will then help to inform the design of methods and tools in a series of participatory workshops. While with the pilot user study I gather data on the experience of the user as they explore predesigned gestural-sound mappings, the participatory workshops will help to explore how participants' personal sonic experience can inform the development of interactive scenarios using our system.

The third and final stage is data evaluation and a discussion of the contributions to the field of Sonic Interaction Design, which will be presented in the Discussion chapter of this thesis.

3.1.3 Methodological Rationale

The methodological approach here undertaken seeks to facilitate the investigation of how a person's sonic experience itself can be the starting point for designing interactions. My aim is to further explore what type of design scenarios may be produced from this starting point. The approach I deploy draws upon a user-centric philosophy and underlying methods, with the aim to evoke perceptual and affective qualities of the sonic experience that could feed scenarios of interactions. To do so, I use and adapt methods from different fields, such as Sound Studies, Acoustic Ecology, Psychology and Interaction Design, to generate techniques for studying and designing embodied sonic interactions that are meaningful to users.

In Sonic Interaction Design, users and the interaction scenarios studied are related to our everyday interactions, artefacts, and environments. By focusing on functional and dynamic aspects of interaction, SID research expands the use of sound design and interactive technology in fields such as motor rehabilitation, product design, architecture and interior design, sport and music (see Rocchesso 2011 for a review). In this specific SID research, I look at non-specialist users, particularly non-musicians, to highlight and understand everyday aspects of sonic experience that are not articulated for musical purposes. Drawing upon a user-centric approach in SID can provide methods and techniques that can help us to answer one of the core questions of this thesis (Q2: "How can we access and draw upon people's sonic experience to inform a development of novel scenarios of embodied SID?") and the methodological questions MQ2 and MQ3 outlined in Chapter 1. In fact, gathering users' sonic experience may prove to be useful for this specific SID research working with embodied interactive technologies, such as motion sensors for free body interaction with sound in the context of everyday usage (MQ2). This will firstly be done by exploring gestural-sonic interactions in a lab through a pilot user study and will be presented at the end of this chapter. The series of participatory workshops described in Chapter 4 provides different scenarios of study that might be useful for exploring the diversity of people's everyday sonic experiences (MQ3) to be used in SID research.

3.1.4 Developing a "Sound-Centred" approach: Starting from Sonic Experience

My methodological approach seeks ways to "start from sound" to design novel scenarios of everyday interactions using body movement and digital sound processing. I observed that Franinović's consideration of sound in SID as an "active medium that can enable phenomenological and social experience with and through interactive technology" (Franinović & Serafin 2013) encourages designers to think beyond the presence of sound feedback itself, towards a greater sonic sensitivity in design. This sonic sensitivity is a modality and disposition towards sound, an attention towards human "sonic experience" which informs the background to my research. Understanding the various nuances of the concept of the sonic can lead us to envision novel interactions with technology that exploit human movement.

The "sound-centred" stance in this thesis proposes that the user's sonic experience can act as the starting point for designing embodied interaction with sound (MQ2). This approach informs my methodological stance for this research. Focusing on sound from the beginning of the research process can serve as a methodological strategy for understanding, questioning and expanding the concept of the "sonic" in Sonic Interaction Design (Q1). One of the challenges of building a "sound-centred" approach is to consider sound beyond its quality as an acoustic phenomenon, and rather as a medium, or as a factor which specifies, influences and dictates the design of interactions. The sound-centred approach relies on a consideration of the sonic which includes extra-auditory elements, such as experience, memories and associations. By looking at existing research in SID with Sound Studies and Embodied Sound Cognition, my approach seeks to explore various forms of listening from the participants' perspective, for which appropriate techniques and methods need to be developed.

Considering, analysing and building methods that exploit listening will be the main principle to inspire the design of the methods and techniques in this research. The involvement of body and imagination when listening and thinking about sound aims to lead us to explore evocative modes of listening, with the objective of designing methods for enquiring about sonic experience in participatory design contexts. This will be used to investigate the research question of how to access and draw upon people's sonic experience to inform a development of novel scenarios of embodied SID. It could also help us to frame and access the diversity of sonic experience as a starting point for design (MQ1). To allow this, the methods, techniques and tools designed in this research will consider a variety of sonic experience and modes of listening, involving for example, drawing upon the memory of participants, or other forms of embodied and introspective listening.

3.2 Research Design

3.2.1 Qualitative research and Data Collection

The nature of this research is mainly exploratory and the study of sonic interactions in this project relies on methodologies deployed in qualitative research. This type of research, born in the field of social science and extended to other disciplines, can be considered to be an approach or a set of strategies aimed to analyse, investigate and discuss the complexity of human understanding, experience, and interpretation of the world (Sandelowski 2004). Instead of analysing data in numeric forms, as in quantitative methodologies, qualitative research focuses on words, descriptions and other phenomena that cannot be easily quantified (Bryman 2012). Qualitative enquiries deal with descriptions given by people, commonly in verbal or written forms and by observing people’s activities, their use of symbols, how they use artefacts and in general what is considered meaningful. Therefore, interview transcripts, field notes, video and audio recordings, photographs, images and documents are often used in qualitative research (Lewins et al. 2010; Preece et al. 2003). In order to make sense of this various, unstructured and non-numerical data, the researcher, using a qualitative approach, usually looks for identification of emerging themes, issues, confirmation of hypotheses or new information.

As the chosen methodology relies on the observation and analysis of phenomena related to sonic interactions through experimental research and design procedures, it is important to define what data will be gathered. Interacting with sound, for example, may involve movements of the human body while listening to or performing sounds. From involuntary movements to gestures, spatial and kinetic data can be collected using motion tracking technologies, such as optical motion capture and accelerometers. Sounds produced in the interactions can be collected as audio recordings to be analysed afterwards. At the same time, a video recording can help to build a series of observations that may allow for extensive analysis. This can be supported by participants' verbal or written descriptions of the sonic interactions. Finally, techniques such as workshops generate different types of data, such as sketches, observations, prototypes and emergent ideas, which can be analysed qualitatively.

I will collect data through different data gathering techniques, such as interviews, questionnaires and audio-video recordings. Interviews are used in this research to gather opinions from participants regarding their experience with the gestural-sound interactions in the pilot user study. Semi-structured interviews are used to gather specific information about various points of interest in the user study. The semi-structured format aims to maintain a focus and specificity, whilst avoiding causing participants to feel as though they should give "correct" answers and fulfil interviewers' expectations (Fontana & Frey 1994). Although, the risk of influencing participants to give a "correct" answer is always present to a degree, the approach I use in this research is more relaxed. I do not aim to be invisible, rather a facilitator for a conversation about sonic experience that can help us to envision different forms of designs and to show us possible user-generated forms of gestural-sound mappings for non-object based sonic interactions.

I will use questionnaires for getting to know participants before the workshops and for evaluating the post-workshop feedbacks. In the questionnaires we will use different techniques to accommodate quantitative and qualitative data. Besides open and closed questions, rating scales are often used in design research to measure attitudes, opinions, and beliefs of the participants on a particular subject or question (Oppenheim 1992; Preece et al. 2003). Two largely deployed examples of scales are Likert and Semantic Differential Scales (Preece et al. 2003). In addition to open and closed questions, we will rely on Likert scales to measure satisfaction or agreement upon a predefined statement which are presented as check boxes to tick.

Audio-video recordings will be made throughout the pilot user study and the workshops to collect participants' opinions and analyse their experience with the interactive technology in use. In the pilot study I will use auto-confrontation interview in addition to semi-structured interviews. Auto-confrontation is a useful technique for retrieving users' opinions while performing an action (Vermesch 1990). The value of this technique is that it can render the actions visible to their performers so that these can be discussed, which is often the case for analysis and evaluation of a performance. The workshops' activities will be filmed, upon consent of our participants, in order to gather video documentation that we will use for analytical purposes. Finally, the recordings play an important role in disseminating phases of the research, particularly in their edited format for presentation at conferences and talks.

To analyse data I will use coding, a technique in which researcher(s) arbitrarily label meaningful parts of text or other media collected to explore and gather some thematic ideas. The aim of coding therefore is to link different segments or instances in the data (Lewins et al. 2010), to find similarities, differences, patterns and structures (Seidel & Kelle 1995). This allows the "simplification" of data (Preece et al. 2003), functioning as a "heuristic tool to enable further investigation and discovery" (Seidel & Kelle 1995). Consequently, themes are inferred by an analysis of the codes built in this phase, and not from the whole body of data. Coding will be used in my research with the specific scope of simplifying the vast amount of descriptions expected to be received from our participants, with the scope of facilitating the analysis and following a discussion of the data gathered.

3.2.2 User-centric approach

The way users are identified in this research is crucial and deserves clarification. Far from trying to locate this project in the field of industrial and product design, in our approach we do not consider users to be at the end of a production cycle. They are not necessarily "consumers". Instead, this research focuses on an understanding of users' sonic experience, particularly when supported by interactive technologies. Here, the users are recognised in different ways: as co-creators, as reference points, as objectified kinetic bodies to study, and live explorers of interactions with sound. Therefore, users cannot be separated from the process of understanding and designing sonic interactions, as well as their embodied, situated, affective relationships with sound.

We can draw upon a few examples that demonstrate how the consideration of users might differ in various fields that inform this thesis. In sound art for example, we can think of the users as members of the audience, but it would be difficult to make such a generalisation. Sound artists operate on different critical levels. While finding the “users” of sound art does not constitute an objective of this thesis, this helps us to trace some preliminary considerations regarding which practices speak to whom. In acoustic ecology for example, users can be researchers that want to focus on auditory aspects of geographical locations and environments, or composers who wants to explore sounds from particular locations as material for their music.

In Human-Computer Interaction (HCI) and design, on the other hand, an understanding of users’ needs and specifications is crucial from the outset, and the discipline has seen qualitative approaches and methods arising to achieve this goal. In particular, User-Centred Design (UCD) describes a methodological approach and design attitude in which the end-users are involved in the process of design (Preece et al. 2004). The origin of the term is attributed to Donald Norman who in the late ‘80s started to work on what he later described as a design “philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable” (Norman 2002, p.188). Users therefore assume a central position in the design process, and their identification and modalities of involvement in the process are complex. As one of the fundamental characteristics of UCD is the focus on users' needs, experience and perspectives, approaches from UCD can be helpful to address the problematic and novel aspects of user experience when interacting with embodied and object-free based interactive sonic systems.

3.2.3 Techniques for understanding and designing embodied interactions in participatory design and HCI

BODYSTORMING AND INTERACTION RELABELLING

HCI and Interaction Designers offer us techniques to understand our embodied experiences with interactive technologies, their possible context of use and opportunities for design. Some of these techniques are used in participatory workshop settings and explore users’ ideas about interaction through processes of simulation, reconfiguration and their rapid implementation. Two examples of this are bodystorming and interaction relabelling.

Bodystorming is a technique for observing users' gestures and body movements involved in the intended scenarios of interactions. This can be seen as a form of "physically situated brainstorming" (Buchenau & Suri 2000; Burns et al. 1995) used by designers to investigate "contextually rich explorations" of users' ideas and solutions. It helps to provide in-depth information about experiential (Buchenau & Suri 2000), contextual (Oulasvirta et al. 2003) and embodied, enacted aspects (Schleicher et al. 2010) of the scenarios from the perspective of the body. It is useful for early phases of design, such as in problem-definition and to imagine interaction scenarios as a replacement for, or addition to, textual and graphic descriptions.

Interaction relabelling is a method for generating design ideas based on re-imagining pre-existing interaction mappings. For example, the actions performed on a mechanical device can be remapped onto an electronic one (Djajadiningrat et al. 2000). It offers a way to use familiar physical actions to re-think normative, pre-existing functions, users' roles and situations in order to generate novel forms of interactions and functions with objects.

EXPERIENCE PROTOTYPING

Prototypes are intermediate artefacts designed to explore and evaluate interactions at different stages of development (Houde & Hill 1997). In HCI, prototyping is a practice that faces various challenges due to the heterogeneity of software, hardware and the complexity of auditory, visual and interactive factors. Often prototypes can be technologically complex and this can be counter-productive. This can generate an unwanted discussion over the technology rather than the users' interaction during an inappropriate moment of the design phase (Houde & Hill 1997; Fallmann 2003). Svanaes and Seland propose an alternative approach to prototyping, with their Low-Fidelity prototypes (Svanæs & Seland 2004). These are made with inexpensive materials, such as cardboard, foam, Posts-its and other stationary material to build mockups focusing only on desired functionalities, rather than the actual possibilities of technologically refined prototypes. This method prioritises interaction, before any introduction of technological complexity, and can be used to quickly generate new ideas and desired capabilities for future products and interactive scenarios.

Experience Prototyping is a method for understanding what users might experience with the product, space or system in a design phase. As a user-centric method, this enables "users to understand the subjective value of a design idea by directly experiencing it" (Buchenau & Suri 2000, p.429). It benefits from active, subjective participation of the users and designers. Techniques for acting-out and testing design ideas such as bodystorming and prototyping can facilitate the process of imagining embodied interactions. This can help designers to build prototypes of lived and felt experiences that can then be discussed and used in different phases of the design process.

PARTICIPATORY WORKSHOPS

Participatory workshops are one of the methods for undertaking research in action-based contexts. They are based on collaborative settings used to explore research issues or to generate ideas in specific learning or design environments. Participatory workshops are usually delivered in a concentrated period of time, usually ranging between a few hours to a few days (Chambers 2002). Workshops include two main parties, (1) the workshop leader(s) and facilitator(s), and (2) the participants. A conventional workshop structure is based on a series of pre-planned and sequential activities. These include: welcoming and warm-up, short introductions from participants, icebreakers, energisers and group forming (Chambers 2002). Other relevant activities include brainstorming, idea generation, scenario development, prototyping, presentation and discussion (Muller 2003; Svanæs & Seland 2004).

Participatory workshops are used in various disciplines, from medical working environments to design and music (Friedman et al. 1979; Muller 2003; Kirisits et al. 2008; Jo et al. 2013). In HCI and Interaction Design, they are methods for envisioning future concepts, ideas and scenarios from the perspective of users and actors, as "potential inventors" (Hultcrantz & Ibrahim 2002). Workshops can facilitate processes of "knowledge sharing" and generative research (Soini & Pirinen 2005). For a successful collaborative approach, participants must feel that the workshops' goals are purposeful for themselves (Soini & Pirinen 2005) and that they are part of a "joint mission" with the workshop's organisers (Johansson et al. 2002). We can consider participatory workshops as ecological niches for research practice that benefit from an internal logic within the activities involved and a favourable atmosphere for collaboration. Participatory workshops can generate new procedures and techniques that can be incorporated into practice (Muller 2003), therefore documentation and multiple iterations are important.

3.3 Review of Methods and Techniques in SID

The following section presents an overview of methods and techniques used in Sonic Interaction Design research which will inform the development of methods used in my research. I will first introduce general design approaches and techniques used in SID, followed by methods used for understanding listening in acoustic ecology, ethnographic research and sound art. Afterwards, I describe methods from embodied sound cognition studies which are helpful for understanding embodied action-sound relationships. I will then conclude the section by discussing participatory workshops in SID and some development toolkits for prototyping interactive sound design.

Different fields contributed to the development of design methods and paradigms used in SID. An important element of transferability of techniques and approaches between design practices and sound computing is the development of pedagogical tools and methods. Rocchesso, Serafin and Rinott (Rocchesso et al. 2013) argue that designers who are not used to working with sound in their practice may lack particular skills, languages, means and processes to facilitate work with sound. To ease this challenge they provide an overview of common design methods that can help designers to think about and use sound in their work. They describe a series of techniques that can be used for incorporating sound at an early stage of design, such as vocal sketching (Ekman & Rinott 2010), sound walks and listening exercises (Franinović et al. 2007) and writing audio films and theatrical performances (Pauletto et al. 2009; 2014). For Rocchesso, Serafin and Rinott, the plethora of techniques from different fields serves the goal of sensitisation to designing interactions with sound, helping to overcome a visually oriented tendency that design students may have, and encouraging exploration of the audible and the sonic in their designs.

3.3.1 Design approaches and techniques in SID

The practice of understanding and designing sonic interactions requires different approaches involving constant evaluation. Qualitative approaches are used together with quantitative-analytical methods, as the sonic phenomena needs to be studied as a whole rather than as an isolated event (Widmer et al. 2007; Brazil 2009; Pauletto 2014). Evaluation, within contextualisation, is an important criterion in SID research, as in traditional interaction design. This is particularly important as SID research spans from the produced sonic artefact to the basis and the motivation of the design process itself, including social and cultural constructions, and performative aspects.

Brazil offers a review of techniques applied to study Sonic Interaction Design (Brazil 2009). He situates the techniques as serving three different design approaches in SID:

1. User-centred, which focuses on usability and gathering user perspectives;
2. Product-centred, which deals with the interaction between users and interfaces;
3. Interaction-centred, which involves emotional sensory and spatio-temporal aspects of interactions.

This list offers a useful overview of the current design approaches that are usually central in SID. Designers can combine them according to specific cases and in iterative ways. These three approaches frame the scope within which the analysis of sonic interaction designs may take place, considering the diverse perspectives of the parts and rationales involved.

Techniques developed in psychology, HCI and Interaction Design are often used to investigate and describe sound, listening and sonic interactions. The Repertory Grid is used in Sonic Interaction Design to group descriptions of the sonic phenomena from the users' own vocabulary. The following step consists of a process of sorting, ranking and classifying based on similarities. It offers the advantage of giving individual responses, which require no training from the participants and a set of descriptors used for statistical analysis. The disadvantage is that the text needs to be interpreted and codified by an experienced researcher who has linguistic or semantic knowledge. Rating and scaling are a second way of analysing users' impressions of sonic phenomena. The Similarity Rating Technique (McAdams et al. 1995) uses participants' evaluations to scale and sort sound stimuli, according to perceived acoustical or physical dimensions (Brazil & Fernström 2009).

Sonic maps are an example of a technique for analysing characteristic features of an acoustic environment based on listening (Schafer 1994; Coleman et al. 2008). These are textual or graphic descriptions of sounds collected by listening to specific places, sites or activities. One of the possible basic classifications in sound maps consists of identifying foreground, background and contextual sounds (Coleman et al. 2008). These can be divided into other information categories to note the users' emotions, actions and perceived signals/signifiers (Brazil 2009).

Narrative aspects of sounds can be gathered using the EarBenders technique, in which written stories of listening situations are first analysed and then turned into interactive tasks which are used to develop auditory interfaces (Barrass 1996). Using the EarBenders technique, the sounds narrated in the stories of listening are categorised according to psychoacoustic analysis and auditory perception (such as timbre, nature of sound, perceptual grouping, patterns and movement) and provide an array of qualities that can be used in the design of auditory interfaces (e.g. the auditory component of a system for monitoring pollution of a river over a one year period).

Finally, emotional qualities of sound and sonic interactions can be analysed using methods for data gathering of affective responses. Affective grids (Bradley & Lang 1999) are a method to evaluate users' feelings towards sound stimuli. The grid is organised using bipolar representation of emotions (pleasant/unpleasant, stress/relaxation, excitement/depression) and users place the sound in a position in the grid that best represents their emotions. Barrass proposes the interactive affect design diagram (IADD) as a grid for evaluating the affective qualities of designed sound which is mapped to possible actions with interactive artefacts (Barrass 2013). He argues that this technique endows interactive artefacts with emotional characteristics and a "personality" trait through the use of sound design. These methods provide techniques for helping designers and researchers to obtain descriptions of sonic phenomena and listening.

3.3.2 Methods for understanding sound and listening

The fields of Acoustic Ecology and Sound Studies introduced in Chapter 2 have developed a series of methodologies to exploit sound as a medium to convey information regarding acoustic features, biological aspects and social and historical activities of a place. Sound recordings are used in this field as basic methods to retrieve information to be analysed with specific techniques, usually aided by a computer. Other methods such as listening exercises (Schafer 1992) orientate the researchers towards different qualities of the environment through specific listening activities (such as sound walking). Textual and graphic descriptions such as Sound Images and Sound Maps offer holistic representations and descriptions of the sonic phenomena that occur in particular places. Physical characteristics of sound are analysed and classified according to their attack, body, decay, duration and related phenomena. Referential aspects are classified instead of using models based on broad categories of sound, which are organised according to natural, human, mechanical and electronic sources.

In ethnographic and social research, Back and Puwar (Back & Puwar 2012) use sound-recordings and sound walks as methods to analyse the live, embodied and situated everyday aspects of the social. Techniques such as attentive listening, sound walking and sound annotation help social researchers to use sound to understand everyday social activities and their contexts (Bull & Back 2003). Sound art explores reflective qualities through practice, using processes and qualitative techniques. The work of Brandon LaBelle, for example, shows how diaries and textual descriptions of sonic memories (LaBelle 2005) can be used as resources to track, study and write about the emotional, subtle and relational aspects of sound. These forms of documentation are more than methods for collecting the past. They are also tools to imagine future interactions, consider issues and articulate discourses that can be investigated through sound.

The art collective "Ultra-red" uses sustained collective listening practices and sound workshops to investigate situations of social and political struggle. In their "Militant Sound Research" approach they use sound as a critical, epistemological tool (Ultra-red 2014). Drawing upon a comparison with acoustic ecology, a typical research question moves from "what is the sound of this place?" to "what is the sound of alternatives to incarceration?" The participants (who may not have a background in sound recordings) are considered as co-researchers that use listening to understand the environment in which they live. To aid this process, Ultra-red provide methodological protocols in their Practice Sessions Workbook (Ultra-red 2014), which include guidelines on basic techniques for non-specialists about listening exercises, audio-recordings, field-recordings, interviews and sound-logs. They use four different types of listening modes (Chion 1983) to help participants situate the objective, subjective, concrete and abstract dimensions of sound. It follows an analysis of sound in a social and situated context using techniques from critical education studies (Freire 1973). This approach can be useful for three reasons. Firstly, it provides a guideline for non-experts, secondly it is a participatory approach in which listening is a form of action, and finally it focuses on the experience of sound as a research method for a critical investigation of the everyday. The methods proposed by Schafer, Back and Puwar, LaBelle and Ultra-Red can provide us with methods to gather contextual, personal and intimate aspects of listening experience.

3.3.3 Methods for studying embodied action-sound relationships and sound tracing

In the context of embodied music cognition, action-sound relationships rendered as gestures and trajectories have been studied through laboratory experiments with participants. Different techniques can be applied. "Sound-tracing" (Godøy 2010b) consists of asking listeners to draw on a digital tablet what they felt as gestures corresponding to the musical excerpts they heard. This technique has been extended to study "free-movements" (Haga 2008; Nymoen et al. 2013) by asking participants to produce spontaneous gestures according to the musical and/or sound stimuli they listen to in the experiment. Sound-tracing provides researchers with ways to collect and analyse data on embodied links between sound and motion from the perspective of listeners.

Studying non-musical sounds, Caramiaux et al. showed in an experiment that the gestures performed by participants while listening to environmental sounds depended on the level at which they were able to identify the sound source. Their experiment studied embodied listening – gestures invoked in the act of listening to sound (Caramiaux, Bevilacqua, et al. 2014). Gestures were performed in response to a sound stimulus, and did not involve interactive control of sound production. The link between the level of identification of the sound source and the gestural description was shown to either mimic what the participants understood the original sound sources to be, or to trace acoustic features of sound, such as its frequency/amplitude profile over time. These multi-layered levels of listening that involve body movement can help us to foresee questions of gestural-sonic affordances in SID systems.

3.3.4 Participatory and User-Centred Design in SID

Workshops comprise an important part of research methods frequently deployed in Sonic Interaction Design (Rocchesso 2011). They include techniques from HCI and Interaction Design such as bodystorming, "Wizard of Oz" technique, interaction relabelling and prototyping (see Rocchesso 2011 for a review). In addition, we can find approaches based on sound practices, such as sonic narrative playing (Pauletto 2009; 2014), listening exercises (Schafer 1992) and soundwalks (Westerkamp 2006). These methods are used to study action-sound relationships (Lemaitre et al. 2009), vocal sketching (Ekman & Rinott 2010), current sonic interactions with artefacts (Franinović et al. 2008; Houix et al. 2013), and to envision future design scenarios of interaction supported by sonic interactive commodities and artefacts (Hug 2013; Tanaka et al. 2013).

Workshops on participatory design and everyday sonic interactions can be organised in a series of different activities. Karmen Franinović et al. (2007) describe the structure of a workshop in Sonic Interaction Design. They focus on the exploration of physical action and sound feedback using computational artefacts for generating future scenarios and concepts of interactions, using inventive methods generated in interaction design. The four phases described by Franinović for her workshops are (1) warm up exercises, (2) creative idea generation, (3) concept exploration and bodystorming and (4) final presentation and discussion. The warm up phase aims to sensitise participants to the sonic domain of the workshop using techniques such as vocal sketching, soundwalking and haptic listening. These exercises explore the "existing sonic experiences" of the users to generate sonic interaction concepts (Franinović et al. 2008). They use bodystorming and interaction relabelling to think about interaction scenarios using the body and novel object-action functionality that can be mediated by sound. Finally, the presentation phase shows the project ideas, which remain at a prototypical, non-technologically implemented status and set the basis for a discussion of the workshop.

Daniel Hug proposes a series of design methods and prototyping techniques for aiding the process of sound design of interactive artefacts for non-specialists or early-stage students. Mixing pedagogical approaches to sound design and interaction design, he identifies common challenges of teaching Sonic Interaction Design. Examples include the problematic dialectic of specialised tools, the aesthetic and technical complexity of interactive sound and an obsession with functional design (Hug & Kemper 2014). Hug uses workshops in classroom settings as a kind of "Dialogical Research Lab" to envision future sonic commodities and scenarios of interactions. One of the techniques developed by Hug is the Foley Mockup (Hug 2013). This is based on Foley, a technique used in cinema to replace missing or wrongly recorded sounds in scenes with studio produced sounds to achieve a very similar effect. Hug uses participants' voice and objects available in the classroom to quickly generate sounds for the prototyping mockups. These sounds are then played back using a sampler to simulate the sounds that the prototypes would generate, in a way similar to the "Wizard of Oz" prototyping technique (Kelley 1984).

Oliver Houix and the STS IRCAM Team investigate sound-action relationships with everyday objects and how these can inform the design of new sonic interactive artefacts for Digital Music, Rehabilitation and Sonic Interaction Design. They use methods from product design to determine the different development phases of the interactive artefacts, which start from the specification of design requirements and arrive at the formalisation of the product (Houix et al. 2013). To do so, they designed three different participatory workshops, each of which focused on three specific aspects: (1) Usage Scenario Development, (2) Sound Metaphor Creation, and (3) Validation/Assessment phase. The usage scenarios are developed through brainstorming and an analysis grid of different qualities of object interactions (affective, functional, aesthetic, cultural) and functionalities of pre-existing everyday objects in terms of their physical manipulation. The scope of the Sonic Metaphors phase is to understand the relationships between sound-gestures and everyday objects (Basic sound-gestures) and envision new sound-gesture relationships (Arbitrary and Metaphorical). In the final phase, they validate and assess the scenarios developed using technological prototyping based on sensory technology and real time sound computing.

Tanaka, Bau and Mackay (Tanaka et al. 2013) use user-centric workshops to investigate the design of future mobile music players. They use ethnographic interviews and the critical incident technique (Flanagan 1954) to investigate when, where and in which circumstances users' experience of listening to music was considered problematic or inappropriate. After using brainstorming, sketches and video prototyping they develop interaction scenarios. In a second phase of the workshop they inject a technology probe consisting of a novel multichannel interactive sound device. As a result, the participants produced prototypes that revealed three potential functions associated with the gestural manipulation with the interactive sound prototype: "association", "communication", and "navigation". A participatory approach used by Tanaka, Bau and Mackay reveals how users can generate ideas about sonic interaction scenarios that can be explored in further phases of design.

3.3.5 Sound prototyping in Sonic Interaction Design

Sound Prototyping toolkits are often used in Sonic Interaction Design. They are particularly relevant to aid forms of sketching through sound-feedback. These toolkits are often based on physical aspects of sound and movement. Delle Monache, Polotti, and Rocchesso (2010) developed an interactive "Sound Design Toolkit" (SDT) for Cycling'74 Max/MSP. Following an ecological approach to sound perception (Gaver 1993b; Gaver 1993a), the SDT is a set of "perceptually-oriented and physically-consistent tools for sound synthesis" intended for use by sound designers (Delle Monache et al. 2010). The SDT is a modular system that uses physical and modal synthesis to generate sounds based on physical interactions of different bodies and materials. The toolkit is designed as a modular system of patches, with independent modules for objects (such as "metallic ball"), physical properties (such as "weight") and actions (such as "hitting"). The versatility and modularity of Max/MSP allows quick adaptations to various sensors and systems. Although very versatile and powerful in terms of sound design possibilities, in its current version, the SDT focuses mainly on sound design and it does not provide a quick and intuitive software package to realise gestural-sound mapping using motion sensors, something that, for example, can be useful in participatory workshops on embodied SID.

Another toolkit for SID comes from Karmen Franinović, Michel Rinott, and Frederic Bevilacqua, who prototyped the "The Voice-Gesture Sketching Tool" (VOGST) which explores sound sampling in real-time, voice and gestures. It is a "gesture-voice capture device", which allows users to move what they call an abstract object with a handle, for the real-time manipulation of audio samples of voice recordings. This offers a platform for sketching novel forms of interactions afforded by this kind of system. Although very promising, the toolkit was not made available for public use. It also seems to be designed for the specific abstract object in mind, whose handle affords grip. This limits possible scenarios of usage, as already observed in previous studies with gestural-sonic embodied interfaces, such as in Tanaka, et al., 2012. This short review of available sound design toolkits shows the need for developing a custom toolkit for gestural-sound mappings that can be quickly used in participatory design settings.[10]

3.4 Methods and Techniques in this Research

After the above review of the methods in SID research, I now introduce the methods I have chosen that will help me to investigate the research questions and to pursue the objectives of this thesis.

3.4.1 Participatory methods in this research

This research will involve participants to allow for an investigation of their sonic experience using embodied interactive technologies. The pilot user study, alongside the series of participatory workshops, will be used to gather users' sonic experience and help us thus to elaborate our knowledge of users' perspectives on interacting with embodied sonic technologies. I will use techniques such as interviewing, questionnaires, brainstorming, prototyping and user evaluation to give fundamental insights into this research. The rationale behind this decision derives from previous research on gestural music interaction made by myself and collaborators (Tanaka et al. 2012), and previous works I produced as a sound artist, which have included participatory methods such as interviewing and collaborative design with other practitioners (Altavilla & Tanaka 2012). At that time, I observed that involving participants at an early stage of development had benefits for the process of designing interactions mediated by sound and technology, although the original fields of application – sound art and interactive music - were different from the current research in Sonic Interaction Design.

Within this research, the participatory approach presents different types of challenges, existing at various levels. The very first challenge is how to gather

[10] This review of the SDT and of VOGST was conducted on March 2013, at the early stages of the Form Follows Sound Workshops development. SkAT Studio, a newly developed toolkit available on GitHub from January 2016, will be briefly presented and discussed in Chapter 5.

participants' sonic experience because of the richness of these experiences and the difficulty in communicating them. A second challenge is to understand what could emerge from participants' descriptions of sonic experience and how to understand and accommodate these emergent aspects in research, beyond what we may expect. Using qualitative methods to gather participants' sonic experience of interacting with embodied sound technology is one strategy through which I aim to overcome this challenge.

As noted by Rocchesso and Serafin (Rocchesso et al. 2013), one of the difficulties in designing sonic interactions is the different terminology used by specialists and non-specialists in sound to describe, use and manipulate sound and the need of deploying design methods to bridge this gap. Finding appropriate methods to help participants to describe sonic experience is another challenge. To tackle this challenge in my research, I utilise a user study and participatory workshops, and employ methods specifically designed to help participants to talk about sound in enriched ways. I will collide existing methods to describe sounds with ideas taken from previous research in Sonic Interaction Design, such as sound and action descriptor cards (Tanaka et al. 2013); these will be merged with activities involving bodily gestures and vocalisation as part of the descriptive task. This approach could help to link together everyday sonic experience, imagination and simulation through interactive sound technology.

A third challenge is represented by the technical component of this research. In the context of the participatory workshops series, the usage of gestural-sound technology, depending on how it is designed, may not be as intuitive and could compromise reaching the final stage of prototypes. This is particularly relevant in the case of time-limited participatory design workshops, in which several different tasks may be undertaken within a short period of time, from brainstorming to realising interactive prototypes. One strategy to overcome this issue would be to design our own toolkit based on a modular paradigm, which would allow the interconnection of a few hardware-software modules specialised in achieving particular gesture-sound mappings, possibly named in a way that would help participants to understand the functionality of the system. As this toolkit would be used in the workshops, the presence of my collaborators and I would allow us to provide technical help if required.

Although I have outlined a few important challenges, working with participants can benefit the research not only in terms of designing methods and tools, but also in revealing other perspectives on the research itself. It could show us a series of possible embodied interaction scenarios, possibly emerging only through enquiring about participants' sonic experience and then exploiting it in participatory design workshops. It can give us important knowledge about how to develop and refine prototyping toolkits based on human gesture and sound playback, and the underlying embodied models of interaction.

3.4.2 Technology used

The research involves two main technological components combined together: the first is the use of motion sensing technologies which will serve to track human movement and convert it into useful data. The second component is the real-time sound playback system running on a computer, which plays back sound through loudspeakers or headphones. The sound playback system is appositely programmed to allow the conversion of the motion data into the real-time manipulation of parameters of the chosen sound synthesis engine (e.g. timbre of sound, amplitude and others).

We have seen in Chapter 2 that these kinds of systems are commonly used in Sonic Interaction Design research. The particular focus of my research focuses on sonic experience with body free interactions - without intermediating objects with specific gripping and holding affordances. The choice of using this system is based on previous research work I undertook with collaborators, investigating the relationship between body free interaction and real time sound playback of musical sounds (Tanaka et al. 2012). The choice of a miniaturised accelerometer relates to observations already published in the 2012 user study, in which we discussed the impact of anonymously shaped miniaturised objects – not reminiscent of any particular existing electronic device - in terms of gestures performed by the users and ideas for future interactive prototypes. Due to the participatory nature of the current research and particularly of group-based workshops in multiple locations, other types of technology, such as optical motion capture, were not considered useful for this specific research project.

The reduction of the technological impact is also a conscious attempt to shift the focus on sonic experience in SID. The use of miniaturised accelerometer sensors can suggest minimal affordances in terms of the appearance of the devices, due to their size and shape. In this way I hope to make the technology less prominent, at least on the level of appearance and physical characteristics. Nevertheless, technology will still play a role in determining the experience of sonic interactions, as this is influenced by aspects of mapping between movement and sound feedback.

The focus on interactive sound feedback is not only based on the academic context and opportunities within which this research takes place. It is also based on exploiting embodied modes of listening and the concept of sonic affordances. By linking bodily trajectories and sonic images which come to the listener, I hope to understand how we can provide designers with methods based on exploiting people's sonic experience to inform a development of novel scenarios of embodied interaction with and through sound. The technological component will be developed in different phases. The pilot study will use a gesture to sound mapping system, which I designed for the user study I conducted in 2012. The system consists of a miniaturised tri-axial accelerometer mapped to parameters of various sound synthesis modules programmed in Cycling '74 Max/MSP. When the user moves a limb, the resultant movement data is mapped to parameters of the sound synthesis engine, producing changes in the heard digital sound played back from the system. This creates a strong link between the user's movement and the sound heard, favouring what we can consider an ergo-audition mode of listening as described by Michel Chion.[11] In the original version for the 2012 user study, the system mapped users' gesture to the playback of musical sound, whereas the forthcoming system of my current research maps movement to non-musical sound. This will be instrumental to the study of gestural-sonic affordances by reducing the possible influence of musical sound to be recognised, potentially impacting upon the gestures performed in a way that is not useful for the current research. Therefore, the design of the sound synthesis engine will be based on reducing this possibility by going towards primitive psychoacoustic dimensions of sound.

Through the development of this research, the function of the technological component will change according to the research needs. In the pilot user study it serves to explore designed gestural-sound mappings with participants in order to

[11] Daniel Hug discusses this mode of listening to interactive sonic commodities mapped to the movement of the user. (Hug 2013; 2014)

understand how they describe their experience of interacting with the system. The role of the technological component is to allow us to conduct the user study and gather the views of participants on this matter. The system to be implemented in the pilot study will serve as the basis for the technological component of the following workshops. There we will design a toolkit for rapid prototyping of gestural-sound mapping. The toolkit will be used by participants to develop their own interactive prototypes, as they will choose and design their own sounds and gestures. Whereas in the pilot we will use sounds designed by ourselves as researchers, in the workshops participants will use sounds recollected from their own sonic experience. This will necessarily imply the use of a different sound synthesis method, based on sound sample manipulation. This will allow participants in the follow-up series of workshops, presented in Chapter 4, to develop their own prototypes based on their everyday sonic experience.

3.4.3 Involvement of Participants in Research

Participants will be recruited among non-experts in Sonic Interaction Design and music technology, although I will look to involve specific design communities, or subjects with a strong interest in designing interactions. The rationale behind this choice relies primarily on the supposed lack of familiarity with the technological system in use, which maps the movement of a limb to digital sound playback. This could potentially lead to different perspectives on the gestural-sound interactions, different mappings, gestures and importantly, a vocabulary to describe all these aspects. Another consideration is that working in a design context, but reducing the presence of specialists in sound and music, could help us to gather emergent scenarios of interaction behind sound design or musical applications. Evaluating the effectiveness of this form of selection is too complex for this specific research project, nor it is its intention, but it is important to mention it.

To recruit participants I will disseminate a call for participation in academic institutions. I will try my best to avoid any particular selection of groups based on gender and age, although, particularly due to the calls being spread across university settings, participants under 18 years will be necessarily excluded. The specific contexts in which participants are recruited, however, is not neutral, nor reflective of the vast range of people and their different cultural, social and economic backgrounds. For the purpose of this research, which is specific to the rising of specific academic occasions directed towards particular design research communities, this is an issue that, although very important, did not required extra attention. Furthermore, the specific idea of developing a prototyping toolkit requires that the it will have a degree of usefulness for the participants' purposes and some relevance or connection to their work. It is expected therefore that people interested in or active within research design communities - although not necessarily specialists in Sonic Interaction Design - are likely to be involved. Finally, a statement about the ethical guidelines followed and the model of the consent form used can be found in Appendix C: Ethical Statement.

3.5 Pilot Study on Gestural Sonic Affordances

This section presents a pilot user study involving non-specialist participants, in which I investigate gestures, movement and sound-related affordances with interactive technologies. The principal aim of this experiment is to understand how participants describe aspects of embodied action-sound perception and their experience of interacting with sonic interactive technology based on body movement. The knowledge gathered from this pilot user study will be used as the basis for designing a series of participatory workshops (Chapter 4).

This pilot study follows an earlier user study I conducted with colleagues (Tanaka et al. 2012) which looked at gestural affordances of musical sound with a movement based, interactive music system.[12] In that study we conducted an interview-based user study comparing three accelerometer based devices, an Apple iPhone, a Nintendo Wii-mote, and an Axivity Wax (a miniaturised 3d accelerometer generally unknown to the participants) and mapped gestures to different musical sounds. We noted that physical affordances of the device and the cultural signifiers of both device control and musical sounds influenced the gestures performed by participants and the descriptions of the experience they gave. Hearing the production of musical sounds separated from their original sources, and linked to human movement through technology, reveals that there is more than only a direct form of sound tracing based on the imagery of the energy associated with the sound. We designed the current pilot study to minimise the impact of the physical characteristics of the device and possible cultural

[12] This study was conducted with Dr Neal Spowage, a researcher from De Montfort University and with Prof. Atau Tanaka.

association of sounds, to concentrate on exploring embodied interactions with sound from the perspective of the participants.

3.5.1 Pilot study: Rationale

Based on the 2012 study, I designed the following pilot user study for the research presented in this thesis. Compared to the previous study based on musical sound, the aim of the current pilot study was to move from music to sound, and to strip away the object's appearance and cultural factors to focus on the affordance that sound itself might provide. This serves the specific reason of gathering knowledge about the individual experiences of gestural-sound mapping as discovered and explained by participants.

To do so, the pilot focuses on exploring the concept of gestural-sonic affordance which, in my view, can represent a link between embodied experience of sound, mental simulation of movement in terms of trajectories and orientation towards a specific goal. Therefore the user study relies on employing this concept towards the development of the "sound-centred approach" mentioned at the beginning of this chapter. The concept of gestural-sonic affordance will be used in a participatory workshop in a following phase (Chapter 4). This concept will serve to form listening imagination, a starting point for creating designs connecting human movement and listening experience.

Looking at previous literature, we can think of sonic affordances as related to gestural trajectories evoked by hearing sound, as renderings of profiles of energy evolution and dynamics, similar to sound tracings (Godøy 2010b), together with the impact of identifying the sound source (Caramiaux, Bevilacqua, et al. 2014). To study these, in the design of the pilot I attempted to minimise both object-based affordance and cultural associations to investigate the potential gestures afforded by synthetic sound, as opposed to musical sounds. Importantly, similarly to our previous study (Tanaka et al. 2012), but differently from Godøy and Caramiaux's work, I did not want to ask participants to listen and then perform a gesture. I wanted to explore what gestures would arise through a direct connection between hearing sound and movement. This removed the need to ask participants to imagine a gesture associated with the sound heard in order to build their own connections and relationships between movement and sound heard.

Finally, the pilot study has the function to test the technological apparatus of this research with users and set the basis for future developments during the following series of participatory design workshops.

3.5.2 Technical apparatus

We used the Axivity Wax, a miniature, low power, wireless 3D accelerometer, to capture participants' gestures.[13] The sensor is about the size of a thumbnail and was housed in a Velcro-band strapped around the hand (Figure 3-A). This minimised the physical form factor of the sensor as an object. The data rate from the accelerometer rate is up to 2 ksamp/sec. The device sends accelerometer data in OSC format over ZigBee to a dedicated receiver unit, which in turn was connected to a laptop computer via USB. The computer runs a Max/MSP patch reading the sensor data, and maps them to sound synthesis control parameters. Two speakers play back the sound produced by the Max Patch. The signal was split in dual mono, meaning that the same signal was distributed evenly between the two speakers. This choice was made to avoid giving the impression to the listener of a precise sound source located in the room, which a single speaker in the centre of the room, or in any other side of the room, can easily create. We produced synchronised audio-video recordings of the performances and the interviews of the participants using standard audio/video recording equipment.

3.5.3 Scenarios

Differently from the experiments by Godøy and Caramiaux - where participants are asked to perform gestures in response to the sound stimuli heard - we opted to design a gestural-sound mapping that participants would actively play. We designed three scenarios corresponding to Schaeffer/Chion's categories of sounds: Impulse, Iterative and Sustained (Chion 1983). These categories have been a standard basis for previous research and studies in the field (Godøy 2010b; Caramiaux, Bevilacqua, et al. 2014; Van Nort 2009). The aim of using these categories for designing our sound stimuli and gestural mapping was to reduce the possibility that participants would start making associations with performance of musical instruments as already noted when using musical sounds in our previous study.

[13] The use of "we" here refers to myself, Dr Baptiste Caramiaux and Prof Atau Tanaka as part of the research team that developed and delivered the user study.

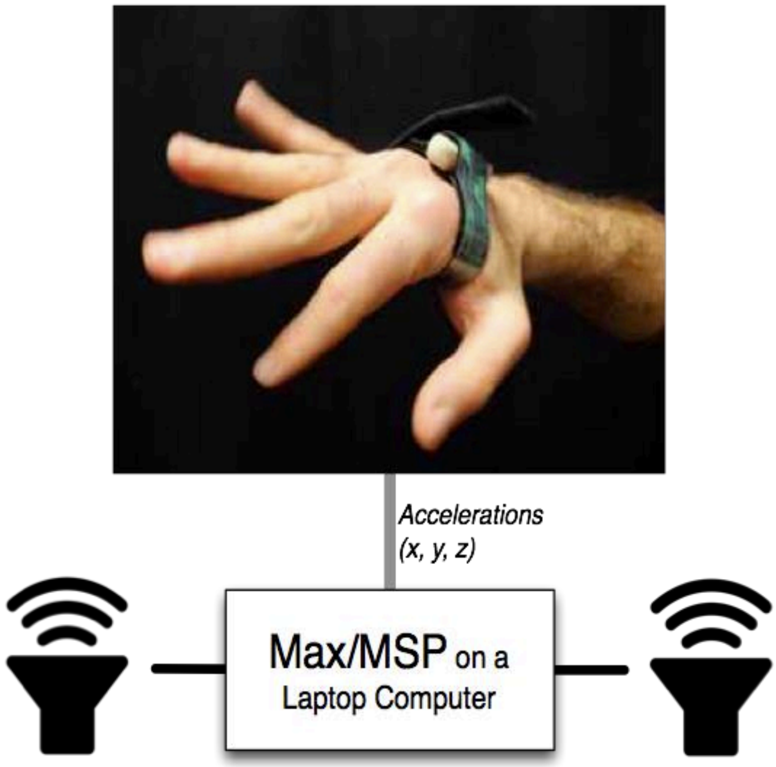

Figure 3-A: The Wax fitted into a Velcro hand-band. Acceleration data is mapped to different parameters for controlling sound synthesis.

We worked with synthesised sounds rather than samples in order to minimise possible associations of the sound with known objects. The Impulse sound was designed with a physical model of a generic percussion instrument (Cook & Scavone 1996) using the Percolate objects in Max/MSP. The Iterative sound uses the physical model of a shaker (PhISEM, by Cook & Scavone 1996), while the Sustained sound was built using amplitude modulation (AM) synthesis.

We created the following mappings (Figure 3-B) between accelerometer input and sound output:

- Impulse sound control, based on percussive action. Sound is triggered once when the instant energy of the movement exceeds a set threshold. We use a reset hysteresis of 200ms to avoid multiple triggering.

- Iterative sound control, based on shaking of the hand. Sound is articulated by accumulating energy. It is first actuated with a minimum movement of the hand. Increasing the frequency of periodic movement controls amplitude of the overall sound and three parameters of the physical model such as: decay, shake away energy and resonant frequency of the filter.

- Sustained sound control, based on continuous movement of the hand or arm. The overall amplitude of the sound is directly proportional to the amount of movement produced. The vertical tilt of the hand, in both directions, controls the depth of the tremolo. A small amount of vibrato (+/- 20hz) is controlled by horizontal rotation. The reference frequency of the oscillator is 420hz. The amplitude of a third sine oscillator set to 880 Hz is exponentially mapped to the speed of the movement.

3.5.4 Procedure

We conducted the pilot study, with 8 participants (4 identified as female, 3 identified as male and 1 preferred to not answer), between 24-40 years old, with little or no experience in gestural-sound interactive systems. I recruited participants by circulating a call via email to Goldsmiths College students. I sent the call to different university mailing lists, public boards across the campus and posts on social media. The pilot was conducted in English.[14]

We created a task-oriented user study to investigate whether participants could play three different sounds based on three different mappings that we designed (impulsive, iterative, continuous, as shown on Figure 3-B). The tasks involved one person at a time. We attached the sensor on the dominant hand of each participant and explained to them that the movement of their arm and hand would produce electronic sounds. They were simply told that there would be three scenarios, without providing them details, nor instructions, about the kinds of sounds or mappings expected. They were told that they were not being evaluated or judged. The order of the scenarios was randomised and counterbalanced across participants. For each scenario, the participants were given up to 1m30s to explore and try to figure out how to play the sound.

We then interviewed the participants individually, first with general questions, which were then followed by a more detailed review of the activity.

[14] One participant, recruited on social networks, did not speak fluent English and would not have understood all the questions asked. The user study was stopped and the data completely disregarded.

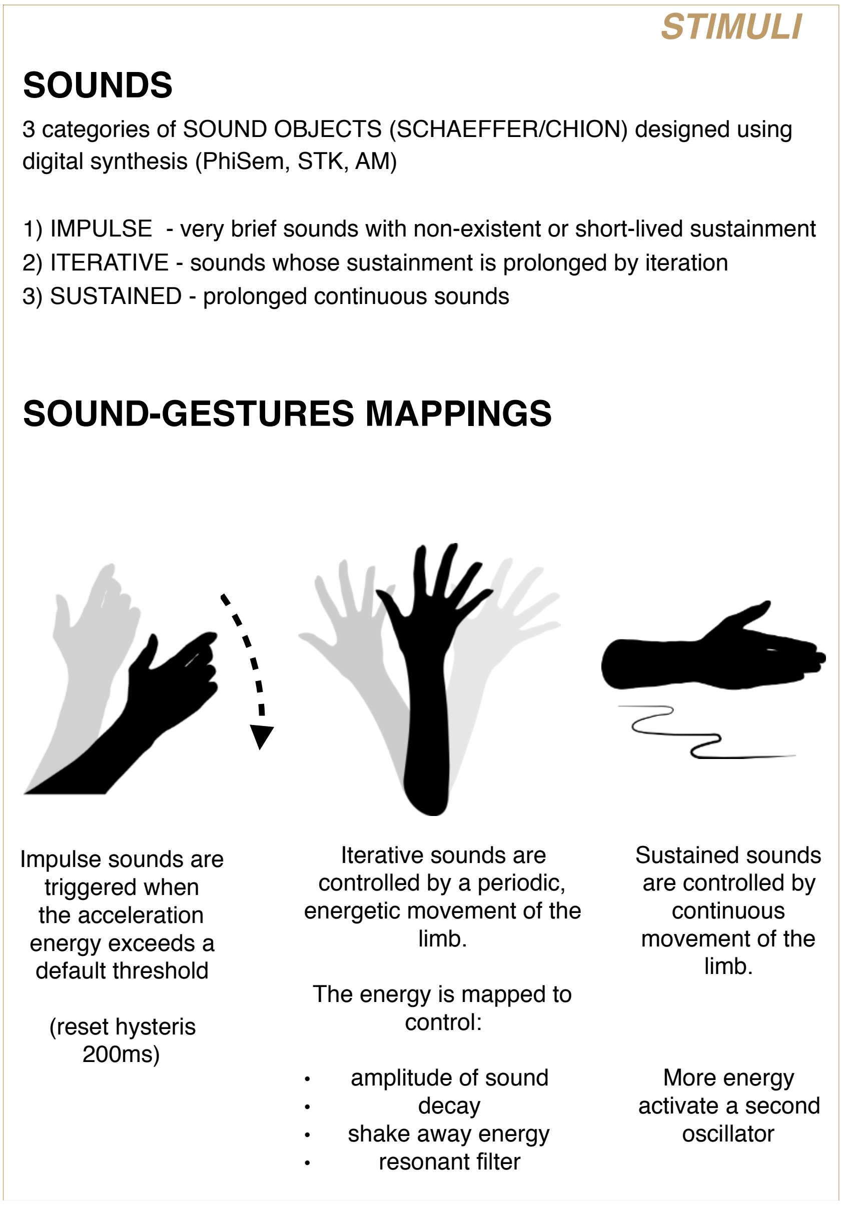

Figure 3-B: Gesture-Sound Mappings designed for the User Experiment

The two general questions asked to each participant were: Was this way of producing sounds natural? Was it easy or difficult? By asking these questions we were interested to see if the experience of playing interactive sound mappings by moving the limb was intuitive for them, especially given their perspective as non-specialists. We also thought that this could help us to understand how effective the designed mapping was in relation to its respective sound stimulus in terms of intuitiveness. Here intuition is meant as the process of gathering an understanding of an interaction mechanism, without a conscious knowledge or recollection of such experience, so that this interaction can be performed without receiving complex instructions. As aspects of intuition and automatization are also important for perceiving affordances (Still & Dark 2013), investigating the intuitiveness of the interaction was intended to help to address our questions about affordances and embodiment.

We then performed an auto-confrontation interview (Vermesch 1990) where participants watched a video of themselves performing the tasks and were asked to base their answers on specific moments in the video. The aim of the auto-confrontation interview was to stimulate participants to observe their own actions, recognise and discuss them, opening interesting possibilities of exploring processes and understanding their own movements. This could also help participants to answers our questions about their experience in the user study, without interrupting the flow of the activity. The auto-confrontation also helped us to avoid asking participants to perform a gesture as a form of answer in the procedure itself, rather we wished to obtain insights into a gestural response to a sound stimulus.[15]

The interview was guided by a series of questions reported in Table 3-1. The first question (q1) asked participants what kind of sound they heard while performing the task and how they would describe it. In this way we aimed to first observe if they would refer to everyday sounds, musical sounds or any of these, and test our selection of sound stimuli. At the same time, we wished to understand what participants perceived in terms of sound sources, considering that they were actively producing it by controlling an interactive system.

Table 3-1: Auto-confrontation interview questions

q1	Can you describe the sound you just played?
q2	Can you describe your action in terms of physical movement?
q3	Can you tell us how to play the sound?
q4	How did you go about trying to figure out how to play the sound?

[15] A video example of this can be found in the storage media attached to this thesis.

With q2, we wanted to know more about what participants describe as physical movement when using this embodied interactive sound system. We wanted to see if, for example, they would describe movement using a symbolic representation of gesture (e.g. hitting) or using geometric, spatial metaphors. This could potentially help our analysis of gestural rendering connected to hearing sound, with the advantage of using the auto-confrontation interview as an embedded element of the task, rather than using a separate task which asks participants to move or render a gesture. With q3, we wanted to observe if participants could explain the mappings we designed. By doing so we could explore matters of intuition and visibility of the mapping in order to cross-analyse affordances through inclusion of questions about the interactive system used in the study. Finally, q4 explores how participants discovered the mappings. We wanted to know more about the relationship between sound perceived and action performed as part of the process of discovery. We could, for example, analyse whether reactions are more involved than plans in this process, and contribute to the discussion on sound-related affordances against system-related affordances.

3.5.5 Results

The audio-video recordings of the interviews were transcribed and annotated using Inqscribe software. We noted the timing of the participants' gestures and added descriptive notes tagged with video timecode. Interview data was factorised to each specific question and used to build a grid analysis (Appendix A – Table A-1).

Participants classified the general experience of playing sounds with limb movement as "natural" and "intuitive". Some participants explained this as an ease with which they perceived a link between sound and movement. The lack of external interface was another element which made the experience "natural". The experience as a whole was also classified as "easy". Participants felt that it was "easy to find how it works" (U3), having one sound for each scenario helped (U4), and acoustic feedback facilitated the experience (U6). It was also classified as "fun" (U4, U7) and the freedom of playing with the body was also here considered to be a positive aspect (U5, U7). The time needed by participants to explore the three different tasks was on the whole shorter than the 1m30s they were accorded. The average timing for impulsive sound was 1m10s, for the iterative sound it was 1m15s and for the sustained it was 1m05s.

DESCRIPTION OF SOUNDS (q1)

The Impulse and Iterative sounds were often described using references to similar and known sound sources from everyday life and musical instruments. Impulse sounds were described using words such as “bouncing ball”, “drum sound” (2 times), “computer error” (2 times). Iterative sounds were described as “rattle” (3 times), “interference noise” (3 times) “insect flying” (2 times), and “driller”. Sustained sounds were described less precisely. Two participants described them as “finger moving on the ring of a crystal glass”, but generally this category of sounds was described using abstract and ambiguous references, such as “U.F.O. in cinema”, “wavy sound” and “digital sound synthesis”. Sometimes our participants mimicked gestures in order to reinforce words that were difficult to articulate.

DESCRIPTION OF ACTION (q2)

For Impulse(s) actions participants used terms such as “like playing basketball”, “pushing”. Iterative actions were described using words such as “touching”, “vibrating”, “shaking” or “scratching”. Sustained control was described using information on the spatial sequence of movement (up/down/left/right, horizontal, vertical, drawing a circle).

EXPLAINING HOW TO PLAY THE SOUND (q3)

In most cases participants were able to explain what were the most effective movements needed to play the three different sounds. Their descriptions linked the imagined object of q1 with the action described in q2. For the impulse sounds they used action verbs such as “pressing”, “pushing”, “percussive” (2), “moving the arm suddenly”, “hitting” (2), “knocking”. For the iterative sounds, participants used words such as “impact and continuity of the impacts”, “scratching”, “rubbing”, “shaking” (2), “swinging”. For sustained sounds, they referred to arm position as somehow affecting the sound (2), while the speed was seen as changing the amplitude of sound (5). One participant described that the sound became “harsher” as a result of moving the arm energetically, correctly identifying the presence of a third, non-harmonic oscillator in the sound engine, activated only when a higher energy threshold was exceeded.

UNDERSTANDING HOW TO PLAY THE SOUND (q4)

Participants used different approaches to understand how to play the sounds. Two participants used a fixed sequence of movements as a reference for the production and control of sound. Two other participants tested general random movements until they could hear some sound and then started a gestural exploration. Finally, the remaining participants declared not to have used any strategy but relied on intuition.

3.5.6 Discussion and Implications for Design

The aim of this study was to form an understanding of how participants would describe the role of sound as causing movement, and the role of movement in controlling the playback of sound. Participants explored ways in which their body movement was the principal cause for the playback of digital sound coming from a set of loudspeakers. This was initially set up as an investigation of the possibility of playing digital sound by only using the body, without any visible instrument.

For each scenario, participants tried to describe the sounds and gestural interactions in terms of causality, shapes and referring to familiar objects from the real world. This may indicate that people have a tendency to look for associations in order to describe sound. Even in the absence of an object, they described the sound in terms of objects. In the absence of cultural referents, participants tried to describe their gestural relationship with sound grounded in present-day culture (drums, computer beeps). These types of descriptions can be seen as associative, as they are in a causal relationship with a source that participants could associate with, as in causal listening. Sometimes, in particular with continuous sounds, they used geometrical shapes to describe sound and actions. These kinds of descriptions can be labelled as morphological, as they seem to follow spatial and kinetic characteristics of the movements participants performed to play the sound in terms of trajectory, energy and speed. They seemed to be related to spectro-morphological qualities of the sound, particularly for the continuous sound stimuli, which lacked any defined impulsive or iterative nature. The results we obtained seem to corroborate some of the observations we made about musical sound in our user study of 2012, and in the study by Caramiaux (Caramiaux, Bevilacqua, et al. 2014) on gestural renderings of environmental sounds. This was the case for relationships between identification of sound and gesture described.

By describing sounds heard and movements performed, participants disclosed to us a rich array of sound sources, actions and contexts from the everyday and their memory. These descriptions gave me an indicator of the possibility to further explore the private and intimate dimension of participants' everyday sonic experience, as well as revealing a need to devise further methods to explore participants' everyday through sonic interaction workshops.

Furthermore, this user study gave me the possibility to observe something I was not expecting: the tracing back of a process of listening as described by participants. The narrative disclosed by the participants included elements of discovery and interesting doubts: they reported what sound they "perhaps" heard, what kind of movement they "think" was connected to a source that was only imagined. This richness and ambiguity of experience, rather than being a problem, posed an opportunity to be further explored. It moved towards addressing research question Q2, regarding how we can draw upon people's sonic experience to inform novel scenarios of embodied SID. This initial exploration warranted further development, which will inform the design of the following participatory workshops. We will look at the particularity of each participant's sonic experience and investigate further ways in which we access and draw upon people's sonic experience to inform developing novel scenarios of embodied SID.

On a technical level, the small dimensions of the motion sensor, the stability in terms of performances and reliability of the system, and the intuitiveness of the experience as reported by participants, indicate to us that the technological component can be used in the following phase of this research in a participatory design context. In the following series of workshops we will explore everyday recounting of sonic experiences from our participants, therefore the research needs will be different and the design of the system will be adapted. We will need to design a toolkit that allows participants to choose their own sounds and design their own gestural mappings. As the hardware component does not need any modification, the main effort will be in designing an interface that can be used by our participants during the workshops.

Finally, the pilot study gave us insight into studying sonic interactions that surpass the role of the physical and cultural impact of the artefacts. It does so by extending the scope of research into Sonic Interaction Design beyond sound-action perception with object manipulation augmented with digital sound feedback (Franinović et al. 2008; Franinović 2011; Polotti et al. 2008). In fact, it presents us with an opportunity to investigate the tension between everyday, cultural aspects of sound and technology in order to understand our complex experience with embodied sonic interactions, based on bodily movement without any interposed object. This is something that will be further explored in the series of workshops in the next chapter.

3.6 Chapter Summary

This chapter presented the overall methodology used in the research, based on the usage of qualitative and user-centric methods. It firstly introduced the rationale of the research design and presented the aim of pursuing a "sound-centred" approach, and the importance of listening and human sonic experience with devising inventive methods in Sonic Interaction Design. It then overviewed some of the methodological approaches, methods and tools used by others in Sonic Interaction Design Research. Subsequently, I presented the research procedure and methods used, including the data gathering and data analysis techniques applied and the technological tool developed in this PhD. I finally presented a pilot user study on gestural-sound affordances that serves as the basis for the development of a participatory design workshop series, which will be the subject of the next chapter.

4 FORM FOLLOWS SOUND WORKSHOPS

4.1 Chapter Introduction

This chapter presents a series of workshops designed and conducted for this research, which assumes central importance in investigating sonic experience, embodied sound cognition and their role in the design of sonic interactions. These workshops introduce a series of methods for implementing a participatory approach to the design of sonic interactions. Conducted in collaborative settings, my specific contribution to these workshops was to design and develop methods for interaction design that exploit users' embodied sonic and listening experiences. [16] [17]

The chapter begins by presenting the rationale and the specific methodology followed in the workshops, and the methods and techniques generated, discussing how they were designed, organised, delivered and evaluated. It then continues by presenting the workshops' results, followed by a discussion of the methods deployed, the technological component in use, the scenarios generated by participants and the models of interactions observed.

[16] *Form Follows Sound* was a series of participatory workshops delivered by Dr Baptiste Caramiaux (Goldsmiths), Prof Atau Tanaka (Goldsmiths) and I. Caramiaux developed the machine learning algorithms for the technical component of the workshop, while I specifically focused on designing activities that started from an attention to sound, towards embodied interactions, scenario development and prototyping. I also collaborated with Caramiaux on developing the Gestural Sound Toolkit. A full account of the division of roles can be read in section 4.2.

[17] A long paper about the *Form Follows Sound* workshops has been published in Caramiaux, B. Altavilla, A., Pobiner, S. & Tanaka, A., 2015. Form Follows Sound: Designing Interactions from Sonic Memories. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, and available in Appendix D in this thesis.

4.2 Form Follows Sound Workshop: Rationale and Methodology

Form Follows Sound is a series of participatory workshops designed to investigate sonic experience and everyday situations to generate novel interactive scenarios. This was a collaborative work with Dr Baptiste Caramiaux and Prof. Atau Tanaka. In these workshops, we concentrated on exploring evocative and embodied aspects of sonic experience, treating them as contexts to explore, rather than focusing on interactions with an everyday object. The second research question of this thesis (Q2) asks how we can draw upon sonic experience to inform a development of novel scenarios of embodied SID. Form Follows Sound tackles this question by undertaking a phenomenological approach to the matter of sonic experience, focusing on ways to gather and subsequently draw upon experience from a first person perspective (Petitmengin 2006; Petitmengin et al. 2009). Therefore, we designed and delivered Form Follows Sound as a series of participatory design workshops that focus on participants' memory and direct experience of sound in the everyday. Since the design process is driven by sonic experience, through looking at participants' sonic memories, we chose the name Form Follows Sound, which is a reference to the idiomatic "form follows function".[18]

In these workshops, we wanted to create activities that could help us to generate descriptions of sonic experience from our participants, but make these meaningful for generating scenarios of interaction. To do so, I propose to explore participants' sonic memories to understand what other information they might reveal regarding everyday situations. The development of workshop methods for Form Follows Sound required me to devise exercises to hone in on participants' memories of everyday sonic experience. I developed exercises focusing on critical, memorable moments from participants' everyday that would instigate a simulation of listening to sounds from their memory. To do so, I looked at listening exercises in the field of acoustic ecology (Schafer 1992), the Earbender techniques from Barrass (Barrass 1996), together with activities for the classification of sound on a qualitative level, and the techniques of the critical incident used in Psychology and

[18] The origin of the expression is attributed to the American architect Louis Sullivan, the first creator of the modern skyscraper in late 19th century. The expression then became a principle followed in modernist architecture and industrial design in 20th century.

HCI (Flanagan 1954) and previously in Tanaka's A20 (Tanaka et al. 2013). The combination of these techniques gave birth to The Sonic Incident and Embodying Sonic Imagination, which will be described in section 4.2.1.

Working with embodied interactive technology, we also wanted to build a link through which participants' everyday sonic experience could be used to generate sonic interaction prototypes. Baptiste Caramiaux and I collaboratively developed a software toolkit to be used in conjunction with motion sensors, for prototyping sonic interaction using body gestures. We therefore designed activities that could use the sonic experience recalled in previous phases, building from it to generate interactive prototypes. To do so we included and adapted techniques such as bodystorming and prototyping from interaction design.

We planned our workshops to consist of two phases: (1) Ideation and (2) Realisation (Table 4-1). In the Ideation phase, participants generate ideas without using sonic interactive technology. In the Realisation phase they develop, prototype and finalise a group project using the provided sonic interactive system. This two-part structure follows the basic organisation of participatory design workshops as we have reviewed earlier in Chapter 4 in HCI and SID, in which the generation of scenarios of interaction should not be heavily based on the technology for which those scenarios are imagined. It also offers a possibility to include diverse participants, including those with no experience as well as those with varying degrees of familiarity with programming, physical computing and sound design. For the Ideation phase, we wanted to explore participants' sonic experience to ideate scenarios of interaction. The Ideation part was designed so that it did not include digital and interactive technologies. In the Realisation phase we introduced gestural-sonic interactive technologies to participants and asked them to generate group scenarios and prototypes, followed by the presentation of projects and discussion. In table 4-1, we can see the general structure of the workshops. The individual activities will be presented and discussed later in this chapter.

We evaluated audio and video recordings to help us understand the projects generated and delivered post-workshop and reviewed questionnaires to explore related questions about each workshop's impact on the participants. We used qualitative methods such as coding to understand emerging connections and themes.

Table 4-1: General Structure of the Form Follows Sound Workshops' activities, divided in Ideation and Realisation phases.

IDEATION
1. Sonic Incident: Remembering, describing and presenting personal sonic experience; 2. Sound and Action cards tagging; 3. Embodying Sonic Imagination: Imagining interaction with sound;
REALISATION
4. Prototyping Tools: Introduction to gesture sound technology for the implementation of the interactive scenarios; 5. Project design: Brainstorming, prototyping and finalisation of projects.

4.2.1 Ideation

In the ideation phase we wanted participants to generate ideas of interaction with sound. To do so, we chose to enquire about participants' memories of sound, explored different ways of presenting these and finally imagined possible forms of interactions deriving from them. We did not want to present interactive technology at this stage, therefore I designed exercises that would use paper, pens, graphic sketching, vocal description and body movement.

SONIC INCIDENT

The Sonic Incident is a specific method for interaction design that I created in this research. It draws upon the Critical Incident (Flanagan 1954), a set of procedures in psychology that elicit specific memories related to particular recent moments experienced by the subject. The critical incident is particularly useful for collecting data regarding behaviour, emotions and actions undertaken in particular situations; these can be analysed by the researcher in a following phase. I combined this technique with an exercise developed in acoustic ecology for developing attentive listening (Schafer 1992) in which students are first asked to remember a small number of sounds heard during the day, and then list and describe them in detail afterwards. Schafer's exercise aims to show participants how difficult it can be to remember and describe sound. By encouraging them to listen more carefully to the world around us, these exercises have the purpose of helping participants to develop a language to describe sounds, using textual and graphic description (Schafer 1992; Coleman et al. 2008). The Sonic Incident is thus a combination of the critical incident technique together with listening exercises proposed by Schaefer and it serves to explore sonic memories for generating ideas of interaction, potentially expanding the methods available for designing SID workshops.

The Sonic Incident is designed as a warm up activity for our workshops. It helps to sensitise participants' thought to sound and interaction, as sensitisation is important when working with non-specialists in sound and music. It consists of a series of exercises that help users to remember sounds which are evoked due to their nature of defining a particular or personal situation. This aims to guide the researcher in exploring people's sonic memories as a resource for understanding, presenting and designing examples of corporeal and embodied interaction mediated by sound, which are not too abstract from users' everyday. This method consists of three exercises:

1. Remember a particular situation in which sound was important;
2. Describe the sound and situations on paper using words and graphic sketches;
3. Communicate these sounds and actions to the peer group through vocalisation and body movements.

In the particular case of the sonic incident, this emphasises specific, recent incidents and incites the subject to remember their sonic qualities. First, participants remember a particular incident that occurred several days ago, and after which the sound was memorable. This helps the participants to remember incidents during a situation which was frustrating, surprising, funny, or where the sound contributed to that situation being memorable. We ask participants to describe the incident, the reason why they remembered the sound(s), the situation they were in while they heard them, and finally how they related to those particular sounds they evoked. In this way, we aim to access not only the sound itself being memorable, but also where and why the incident is memorable, possibly disclosing different levels of information regarding the interactions mediated by sound as being described by the users. These may reveal gestures performed, emotions or reactions involved, information retrieved and decisions made in the particular situation and how this was exclusive to sound being noticeable.

After remembering the sound and situations in the Sonic Incident, we ask participants to write a text and/or graphical description of the Sonic Incident. Importantly, these descriptions are not communicated to other participants in the group. Instead, they are narrative plots that help participants to present their sonic incidents with their bodily abilities, using voice and gestures. To do so, we use vocalisation, an established technique in SID workshops for producing quick sketches of sounds with a variety of participants (Ekman & Rinott 2010; Rocchesso 2011; Rocchesso et al. 2016), and which consists of a simple imitation of the sound described in the incident by only using the voice. After a round of guessing, the participants describe the sonic incident with words. The use of vocalisation in the Sonic Incident brings a physical awareness of producing sound. Furthermore, vocalisation often produces ancillary gestures. These can become additional information that can be abstracted and observed, feeding into the design process. For this reason, the Sonic Incident technique may be useful for two important processes: (1) to access sonic qualities and the context of the experience described in the incident, helping to generate design ideas, and (2) to include aspects of body movements which we can explore with motion-tracking based technology in the following phases of design.

SOUND AND ACTION CARDS

We use a card-based exercise to aid participants' description of the sonic incident. We provide them with two types of printed flashcards containing keywords in the form of adjectives (descriptors) or verbs (actions) they can use to further describe a sound, a technique previously used in Tanaka's A20, a participatory design workshop on gestural-sonic interfaces for future music consumption (2013). We take these adjectives and verbs from a series of antonym pairs derived from previous research within acoustic ecology and embodied sound cognition (Altavilla et al. 2013; Caramiaux, Bevilacqua, et al. 2014). This exercise aims to give non-specialist participants a common vocabulary for talking about everyday sounds. By providing a pre-defined lexicon we aim to focus the discussion and help to highlight similarities that might exist across incidents, which may initially appear to be unrelated. We also provide blank cards to see what additional words participants might use to describe their sonic incident.

EMBODYING SONIC IMAGINATION

Embodying Sonic Imagination is a method that comes from combining together "bodystorming" and "interaction relabelling", as introduced in the previous chapter. With this method we want to explore affective, personal and embodied relationships with sound offered by the Sonic Incident as a resource to generate possible scenarios of interactions. This method helps participants to imagine they can actively interact with the sounds and situations evoked in the Sonic Incident. We start by asking participants to imagine being able to manipulate or change the sound by using their body movements. After a written description, participants act out the interaction as a gestural charade and discuss with the group.

In the Form Follows Sound workshops we use several strategies to invoke corporeal engagement with sound in the different iterations of the workshops. The first is to adopt the metaphor of "superpowers", encouraging participants to think of themselves as having an imaginary power over the sound through bodily actions. In another approach, we ask participants to think about what the sonic incident did to them, as though investigating a form of sonic affect. Here, our interest is in encouraging the participants to think about what happened to them through sound, and to see if they can take ownership and agency over the situation. In both cases, the goal is to move from remembering a sound heard to sketching an active and bodily interaction with it.

4.2.2 Realisation

In the realisation phase we introduce our interactive toolkit for gestural-sound mapping to workshop participants and then we form breakout groups. These groups collaboratively develop projects using our technology and following ideas generated in the ideation phase. I will now present our interactive technology followed by a presentation of the project design phase.

INTERACTIVE TECHNOLOGY: THE GESTURAL SOUND DESIGN TOOLKIT

The context of the participatory workshops requires us developing a toolkit that could be used by participants to design their interactive sound prototypes based on the recollection of sonic memories. The pilot study in Chapter 3 provided us with a technological component, based on the miniaturised accelerometer and a modular sound programming environment revealed to be functional and efficient for realising gestural-sound mappings. The anonymous and minimal aspects of the motion sensors did not show the same degree of physical and cultural affordances of control devices available in the market with built-in accelerometer, such as wiimote and smartphones. This shared consideration between the user study from 2012 and the pilot study conducted in Chapter 3, made the system an ideal candidate to be used in participatory design workshops as it could be easily attached to the body of participants. The specific idea for the workshops though relied on exploring sonic experience from participants, relying on their memory. Therefore, rather than us choosing the sound stimuli as in the pilot, we needed to allow participants to choose their own sounds. This would also apply to the choice of associated gestural mapping. The need of such modularity therefore developed in the concept of the development of a toolkit, which could help participants to choose their own sound and mapping.

Although the SID sketching tools reviewed in 3.3.5 proved to be useful for the workshops, some of their limitations – unease of use, lack of availability and being device-specific - were too inhibiting for adopting them in Form Follows Sound workshops. In our case, we needed a toolkit that could exploit participants' embodied interaction and familiarity with the sounding and movement abilities of the body, that could be easy to use, non-device centric in terms of shape and manipulation and importantly available to a bigger community of non-specialised users.

The Gestural Sound Toolkit is our answer to this emergent need of the research. It is a software/hardware prototyping platform we designed to aid the development of interaction scenarios into working projects. The toolkit was developed collaboratively between Baptiste Caramiaux and myself. We designed the general idea and the graphical elements of the interface. On an individual level, I focused on the high level design of sound synthesis modules and the interfacing with the accelerometer-based devices we used in the workshops.[19] Caramiaux developed the movement analysis and machine learning modules and the low-level elements of the sound synthesis engine. The toolkit uses MuBu lib developed by the ISMM

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[19] Axivity Wax3. See https://axivity.com/downloads/wax3

team at IRCAM[20] and CNMAT Max/MSP Externals library. [21] Both these libraries are currently free to download and to use. Our toolkit can be downloaded for free.[22]

The function of the toolkit is to give participants a sketching tool to develop prototypes using interactive gestural-sound mappings. It integrates complex techniques for sound synthesis with machine learning of movement, making these techniques available to participants with no background in interactive systems, sound design, and more generally in programming and physical computing. It comprises modules for receiving movement data from sensors, analysing data through machine learning and gesture recognition, and mapping participants' gestures to sound synthesis.

The toolkit consists of three main categories of modules. The first one is the Receiver module. It receives motion data from the Axivity wax3 wireless accelerometer device we will use during the workshops. It accepts any list of three values, such as in the case of Open Sound Control messages (OSC) that these devices – or any others compatible with this protocol – transmit.[23] It also offers possibilities for fine-tuning of the calibration system.

The second category of modules performs movement and gesture analysis (Analysis modules). These modules analyse accelerometer data such as reducing noise, extracting energy and impact, and performing gesture recognition. This is based on machine learning techniques, and it specifically uses the Gesture Variation Follower algorithm developed by Caramiaux (Caramiaux, Montecchio, et al. 2014). This is based on a learned, pre-recorded database of gestures and permits the early recognition of a live gesture as soon it starts. It also estimates variations of characteristics of speed, scale and orientation. This is particularly useful in the case of real-time interactions with sound in the prototyping phase as it facilitates procedures of gestural-sound mapping.

The Synthesis modules compose the third block of our toolkit. They enable participants to play with pre-recorded sounds and to manipulate them. In the Trigger module participants can play sound samples once, as if pressing a key on a

[20] MuBu lib is available at http://forumnet.ircam.fr/product/mubu-en/
[21] CNMAT Max/MSP externals are available at http://cnmat.berkeley.edu/downloads
[22] Gestural Sound Toolkit page on Github. Fork of the author based on collaborative work with Dr Baptiste Caramiaux, who is currently maintaining it: https://github.com/12deadpixels/Gestural-Sound-Toolkit
[23] OSC Specifications are available at http://opensoundcontrol.org/introduction-osc

keyboard or hitting a drum snare. The Scrubbing module allows users to start the sound playback from a chosen playhead position and to change it in real time. The Manipulate module controls frequency aspects of the sound, the pitch, speed and filtering. The Scratch module works similarly to a vinyl player and the variation of speed changes the pitch of the sound sample. The Stepping module divides the sample in parts according to the detected greater variation of amplitude of the sound, such as for beat detection. These can then be played as single triggers, creating a sort of shaker effect.

The modules can be assembled and linked as the users prefer. They are individual and can be copied, duplicated and rearranged. Figure 4-A shows an overview of the available modules, while Figure 4-B shows an example scenario.

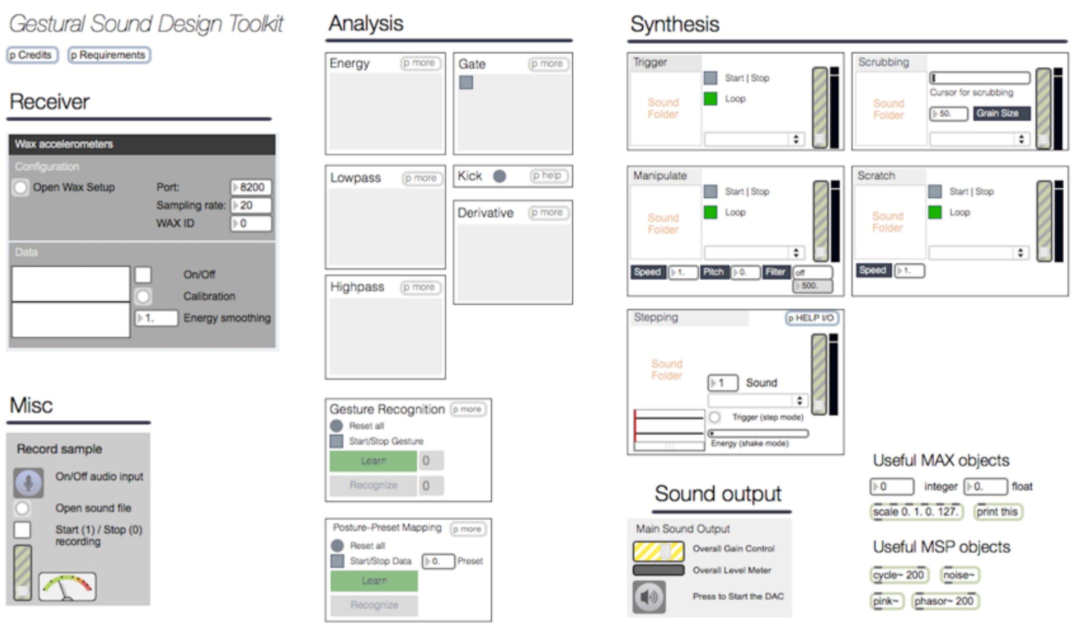

Figure 4-A: An overview of the modules available in the Gestural Sound Toolkit

In our workshops we introduce the toolkit with a preliminary tutorial, including a short presentation and ending with a short hands-on session where participants build simple interaction examples, such as triggering a sound with an impact gesture captured by the accelerometer, or shaking a sound with rapid iterative movement. The objective for the tutorial and the following short hands-on session is to provide participants with enough knowledge about the toolkit to develop the final projects on their own. The effort we put into designing and programming the toolkit aimed to make it easy to use and effective for general users to quickly prototype gestural-sound mappings. The workshops offered us a possibility to test this toolkit in action with non-expert users.

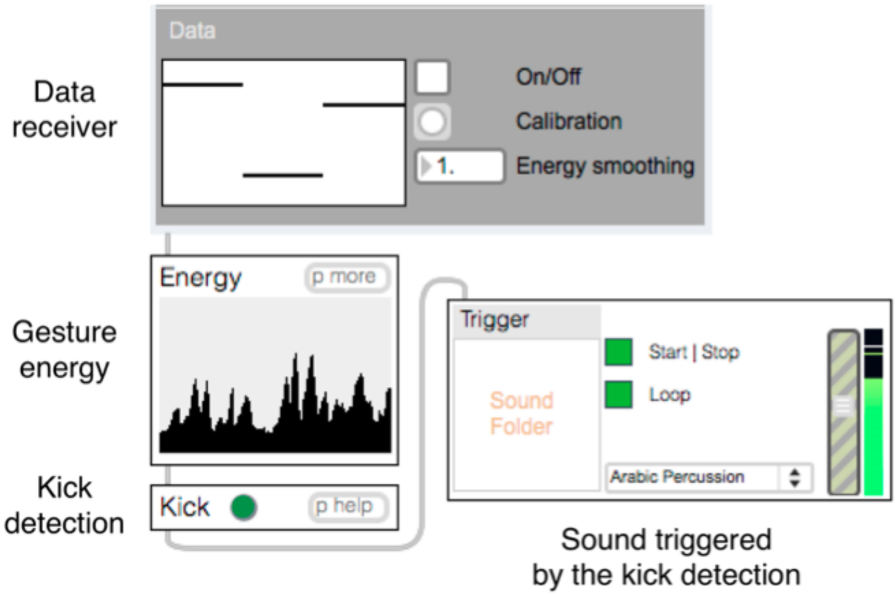

Figure 4-B: Gestural Sound Toolkit: Articulating sound through an impact gesture. Accelerometer data enters (top), energy is calculated (middle), and a kick is generated (bottom) when energy crosses a threshold, resulting in sound being triggered (right)

PROJECT DESIGN

The Project Design is the final stage of the workshop. Here, participants are grouped in small teams and develop a working prototype of the interaction scenario arising from their sonic incident. This involves group brainstorming about a project to be realised collaboratively, storyboarding it (both of which are specific to group projects), followed by implementation, testing, and public demonstration. At the beginning of the Project Design, each group selects one sonic incident and starts to brainstorm a project they want to develop. We provide groups with an empty graphic storyboard they can use as a template in which to present the imagined scenarios. This aims to help them define the set of actions needed and gestural-sound mapping strategies for their imagined interactive situations.

In the following prototyping step in the Project Design, participants use the interactive gestural–sound design toolkit in their projects. Each group develops this on a laptop and then tests the sounds using headphones or multimedia speakers. In the final stage, each group of participants connects their laptop to a main sound system in the presentation space and presents their projects and their rationale to the others. We close this phase with a group discussion with the participants to investigate the relation between the sonic incident and the final projects, to discover strategies adopted for their development and to extract emerging, broader themes.

4.2.3 Delivery

The preparation for this workshop lasted for 3 months, between February and April 2013, in which its structure, exercises and prototyping technology were developed. We delivered the workshop four times in the following 8-month period, between May 2013 and January 2014. The majority of the participatory workshops were organised in university and academic institutions, often in the occasion of special classes, upon invitation of the course leader and organisers. The call for participation was distributed by email to the specific institution at which we were invited to deliver the workshops and details about the target and content of the workshop was available on a purposefully built website.

We had a total of 42 participants of varying degrees of experience with sound and music:

- Workshop 1 - London. A one-day workshop at Goldsmiths College. 9 participants (2 identified as female and 7 identified as male), aged 22-31. Their background included, art and technology, social science, film studies, sound design and computing.

- Workshop 2 - New York. A two-day workshop at Parsons The New School for Design. 15 participants (8 identified as female and 7 identified as male) aged 22 - 44. Participants' background included graphic and interaction design, theatre and dance performance, music.

- Workshop 3 - Paris. A two-day workshop at IRCAM Centre Pompidou as part of the European summer school, Human-Computer Confluence (HC2). 6 participants (2 identified as female, 4 identified as male), between 24 and

35 years old. Participants were from a wide range of fields including engineering, rehabilitation, music technology, physics, bioengineering, and art.

- Workshop 4 - Zurich. A one-day workshop at the ZHdK academy of art as an activity within a teaching module in Sonic Interaction Design. Participants were 12 students (4 identified as female, 8 identified as male) aged between 20 and 24 years, with no or beginner's experience in sound design and music.

The overall length of the workshops was different between the 4 different iterations, with each consisting of the same activities, but with variable individual lengths. Each workshop followed the structure described earlier in section 4.2, consisting of Ideation and Realisation. As we were open to reflection and feedback from participants during the delivery of the workshops, we made some changes in their various iterations, to reflect some issues and opportunities that arose. From questions about the clarity of tasks, to improvements in the way we used sound and action cards, we took various decisions for modification, particularly following workshop 1 in preparation for workshop 2. Although these changes could potentially introduce slight inconsistencies across the three different workshops, we decided to favour the clarity of the delivery and to not confuse participants. As opposed to the pilot user study presented in Chapter 3, these participatory workshops are thought to be more open ended and welcome changes and refinement through its various deliveries. Therefore, analysis of preliminary results and self-reflection were vital to understand and avoid possible complications through the various iterations.

One of the challenges was the clarity of the Embodying Sonic Imagination activity in the Ideation phase. The first important change was the metaphor we used for that activity. In Workshop 1 we used the metaphor of superpowers in which we asked participants to think what they could do with the sonic incident and specifically that they were able to manipulate the sound or the situation described. The initial analysis of the results from Workshop 1 induced us to explore an arising opportunity, which consisted of removing any reference to volitional control of sound in the presentation of the task. Therefore, in Workshop 2 we removed this metaphor, asking participants to focus on sound and interactions beyond their own possible control. As we will see in detail discussing the results, we noticed during workshop 2 that this was confusing for the participants and we observed a change in the final projects produced. In Workshop 3 and 4 we decided to go back to the metaphor of superpowers to address the confusion experienced in Workshop 2, and to focus again on bodily, gestural interaction with sound.

We made another relevant change in our methods, regarding the contribution of the Sound and Action descriptor cards. In Workshop 1 we used only the sound descriptor cards in the Sonic Incident phase. We wanted to explore actions as well and we designed the action descriptor cards for the following workshops and used them in the Sonic Incident.

4.2.4 Evaluation Methods and Analysis

The post-workshop phase is important to collect feedback from participants and other additional thoughts. We distribute online surveys to participants at the end of the workshop to retrieve satisfaction ratings, opinions and to ask further research questions. We ask if they are more attentive towards sound after attending the workshop and how this may have implications for their own professional activity or area of study. Other questions aim to gain an understanding of how the workshop was generally perceived and define possible changes for the future.[24]

For the analysis of the results and their discussion, we collected graphical and textual descriptions from participants' sonic incidents and scenarios and then analysed them using grids and coding. We also annotated video documentation collected in the workshop against the graphical and textual descriptions. Audio/video documentation and photographs of the workshops can be accessed online.[25] [26] We then generated a table describing each step of the sonic incidents (columns) in the realised project for each participant in each group (rows) (Appendix B, Tables B-1 and B-2). The data was then analysed to identify emerging interaction strategies. Finally, we analysed the post-workshop surveys. The following sections report the results for each stage of the ideation and realisation phases across the four different workshops.

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[24] See Appendix B – Table B-4 for the questionnaire given to participants and their responses.

[25] Form Follows Sound documentation is available at: http://mgm.goldsmithsdigital.com/formfollowssound

[26] These are also available on the storage media attached to this thesis. See List of Audio-Video materials on page 11.

4.3 Workshop Results

4.3.1 Sonic Incident

All participants across the four iterations of the workshop were able to describe one or two sonic incidents, with several describing more than three incidents. Of the 61 total sonic incidents, 57 were sounds produced by non-human events from the everyday. Of these, 20 sonic incidents referred to transport situations: "beep before tube's [sic] doors closing", "squeaking doors in the bus", or "bike hitting a manhole". 14 sonic incidents referred to domestic situations: "bubbling of oil while cooking", or "stormtrooper wake up alarm impossible to stop". Two other categories are: environmental sounds such as "wind" or "rain" happening in a particular situation such as "rain at the train station"; and electronic sounds such as "Skype ringing" while not being in front of the computer. Human-produced sonic incidents mostly involved social situations (8 sonic incidents), for example "children playing football" (See Appendix Table B-1, P11). Every sonic incident involved a sound that was not produced by the participant but that happened in a situation in which the participant was an observer.

The vocalisation exercise that followed the recollection and written description of the sonic incidents, created some discomfort at the outset for the participants. They were understandably embarrassed to use their own voice to mimic one of their sound incidents. Because we had not informed them of the running order of workshop steps beforehand, the choice of sound for the sonic incident would not have been chosen for its suitability to be voiced. Once the ice was broken, the vocalisation activity, which was based on a charade, was a playful moment that helped participants to get to know each other. Most of the vocalisations were spontaneously accompanied by gesticulations.

4.3.2 Embodying Sonic Imagination

While the vocalisation exercise in the Sonic Incident caused some hesitation at first, the Embodying Sonic Imagination exercise also caused initial difficulties and resulted in more questions by the participants for clarification. In Workshop 1, we introduced the metaphor of "Super Powers" encouraging the participants to imagine themselves as all-powerful beings who could create events and sound. We used this metaphor to relate the possibility of active manipulation of sound/situation with body movement. It gave rise to interesting questions, particularly from which perspective the participants should imagine the interaction: “Can I be the sound?”, or “Am I listening to the sound?”.

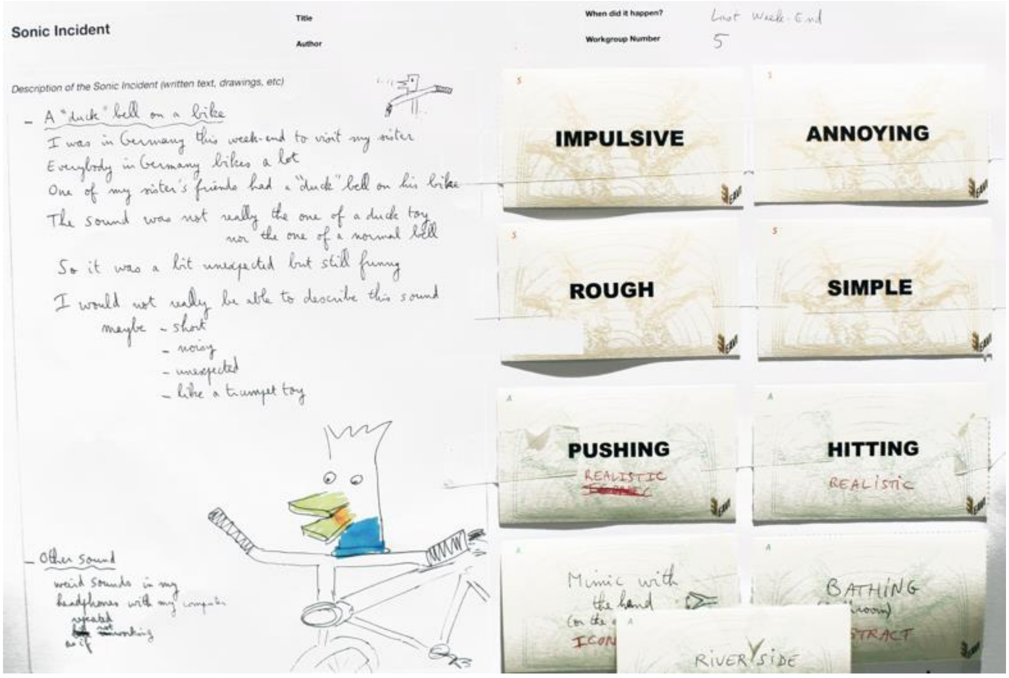

Figure 4-C: Sketch of one participant’s Sonic Incident, a duck-shaped bicycle horn (Workshop 3, P25). Sound and Action cards on the right used to tag qualities of the sonic incidents

In the second workshop we wanted to explore the questions of perspective raised in the previous iteration, and slightly reduce the perspective of volitional control. In this way we tried to describe different possibilities for corporeal engagement with sound, either as the cause of sound, or in reaction to it. To introduce corporeal engagement, we opted to use words as agency and relationships. The concept of agency was difficult to grasp for several participants, who asked us more questions and to explain the task again, showing that perhaps the task formulation was not ideal. Our main response to their questions about the exercise was:

“Imagine if your body could be the cause of the sound. How would it cause the sound to happen? Or, imagine if the sound had an impact on your body. How would it react?”

This resulted mainly in participants giving descriptions of what they thought was involved in the production of sound from a listening perspective. In this sense, the graphic sketches given by participants showed in particular how they were able to "zoom" in on the moving mechanical parts of the sound sources. For example, one participant chose as a sonic incident the sound of filling a bottle of water. The sketch proposed here was the bottle of water itself (Workshop 2, participant 16). However, the focus we intended when designing the workshop was more to relate to physical body actions instead of sound sources.

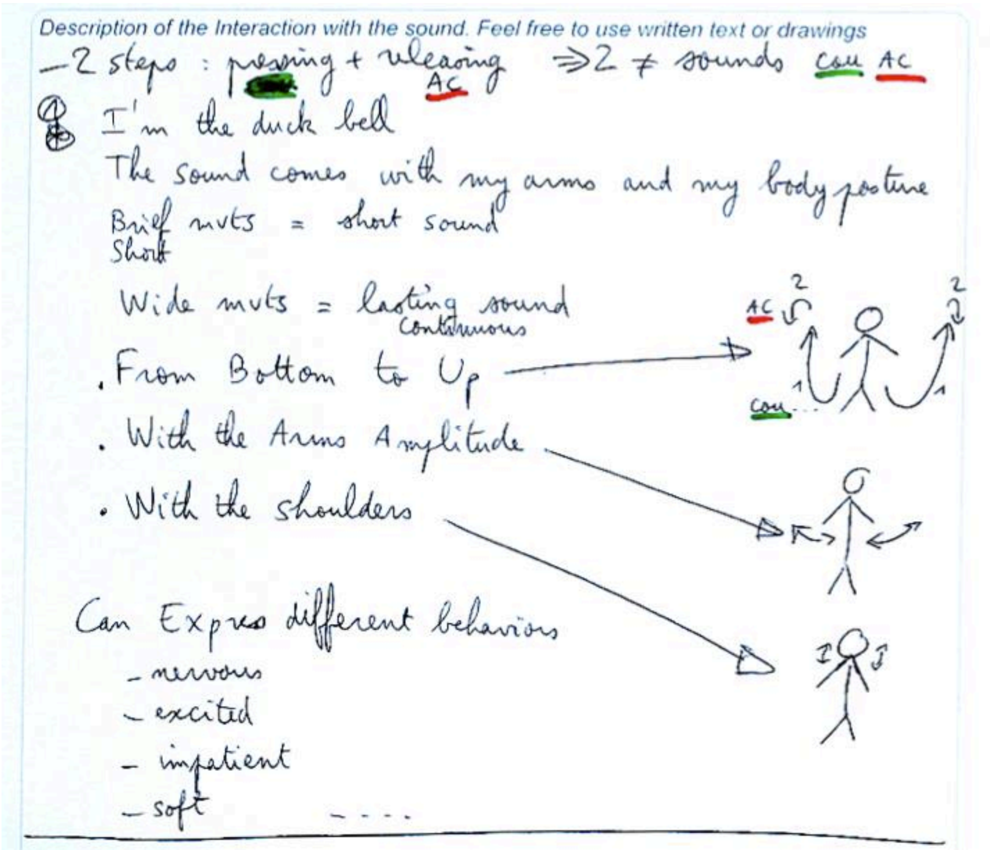

Figure 4-D: Embodying Sonic Imagination of being inside duck-shaped horn as directly derived from the Sonic Incident shown in Figure 4-C, modulating the squeaking sound with the movements of his arms

In the third and fourth workshops, we sought to somehow encourage the participants to think about agency, and encourage them to apply it by imagining possible interactions with the sonic incident. We reintroduced super powers in a modified way. The precise formulation of this task was as follows:

"Imagine you have super powers and through action with your body, you can manipulate the sounds/situation described previously in the sonic incident. So, look

at your sonic incident, and imagine what happens and how it happens. It doesn't have to be realistic."

This resulted in the use of the body in the scenarios imagined by participants, rather than the objects which emerged in Workshop 2. Using the superpower metaphor, participants produced examples in which they were embodying the sound sources, finding movement strategies to imagine modulation of sound. For example, one participant chose as a sonic incident the sound of duck-shaped bicycle horn, which he encountered in the street and, according to him, sounded "inappropriate". The sketch proposed was to become the duck-shaped horn, where three different movements of the arms-down-up, circular motion, and shoulder movement up controlled the duration and sharpness of squeaking (Figure 4‑C/D).

A table with the list of the sonic incidents and the relative imagined interaction scenarios that the participants generated can be found in Appendix B (Table B-1).

4.3.3 Sound and Action Cards

We used the sound descriptor cards in all the workshops, while the action cards were added in Workshops 2, 3 and 4. In Workshop 2 we used the actions cards for Embodying Sonic Imagination, while in Workshops 3 and 4 we used them earlier, with the sound descriptor cards in the Sonic Incident.

We had 16 pre-defined cards (cf. Appendix B – Table B-3), the most frequently used descriptors were: "annoying" (17 times), "close" (15 times), "loud" (14), "continuous" (14), and "personal" (12). Participants supplemented the pre-defined cards with 33 keywords using the blank templates. No duplicates occurred in free form user generated keywords. Some of the free form words, such as "aristocratic", "pretentious", "antagonist" refer not to qualities of the sounds themselves but to what they may represent for the participants in situations described in the incidents.

For a total of 8 pre-defined action cards, participants added 58 free form keywords, a higher number than for the descriptor cards. The most recurring pre-defined action words used by participants were "hitting" (9 times), "pushing" (8), "shaking" (6) and "scratching" (6). The participants' keyword "squeezing" was used 3 times by different participants.

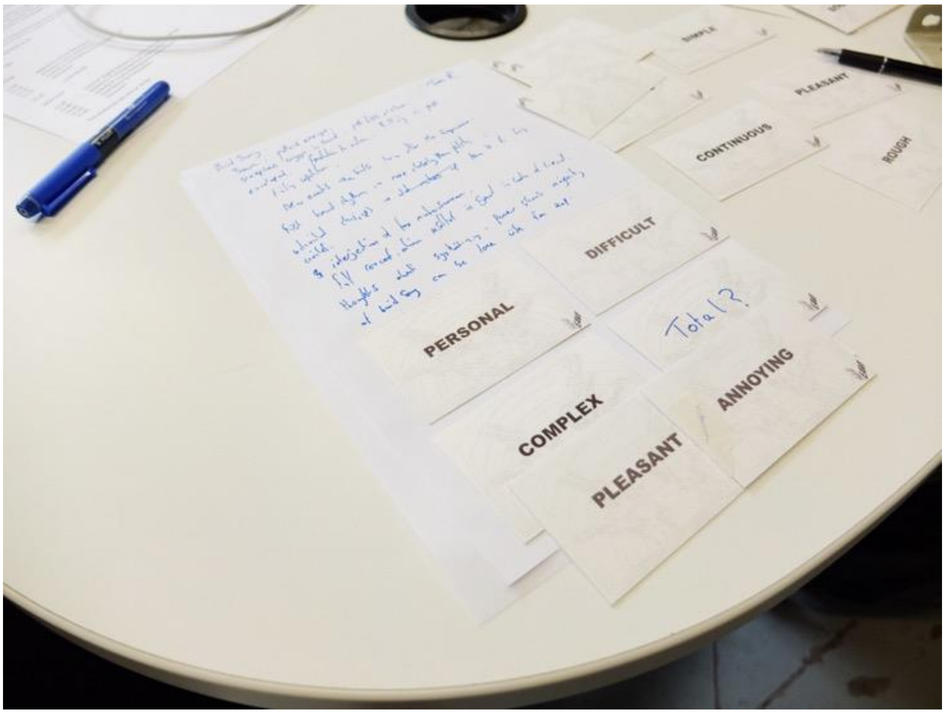

Figure 4-E: Sonic Incident with relative Sound Descriptor cards,
showing an example one participant added (Total?)

4.3.4 Projects Developed

During the four workshops, 14 projects were realised. In 13 cases, participants produced fully working prototypes that were presented to the whole group, while in only one case participants were not able to complete a final implementation. Only one project was realised without using sound material from the Sonic Incident activity in the first phase. Although all the 12 other projects made use of a recalled sound from sonic incidents, the final projects made different use of the situation in which the sound from the Sonic Incident occurred.

In the realisation phase, each breakout group chose one scenario from their group to develop into a functioning prototype. They first created an interaction scenario using a storyboard template, which was provided for them on paper, in which they described actions, sounds and interactions. They then recorded or searched online databases for sounds that approximated the sound of the incident. With this, they authored a movement/sound interaction using our Gestural-Sound prototyping toolkit.

Despite the potential difficulty of working with interactive sound software, the high level abstractions and workflow of our gestural sound toolkit was generally well understood by the participants. During all the workshops, the participants were highly independent and asked for help from the facilitators only when they wanted a software feature that was not included in the toolkit, for instance a sound synthesis engine such as sine wave generator (Workshop 3). We believe this was facilitated by the modular architecture of the toolkit and also by working in breakout groups, thanks to reciprocal help and co-operation between their members. There were two types of projects. The first implemented a scenario, or part of a scenario, from the ideation phase. The second used only the sound from the sonic incident and implemented it to generate a very different situation and interaction than the one originally imagined in the incident. A table with the list of the projects realised can be found in Appendix B (Table B-2).

Of the first type of project (of these there were 8 in total), an example includes: “Hum of airplane revealed by baby crying” and the participant imagined “conductor gestures, e.g. dynamic responding to raising/lowering hands” as the relative interaction mode to be developed. The prototype recognised three gestures. The first one triggers the hum of an aeroplane, the second one starts a baby crying, the last one stops the sounds. In this case, the participants found sounds in the Freesound online sound database.[27] During the demonstration, the participants placed the sensor on the hand. Accelerometer data was low-pass filtered to remove noise and then sent to the gesture recognizer. The recognised gesture was used as a selector for a sound in a playlist and subsequently played. Figure 4-F shows an example of a conducting situation.

In another example, the sonic incident was the “vibration ring of phone on a shelf while sleeping”, which was characterised as “wrong rhythm, it was like a call, instead it should have been like an alarm”. The imagined interaction was the “Snooze action to fall asleep again and creating a sound that would suggest me as being awake while still sleeping”. The group implemented a scenario in which after the alarm clock is heard, moving (mimicking the movement in bed) against the clock activates a "snoozy melody". Subtle movements change the speed of the melody played back to help waking up. When moving towards the clock, the alarm

[27] http://www.freesound.org

sound plays back to wake up the user. Here, participants substitute the alarm mode of operation through actions related to sleep (Figure 4-G).

Of the second type of project (4 in total), examples include a sonic incident of the "Sound of filling water bottle, changing" where the participant represented the action linked to the sound as "Bottle being filled with water" changing the pitch. The implemented prototype gives different sound feedback (based on the recorded sound sample of water poured in a bottle) according to the position of the leg or the arm (depending on the position of the sensor). This resulted in an application, the "Yoga corrector" that facilitates adapting body position during a yoga exercise according to sound feedback similar to the rising pitch of the filling water incident (Figure 4-H). The sensor was strapped on the arm or on the leg. They used the variations in orientation of the sensor to control the reading cursor and pitch transposition.

Figure 4-F: "Plane, Baby Crying" project (Workshop 1), in which participants controlled sounds heard in the airplane, including a baby crying out loudly, with conducting and other semantically rich gestures

Figure 4-G: "Snoozy bed linen" project (Workshop 4), in which participants imagined a less traumatic way of waking up by connecting their accidental movement in the bed to modification of the alarm sound

Figure 4-H: The Yoga Corrector project (Workshop 2). The position of the leg is mapped to the changing pitch of the sound, providing an auditory feedback about the angle of the leg

4.4 Discussion

4.4.1 Sonic Incident

In the Sonic Incident, participants tended to describe sounds that happened to them, rather than sounds that they caused. Participants posed themselves as receptors and not the sources of the sounds in the described incidents. They were able to follow the task of looking for situations in their daily lives, which suggests that we can explore users' everyday experiences through sound. In many cases, participants described stressful situations by tagging their sounds as "annoying" or "repetitive". In other cases the situations described were pleasant ones, and sound was considerate as "personal" or "soft". Descriptions of other situations included sound perceived as information, to alert to a possible physical impact, evoking nostalgic thoughts, as well as curiosity and uncertainty for sounds that could not be recognised.

The technique makes the participants aware of why sound was an important part of the incident, why they remember it and what would be the normal situation in which they would encounter this sound. It was particularly valuable in facilitating users' thinking about sound in context, as taken from the participants' idiosyncratic everyday life. Engaging the everyday of the participants is an important conceptual aspect of the technique as it can provide a context of use through the Sonic Incident itself. As such, we can suggest that the Sonic Incident can be thought of as a technique that could facilitate the design of situated interaction, as defined in (Beaudouin-Lafon 2004).

The focus on situations evoked by sound was a way to recall situations in which sound was temporarily dominating participants' attention. This considered regarding everyday sounds as a way to perceive events (Gaver 1993b). The sounds evoked were from everyday situations (interestingly, not taken from musical contexts). The focus of this exercise was to activate and recall the configurations of actions which participants generated from these sounds and the way that they revealed particular situations. The sounds evoked are perceived by participants as a manifestation of "new" information or a new state, an audible event that interrupts what they were doing before and affords what they could have done after, or in a more subtle way, something that tunes their flow of actions. In that sense these sounds were incidents, they happened to them from "outside" their sphere of control: they were external. What is significant in this case is that remembering the sounds as descriptors of particular situations was a way to focus on an understanding of the interactions between the agents, but importantly evoking temporal, dynamic, causal and affective aspects of this interaction. Participants may have heard the sounds they evoked in a past moment, however, this exercise aimed to activate processes of intentional analysis that are typical of listening. This action of remembering heard sound is more similar to the action of listening than to simple hearing.

The initial shyness in the vocalisation exercise, leading to subsequent playfulness, confirms previous dynamics noted by Ekman et al. (2010) and Rocchesso et al. (2013). In our workshops, the playfulness was a facilitator for discussion and created a collaborative atmosphere later for the breakout groups. In the guessing game, the actual success rate of recognition was low, as the sonic incidents people presented were from specific, sometimes obscure events. However, once the answer was given, the others in the group could relate to it, opening up keys to understand how sound could be represented, abstracted, and described.

The vocalisation thus aided participants in the process of design in two ways. First, vocalisation may have helped non-expert participants to think about how to reproduce a sound with the most embodied tool available, the voice. Second, the vocalisation of the Sonic Incident became, in 13 of 14 cases, the basis for the final projects realised by the breakout groups. This suggests that when the sonic incident is rendered through voice it becomes a reference that participants used for the development of the projects.

The sonic incident can be a useful technique in the current methodologies for studying and designing sonic interactions. By using this technique, we could provide an answer to the need of drawing upon people's sonic experience to inform a development of novel scenarios of embodied SID, as in our research question (Q2). It gives designers a method for evoking latent sonic memories which may be valuable for scenario-based sonic interaction design. It enables designers to focus on nuanced aspects of the sonic, exploiting hidden aspects of sonic experience.

4.4.2 Sound and Action Cards

The Descriptor Cards helped the participants to quickly describe affective qualities of sound. Seeding the descriptor cards with a common set of keywords had several benefits. Firstly, it provided a common lexicon to look for commonalities in the diverse set of incidents described by participants. It also aided workshop participants who do not have training in music or acoustics to describe sound in concise, objective language. The combination of sonic incident and descriptor cards thus provides a method to access subjective personal experience, yet describe its sonic qualities succinctly and precisely.

The Action Cards were more problematic and point to the difficulty of moving from describing the experience of sound to imagining causality and interaction with sound. This was compounded by the fact that we, as workshop facilitators, did not want to impose a control paradigm on the users. Instead, we wanted to find a language, be it through the action cards, metaphors like the super powers, or words like agency, to encourage the participants to think of sound as an active medium.

We observed that the use of sound and action cards helps to give participants in an SID workshop an extended lexicon to talk about sound. This helps to overcome what Rocchesso and Serafin described as the problem of "sensitisation" of students and designers to work with sound, as we saw in Chapter 2. We argue however that although the use of cards for describing sound and action was useful to an extent, it is somehow of limited use in the context of embodied SID. This limit is inherent in the usage of words and pre-defined labels to fully describe sonic experience. Other techniques such as the sonic incident, vocalisation and embodying sonic imagination can explore other hidden, embodied qualities of sonic experience.

4.4.3 Embodying Sonic Imagination

Participants in general were not accustomed to imagining interactive scenarios with sound. A critical aspect of the ideation process was therefore to aid the participants in thinking about acting in the situation of the Sonic Incident. With the superpower metaphor, we wanted to encourage participants to imagine interactions not constrained by physical limitations. However, we were mindful of describing the metaphor not to suggest a control, or command paradigm. When we replaced superpowers with the concept of agency over sound, the body interestingly became more of a listening channel for participants. It is interesting to note that in encouraging participants to take ownership of sound through their body, that the body, its potential for action and engagement with sound became a way to behold sound, to find new ways of listening and experiencing sound.

Mentioning actions in relation to sound did not lead the participants to involve the body in the interaction. The metaphor of superpowers was more successful in generating physical action–sound relationships in the imagined sonic interactions. We used this metaphor in three of four workshops (Workshop 1, Workshop 3 and Workshop 4), and interestingly faced questions about the meaning of the task. Participants questioned from which perspective they needed to imagine the interaction. This shows us that the metaphors we, as facilitators, use during the workshop activities have an impact on the scenarios imagined by participants.

The embodying sonic imagination technique proved to be very effective for designing action-sound relationship based on the personal experiences of participants. We argue that the metaphors used in the workshop phases play a fundamental role in driving participants to imagine particular scenarios of interactions. Although this is something to be taken carefully into consideration, the technique can help designers to imagine sonic interaction scenarios that could fit gestural-sound interactive systems. The central focus on body movement as connected to an imagined sound scenario can help designers to envision aspects of mapping that are based on the sonic imaginations of potential users.

4.4.4 Gestural Sound Toolkit

The Gestural Sound Toolkit and the accelerometer importantly contributed to the final project realisation. Participants spent a considerable amount of time with the system. In the second half of each workshop, they first familiarised with the toolkit, then they imagined group scenarios of interactions that would use, develop and present it to the others. It is important to note that our interactive technology was not invisible or neutral, however it is physically minimal and light enough. It was also not visible as a musical instrument or a known pre-existing sound producing artefact. There are three major considerations. The first is the impact of the way we designed our modules for sound sample manipulation and the sonic effect they created. It is possible that the metaphors we used to describe their functionality (scratch, stepper, manipulate, trigger, shaker) influenced the projects participants designed, in terms of the actions they chose to activate the sound synthesis.

The second aspect that needs to be considered is related to our gestural mapping and machine learning modules. Apart from technical glitches in the system due to its developmental nature, we found that what the system meant for gestures was not the same as understood by our participants. Often they imagined complex gestures, while the system was fairly simple, although technically promising. For example, a circle as imagined by participants might be the same as the one understood by the system, while an index finger moving to the mouth to communicate silence was not necessarily understood by the system. This discrepancy gave rise to a degree of frustration in some projects, while it was used creatively in others. One example of this is the "Pneumatic Step" project (Figure 4-I), developed in Workshop 2. The movement and sound that were designed were made to work around the glitches of the machine learning modules of the Gestural-Sound Design Toolkit. To do so, they modified the surrounding space with paper strips in order to create physical constraints that would modify their movement to fit their imagined scenarios.

Figure 4-I: The Pneumatic Step, a project based on the limitations of the gesture-sound prototyping toolkit and of the machine-learning algorithm (Workshop 2)

The third aspect is related to the affordances of the gestural-sound system as a whole, rather than as the union of sound and gestures. The difference between gestures and movement is important. In our workshop movement is designed as gesture, with a specific start and end, afforded by our specific interactive technology. It is important to consider sound-related affordances and device affordances together, as inextricably linked, as well as the context of use. The Gestural Sound Toolkit helps thinking about sound as connected to or caused by participants' movement, making it more similar to a musical instrument than an everyday non-musical object. The minimal aspect and weight of the accelerometer enable it to be attached to another object or to the body. When augmented with sound it becomes something different. It becomes one single sonic entity that is bound to the augmented body, which makes our actions "ensounded".

4.4.5 Scenarios Developed

The vast majority of participants' projects were related to the sonic incidents described in the first part of the workshop. The Embodying Sonic Imagination technique helped participants to move from a passive description of sound heard to an active playing in the scenarios. Some of the prototypes focused on the narrative element of the interaction described on the first day, a technologically aided re-enactment of the sonic experience itself. Several examples were instead focused on a sense of embodiment and substitution with the sound source itself (Figure 4‑J below). Other prototypes focused on the creation of interactive auditory display with some functional aim, such as a sonic "yoga corrector" (Figure Figure 4-H, page 125).

Interactive scenarios with their relative prototypes were produced using the technology provided, over the 4 different workshops (for a complete list with related description see Appendix B, Table B-2). From these projects, 5 types of scenarios can be identified. These are not necessarily exclusive and we found that some projects could fit into two categories.

- Narrative situations: playing the sounds on command to represent a sequence of actions in a particular scene or to tell a story (e.g. *The Snow Cracker, The Flap Pen*);

- Phenomenological substitutions: Being the sound sources. Presenting the sound without a narrative element, being the cause of sounds from one single perspective - phenomenological) (*The Wind Maker, Inside the Duck, Super Champagne Man, Being the Car, Pneumatic Step*);
- Controlling annoying sounds or situations: (*Alarms, Fireworks, Plane Baby Crying, Umbrella*);
- Functional sound-interactive artefacts (*The Yoga Corrector, The Snoozy Bed Linen*);
- Artistic objects for performances (*Test Your Mettles*).

Figure 4-J: Being the Duck project (Workshop 3), an example of a phenomenological substitution. The three images show the different phases of the project, from the sonic incident to the final realisation

4.4.6 Embodied Sonic Interactions Models

In 9 of the 14 projects, we found that the prototypes involved bodily actions that conducted the sound, substituted the sound cause, or manipulated the sound. These projects implemented ideas generated in the Sonic Incident and in the Embodying Imagination activities in the ideation phase. In the remaining 5 projects, participants used the sound imagined in the Sonic Incident, but they did not develop interaction scenarios based on the Embodying Imagination phase. We noticed that these projects were all from Workshop 2, in which the embodying imagination phase was formulated to participants in a way that we could enquire about actions in reaction to sounds. Interestingly, the 9 projects that show bodily, gestural interaction with sound occurred in the workshops in which we used the superpowers metaphor. We infer from this that the use of technology to realise scenarios has an effect on previously imagined action–sound relationships. This is dependent on the metaphor (actions in sound or the superpowers metaphor) used in the task from the first phase.

In the three workshops where volitional control of sound was explicitly mentioned (Workshops 1, 3 and 5), the scenarios that were generated showed interaction scenarios involving movements that substitute, manipulate, and conduct sounds, and their technology implementations captured user movements that reflect this. These action/sound relationships can be considered to be embodied sonic interaction models. They are described as:

- Substituting: the movements substitute the cause of the sound or the sound itself. Possible actions are defined by the sound itself and are not constrained by an interface. Then there is a direct modulation of some aspect of the sound (volume, brightness, playback speed) by the participant's actions.

- Manipulating: where movements manipulate the sound. The possible actions in interaction should be left to the choice of participant/user. They can be constrained by the interface. Then there is a direct modulation of the sound through the participant's actions, similar to the previous model.

- Conducting: there is a semantic relationship between the participant's gestures and the sound. The gestures should be free to be chosen by the user but they are, eventually, part of a finite set of gestures (a vocabulary). Then there is a direct relationship between a symbolic feature of gestures (what gesture, how it is performed) and the sound.

These three interaction models provide operational descriptions that can be used by interaction designers or developers to build sonic interactions based on gestures and body movement. To guide interaction designers, an interaction model can be characterised through its descriptive (incorporating existing interaction techniques), generative (facilitating new interaction techniques) and evaluative (comparing techniques) powers.

4.4.7 Ergo-audition and Augmented sonic memories

In the workshops, we wanted to explore what design scenarios and ideas would emerge from the participants' everyday if it were possible to have a direct, continuous and intentional relationship between their movement and hearing sounds. In some ways, we can see this aspect as a technologically mediated form of "super-agency" over sound, in which sound is linked to participants' own movements. Michel Chion calls this "Ergo-Audition" (Chion 2010), a form of listening in which we hear ourselves as acting. Daniel Hug observed similar results in his workshops about imagining future sonic interactive commodities (Hug 2013). In our workshops, participants produced scenarios focused on establishing their own relationships between their body movement and the sound produced. The personal, autobiographical function of remembering sound, as used and evoked in the Sonic Incident perhaps had an impact, by enabling these forms of ergo-audition when translated in scenarios of bodily, active interaction with sound. Likewise, the metaphors we used in the Embodying Sonic Imagination, super-powers (Workshops 1, 3,4) and agency (Workshop 2), helped participants to relate changes in sound production to themselves, although producing different results in terms of volitional aspects (Workshops 1,3,4) and bringing back causal, semantic and figurative aspects of listening (Workshop 2) from the participants' perspective. With the introduction of the Gestural Sound Toolkit, participants actively put themselves in relation not only to the sound, but the whole situation re-evoked from the Sonic Incident, and sometimes transformed into something new. Their body was experiencing a technologically mediated condition of being "ensounded" in a situation of ergo-audition, crossing between past sonic experience and future scenarios of interactions and even functional ideas.

We observed that many of the projects realised by participants were creatively rich and expressive. The combination of sound and body movement was considered almost as a choreography which was presented as part of performances. Some of the situations imagined by participants were far from realistic scenarios, but retained elements of participants' everyday; they turned the everyday situations into something else. They added a sort of what can be described as magical dimension which was actualised by evoking sound from their memory and reinterpreted with interactive technology. At the same time, they offered a different perspective from which we can look at interactive prototypes and their possible functions. One of the participants described the process of going from the Sonic Incident to the final project as "an augmented sonic memory" which "led to an improvisation and research into the psychological aspect of the prototype" (P30). In relation to one of the research questions (MQ2), our exploration of sonic experience and the use of embodied sound interactive technology reveals a connection between participants' psychological and subjective experience of sound.

4.4.8 Workshops' contributions to SID

This series of workshops investigated user-centred and sound-based methods for the design of sonic interactions, making five contributions to research in Sonic Interaction Design:

- The Sonic Incident technique as part of an ideation process for generating ideas for sonic interactions;
- Starting from sound for thinking action/sound relationships;
- Rapid prototyping toolkit for gestural-sound mapping;
- Participatory approaches to the design of embodied sonic interactions;
- Three models of bodily action–sound relationships to inform embodied approaches to Sonic Interaction Design.

The next chapter will discuss these contributions in full detail in the context of this thesis, supported by relevant themes emerging from the previous chapters.

4.5 Chapter Summary

This chapter has presented *Form Follows Sound,* a series of participatory workshops delivered in this research, in which we draw upon participants' sonic experience as a starting point for designing interaction scenarios. After a discussion of its rationale and design, I introduced a novel design technique to be used in early phases of design, the Sonic Incident technique, followed by the Gestural Sound Toolkit, a software library for Cyling'74 Max/MSP developed for helping participants to design their own gestural-sound mappings. The chapter continued with the presentation of the workshops' results and their discussion and contributions that *Form Follows Sound* gives to research in Sonic Interaction Design.

5 DISCUSSION

5.1 Chapter Introduction

This thesis has addressed how focusing on the subject of human sonic experience in research fields such as Auditory Culture, Sound Studies and Embodied Sound Cognition can inform an embodied approach to Sonic Interaction Design. In this chapter, I discuss the two core research questions posed in Chapter 1, followed by a discussion of the methodological questions and the role of participatory methods in this research. I then present four contributions of this research to the field of SID. The first is the concept of Retro-Active Listening, a concept generated in this research that helps to explain modes of listening observed in the Form Follows Sound workshops. The remaining three contributions are the Sonic Incident, the Gestural Sound Toolkit software and models for Embodied Sonic Interactions. The chapter concludes with an initial discussion of an emerging concept of gestural-sonic affordances which needs further research in the future.

5.2 Answering Core Research Questions

This research was motivated by a need to understand how an exploration of embodied sonic experience can be helpful for generating methods for the development of embodied Sonic Interaction Design. The overall aim was to contribute to the deepening and development of an understanding of sonic experience that can be useful for interaction designers who wish to work with sound and embodied interactive technologies. One of the problems of undertaking such research was to deal with the complexity of embodied experience with sound. To research these particular issues I decided to focus principally on two objectives: grasping a broader understanding of embodied experience with sound in SID research and finding an appropriate set of methods and techniques for undertaking such research using a participatory, user-centred design approach.

In the first chapter I presented the research questions and decided to divide them into two typologies: core (labelled with the letter Q) and methodological questions (MQ). The core questions were set up to investigate the subject of embodied experience with sound in SID, while the methodological questions were to address the selection of methods and techniques in the research. The next sections restate and discuss each of these questions.

5.2.1 The Sonic in Sonic Interaction Design

The first research question posed at the beginning of this thesis asked:

- Q1: What is the sonic in Sonic Interaction Design?

The rationale for this question was to explore different forms of the concept of "sonic" in Sonic Interaction Design research and provide us with insights into opportunities to explore.

The pilot study on gestural sonic affordances exemplified how we may explore the "sonic" through embodied interactive technologies, alongside the help of participants. By using a gestural-sound mapping in real time and miniaturised sensing technologies, we adopted a classical approach to Sonic Interaction Design in terms of typology of user study based on auditory stimuli and study of perception, in order to find relationships between participants' movements and digital sound feedback. As already noted, the principal feature of this study was the strategy of reducing the technological component of the interaction so that the influence of physical characteristics was minimal. This strategy allowed us to identify action-sound relationships that were not particularly dependant on the physical aspects of the control device. Participants' associative and morphological descriptions of sound revealed that sound entails a tension between its acoustic and physical aspects, and their cultural, everyday and situated qualities. These need to be considered in the design of embodied interactions with sound, deepening our knowledge of "sonic" in Sonic Interaction Design.

The Form Follows Sound workshops helped us to explore the intimate and private dimensions of participants' sonic experience. This helped us to focus our attention towards other ways in which sound can be engaged in Sonic Interaction Design, drawing upon memories and imagination. By investigating methods in which we can reimagine ourselves listening to a private and particular sound of the past, we developed methods such as the Sonic Incident technique, which enabled participants to be more sensitised and attuned to the sonic dimension of their life. This form of engagement with a wider dimension of the sonic, through techniques exploiting imagination and memory, can help us to imagine further ways in which, as SID researchers, we can adventure into richer deployments of the concept of the sonic.

The literature review of SID helped us to trace a general map of the sonic in this specific field of research. With her statement about Sonic Interaction Design, Franinović suggests the importance of exploring the complexity of sound as a spectrum of experience rather than a 'pure' phenomenon of audible vibration. Despite this, the research reviewed in SID has focused mainly on a consideration of sound as a form of acoustic feedback for aiding users' interaction with devices, utilising sound in a way which is centred around the idea of a 'pure', acoustical phenomenon. In Chapter 2, I reviewed current practices of SID. This showed how, for Rocchesso, SID offers "a privileged framework" for design practices which exploit links between sound perception and continuous interactions with embodied interfaces (Rocchesso et al. 2008). User studies on continuous motor interaction with sound playback, such as the Spinotron (Lemaitre et al. 2009), have at their core of investigation this idea of manipulating digital sound feedback through human movement – and vice versa – mediated by interactive technologies. The basis of this interaction is a mapping between the parameters of a sound synthesis engine – which cause sound to change – to the speed and energy of human movement manipulating an object. Other works reviewed in Chapter 2, such as the Flo)(ps or Polotti's Gamelunch, show how this mapping between digital sound feedback and continuous human movement generated a rethinking of habitual interactions aided by a form of "circuit bent sonic feedback" (Polotti et al. 2008). The examples of research in Sonic Interaction Design conducted in Chapter 2 show a use of sound that is primarily conveyed through digital sound feedback, played back in real time. This feedback was associated with the physical manipulation of interactive devices to improve or affect the performances of task-oriented activities or performative scenarios. This consideration of sound in SID illustrates one way in which the action-sound perception loop can be exploited, consisting of a conception of sound as a design medium that can facilitate human movements, such as manipulation, rotation, pushing and other actions.

In such cases, the word "sonic" in SID appears to be a statement regarding the presence of sound and vibration in processes of designing interactions by relating aspects of continuous interaction, body movement and technology. Although this is one the biggest advantages of designed sound as an effective medium for facilitating particular human movements thanks to its strong feedback component, the sole consideration of sound as feedback in SID poses some limitations. The problem with this idea of sound is that it has the risk of limiting the scope of Sonic Interaction Design exclusively to the presence of sound during the interaction, leaving unexplored the richness of sonic experience and the knowledge we can gather from exploiting human sensitivity to sound, including listening experience, memories and embodied imagery of sound.

To address this limitation, and build upon Franinović's idea of experience of Sonic Interaction Design, we looked to a different concept of "sonic" that could inform the research field, researching different literature and practices, including Auditory Culture, Sound Studies, Acoustic Ecology and Embodied Cognition. This opened up ways to frame the discussion of sound beyond a focus on auditory perception and psychoacoustics, considering experiential, extra-auditory approaches to sound too.

By looking at a phenomenological approach to the bodily experience of sound, such as in Ingold's concept of "ensounding" as an immersion in the medium of sound (Ingold 2011) or Henriques' "sonic dominance" (2003), we found an angle to investigate participatory, bodily involvement with sound that includes not only hearing sound but also the possibility of listening to it and thinking about it. The concepts of "ensounding" and "sonic dominance" offer us an important consideration of sound in relation to the potential experience of the listener, describing sound not as an object, as something that we hear, but as Ingold wrote "we hear in"(Ingold 2011, p.138). This consideration of sound is useful to expand the concept of the sonic in SID, to include psychological perspectives of other aspects of sonic experience, such as listening or remembering actions associated with sound. Acoustic Ecology illuminated how listening is important in the process of making sense of biological activities, in particular geographical places, and therefore gives a sense of their context. Godøy and Leman's work on cognitive studies of music and sound links an embodied relationship between sound perception with the actions we imagine and perform with our body. The triangulation between these research practices offers an understanding of sound that entails a consideration of "sonic" which includes both contextual and phenomenological aspects of our everyday sonic experience, illuminating concepts such as our "ensounded" condition - our immersion into the medium of sound, rather than considering it as an object – which affords a sense of place and memory. This sense of place and memory in providing case studies for sonic experience has been actively explored in this research through the use of the Sonic Incident technique and the activities of the Form Follows Sound workshops.

5.2.2 Drawing upon embodied experience

The second research question investigates how embodied SID research can be informed by looking at intimate and personal dimensions of people's sonic experience and their richness and diversity:

- Q2: How can we access and draw upon people's sonic experience to inform a development of novel scenarios of embodied SID?

The workshops presented in Chapter 4 explored private and embodied experience of listening as a method for imagining sonic interaction scenarios involving bodily movement. When designing the workshops, I did not wish to focus on problematic aspects of interactions between humans and devices in a way that augmented or facilitated interactions with sound by providing functionality for an optimal, positive, interaction. I instead tried to explore sonic experience as a way to generate new metaphors of bodily interaction, afforded by focusing on encompassing less commonly explored dimensions of the sonic, such as imagining and remembering ourselves as listening to a sound.

For example, the Sonic Incident technique can help to evoke problematic or unusual episodes by remembering their sounds. It proved to be a useful technique in our workshops, as participants generated scenarios of interactions following the sounds they evoked using our technique (see Appendix B, table B-2). The embodied sonic interaction models, described previously in Chapter 4, are afforded by the technological apparatus composed by miniaturised accelerometer and real-time digital sound feedback. However, it was important that the connection between the Sonic Incident and the scenarios proposed provided the source from which we derived the interaction models. Conducting, Manipulating and Substituting were models of interaction with the sound evoked by the sonic incident; they were not merely a means to control a gestural-sound mapping made by arbitrary movement and sound feedback. We can argue that participants derived the ideas for their movements by thinking of sound as related to their bodily and personal experience, as evoked in the Sonic Incident. The knowledge that the workshops give to the "sonic" in interaction design is one of accessing sounds experienced in a personal and embodied way without necessarily using external sound stimuli.

Drawing upon participants' sonic experience allowed us to actively expand the research already undertaken regarding the consideration of "sonic" in SID. By considering the full spectrum of experience towards not only sound, but also listening, body movement and imagination, we do not consider sound in its solely acoustic dimension, but explored auditory culture, embodied action-sound relationships and through remembering listening. This allows us to imagine other possible ideas for the sonic in interaction design that go beyond its manifestation as sound feedback to fix an interaction problem between human and artefacts. In our workshops, the "sonic" became a method to explore interaction problems that are specific not only to the presence of sound, but also our mode of experiencing it, including listening and thinking. This research developed some specific methods that belong to thinking "sonically", such as the Sonic Incident technique and Embodying Sonic Imagination, and used them as stimuli for the development of embodied interactions with technologies. This helped us in our participatory workshops to find problematic examples of everyday sounds, revealing situations that can be explored by focusing on the sonic aspects of the everyday. These techniques provide a few examples of how Sonic Interaction Design can access participants' intimate and personal experiences of sound for imagining new forms of embodied interactions with sound.

I have underlined how the most important aspect of starting from sonic experience was to give an initial context and situation of interaction. However, further research into extracting qualities of embodied sonic interactions would be valuable. It could provide a way to transfer these qualities into other practices and fields, without being obsessed with the idea of producing sonic interactive artefacts, but rather services or even informing techniques in other fields. To give an example, one of the participants (see Appendix B- Table B1- P28) of the workshops evoked a traumatic episode of his life, remembering the sound of a train horn before an accident that happened to him when he was a child. The task of imagining a possible interaction with the specific sound evoked helped him to find a different way to re-enact that memory from an active perspective, by "throwing away" that particular sound. This could valuably contribute to other fields, such as psychology and in particular counselling regarding evocation of memory of the patients using bodily techniques. This expanded our idea of the sonic to include contextual aspects of personal sonic experience, enabling us to think about body movement and possible scenarios of everyday interaction in imaginative ways.

5.3 "Sound-Centred" Approach: Answering the Methodological Questions

5.3.1 Methodological questions

The fulcrum of the approach used in this research was to exploit the realm of the sonic and in particular the listening abilities of all the actors involved, from participants to myself as a researcher. It was important to use a methodological approach that focused on sonic experience, to see what it could generate in terms of methods, techniques and overall research design. After having addressed the core research questions in section 5.2, I will now review how the "sound-centred" approach and the methods used in this research helped to address the methodological questions.

I first asked:

- MQ1: How can we draw upon sound as a starting point in designing embodied interactions?

Considering, analysing and designing methods using a sound-centred approach and starting from sound and listening became a way to begin exploring embodied aspects of sonic experience. In the pilot study on gestural-sonic affordances, the description of listening experience given by participants revealed information about action-sound relationships. In the Form Follows Sound workshops, we incorporated an investigation of participants' listening experience in the early phase of design, which helped to give rise to the Sonic Incident technique.

By focusing on sound since the beginning of the research process, it can serve as a point of departure and as a methodological strategy for understanding, questioning and expanding the concept of the "sonic" in Sonic Interaction Design. This can be done in two ways. The first is by using a sound-stimuli approach, in which sound is actually heard and discussed in relation to the phenomenon of observation, such as in the pilot user study in Chapter 3. The other approach is to use methods that enquire about the complexity of sonic experience, including thinking sound or remembering sound. This second approach helps to envision scenarios that are based on our lived experience of being "ensounded".

The second question was:

- MQ2. How can an understanding of our sonic experience be useful for designing interactions with motion sensor technologies?

The use of embodied interactive sound technology in this research has been used in two different stages. Firstly, to look at corporeal forms of listening and descriptions of sound in the pilot study. Secondly, as a sketching tool for prototyping scenarios of embodied sonic interaction in the workshops. To gather an understanding of participants' sonic experience in the user study and the workshops we used interviews, questionnaires and audio-video recordings. In the pilot study, we asked specific questions regarding processes of identifying sound, descriptions of movements, action-sound relationships and the general experience of interacting with the system. This provided us with an understanding of different processes of discovering gestural sound mapping used by participants. It also enlightened the embodied modes of listening and ergo-audition (listening to our own actions) as the modes of listening commonly used when interacting with our system.

In the workshops, the role of the technology was to enable participants to sketch and design their own scenarios of embodied interactions with sound. The observation of the final projects realised by participants, together with the analysis of results of the ideation phase of the workshops, suggested three possible models of embodied interaction (conducting sound, substituting sound sources, manipulating sound parameters). The embodied interaction models can be helpful to designers who want to work with sound and embodied interactive systems.

Finally, I asked

- MQ3. How can participatory activities help us to explore the diversity of people's everyday sonic experiences and inform our approach to designing interactions?

Working with participants benefitted the research not only in terms of the design of methods, techniques and tools, but it also showed us other perspectives of the research itself. It showed us a series of possible embodied interaction scenarios that could emerge only by enquiring about participants' sonic experience and then exploiting it in participatory design workshops. It gave us important knowledge about the development and refinement of the Gestural Sound Toolkit and helped us to outline embodied sonic interaction models.

Participatory workshops provided an inventive way in which sonic interaction can be imagined and they helped us to gather participants' sonic experience and inform our research. Techniques such as interviews, brainstorming and prototyping helped us to gather a variety of users' stories, perspectives and opinions. They were useful tools to data gathering and their following analysis. The settings of the workshops, open to several participants, had the advantage of providing us with the possibility to look at multiple experiences for each participant. Regarding the specific techniques we used, such as the Sonic Incident, they were framed to explore participants' everyday sonic experience. They worked in participatory contexts because they afford an initial discussion of episodes that can then be used for brainstorming scenarios. A participatory approach provided multiple windows into the complexity of sonic experiences from each participant, including their needs and the contexts of their everyday interactions; these are a valuable resource to explore in SID research which deserves further exploration in future work.

5.3.2 Participatory methods in this research

One reason for involving participants in this research was to allow us to investigate their sonic experience using embodied interactive technologies. The focus on human sonic experience in participatory contexts was motivated by a need to inform a better understanding of the "sonic" in SID, from the perspective of participants. The methods deployed in this research drew upon user-centric techniques from interaction design research. The pilot user study, alongside the series of participatory workshops which gathered users' sonic experience, helped to elaborate our knowledge of users' perspectives of interacting with embodied sonic technologies. Techniques such as interviewing, questionnaires, brainstorming, prototyping and user evaluation gave fundamental insights into this research and helped to shape specific techniques and tools - such as the Sonic Incident and the Gestural Sound Toolkit - for the development of embodied SID.

The pilot user study presented in Chapter 3 set the basis for an involvement of participants in this research by gathering from them a range of descriptions of sounds and actions, and reflections of the experience itself. We used this data and investigated the experience of listening in Chapter 2 to inform the initial phases of design of the "Form Follows Sound" workshops (Chapter 4). In the workshops, we deployed a series of sound and action cards that were generated by taking into account descriptions of sounds which I have derived from Sound Studies literature (Schafer 1992; Augoyard et al. 2006)), our own research (Altavilla et al. 2013) and collaborators (Caramiaux, Bevilacqua, et al. 2014). We chose the technical apparatus itself for the user experiment and the workshops after the pilot user study (Tanaka et al. 2012), which suggested possible usages.

The participatory approach showed us different types of challenges, existing at various levels. The very first challenge was how to gather participants' sonic experience. We used qualitative methods to gather their sonic experience of interacting with embodied sound technology, together with information about their memories of their everyday. As noted by Rocchesso and Serafin (2013), the different terminology used by specialists in sound and non-specialists to describe, use and manipulate sound is a challenge that needs to be addressed in design research. The need of deploying design methods to bridge this gap was therefore an important consideration. In our case, one of the difficulties of this enquiry was to capture the variety of ways in which non-specialists described sound, which is often full of links to everyday scenarios, emotions and personal anecdotes, together with untold qualities, such as mental images and physical reactions. These "hidden" elements of sonic experience constitute a fundamental "richness" which warrants further investigation in the future for disclosing a better understanding of sonic experience from the perspective of the participants. Finding appropriate methods to help participants to describe this was challenging. A strategy to overcome this difficulty was employed in the workshops, entailing the provision of methods to help participants to talk about sound in enriched ways. Sound and action descriptor cards, activities involving bodily gestures and vocalisation as part of the descriptive task, as reported and discussed in Chapter 4, helped us to facilitate ways in which participants could describe their sonic experience.

A second challenge was inherent to the various ways a group exercise can be interpreted by participants in a workshop and the metaphors used to explain such activities. In the ideation phases of the workshops, participants generated very different scenarios according to the metaphors which took place in each activity. The metaphors such as "superpower" and "agency", and the word "incident" in the sonic incident drove results that had involved the body to different degrees in the imagined interaction and their related prototypes. This interestingly generated many examples in which the scenario of interaction was intended only for one participant, with the others watching their team member performing it. The few examples that were collaborative occurred when we did not use the metaphor of superpower in the embodying sonic imagination phase. This underlines the importance of carefully choosing the facilitative metaphors, as some words may favour scenarios of individual usage rather than collaboration. In our workshops, we addressed this challenge by adjusting the formulation of the Sonic Incident technique to reduce the ambiguity of the metaphor of control.

A third challenge was technical in nature, represented by the different grade of technical expertise that our participants had. In a busy co-design workshop with a few hours allocated for this specific task and a facilitator team of only three researchers, the usage of gestural-sound technology was sometimes not intuitive, although this did not compromise reaching the final stage of prototypes. We addressed this challenge by modifying the different versions of the Gestural Sound Toolkit to fix the usage difficulties and conceptual flaws of the system observed in every workshop so that it could be improved each time, eventually leading to the development of a more easily accessible system.

Addressing these challenges was important to the refinement of the methods developed in my research. This constant evaluation of the research with participants helped me to shape the methods of the Sonic Incident technique and the Gestural Sound Toolkit so that other researchers could understand why and how to use them in their own work. The Sonic Incident technique is user-centric as it focuses on gathering personal memories of participants' sonic experience, including their own perspectives and feelings. The Gestural Sound Toolkit is designed so that it can be used directly by participants from various backgrounds and with different expertise in sound. Using such tools and techniques, with the help of participants, helped me to evaluate and generate interaction scenarios. An encouraging demonstration of the possible usefulness of these methods in the field of SID is the adoption of the Sonic Incident technique and the Gestural Sound Toolkit in Sonic Interaction Design research workshops conducted by Erkut, Serafin, Hoby and Sårde (Erkut et al. 2015).

5.3.3 On collaboration and research settings

During my experience of working in the research team and in participatory design settings, I learnt more about the potential and need of design methods for sonic interaction, and the collaborative nature of this work. Collaboration occurred in two ways. The first involved different stakeholders and workshop participants. Particularly during the workshops, I dealt with different educational institutions with wide-ranging research agendas and goals, as well as the diversity within the workshop group itself. These workshops sometimes generated from broader multidisciplinary academic opportunities, whereas at other times they arose through specific commissions. The common principles that bound these workshops together were the interests of all those involved which encompassed research into sound, interaction, embodied technology and participatory design. My role as a workshop designer and leader consisted of designing the workshop activities, and facilitating their delivery. At the same time, the discussion with the stakeholders contributed to the workshops themselves and the evolution of my research. Talking and writing to the different parties served to generate and refine the workshop methods, particularly towards qualitative methods for gathering sonic experience from participants and the different strategies towards doing so. My focus was to be sure that the word “sonic” in Sonic Interaction Design would not necessarily be taken to mean digital sound feedback mapped to the movement of a sensor. Rather, I aimed for a deeper exploration of the sonic and its experience.

The second way in which collaboration shaped a reconsideration of my practice in SID is my being a member of a research team funded by the ERC project “Meta-Gesture Music”, led by Prof. Atau Tanaka. The project had a specific focus on sound, music, auditory culture, gestures, machine learning and embodied interaction. One of the team members included Dr Baptiste Caramiaux, who conducted research on machine learning of gestures. This collaboration shaped the design of the user study and some details of the workshops. Often the team worked with a set of technologies that could be used as tools to explore certain research aims, while at other times the design of technology in itself formed part of our research. In addition to the technical aspects, I focused on ideating activities for the workshops to support the gestural sound system so that it could be used to develop interaction scenarios in participatory workshops. The focus on ideating methods to exploit sonic experience and memory was a strategic approach to placing together the potential of sound to drive body movement, the exploration of everyday, non-specialist attention to sound and the technical possibility of the system. The work I undertook was to find methods that would ensure the possibility of a fluid transition between the ideation phase and the realisation, with the objective of drawing upon participants' sonic experience to develop sonic interaction ideas.

5.4 Research Contributions

In this section I identify and discuss the four main contributions of this research. The first consists of a concept which is useful for investigating the modes of listening involved when we remember ourselves listening to sound. The second contribution is a brainstorming technique for designing sonic interactions in participatory settings based on re-evoking problematic or unusual aspects of everyday sonic experience. The third is a technical contribution consisting of a toolkit for sketching gestural-sound interactions using motion sensor technology. The fourth and final contribution is the identification of three models of interaction which may be helpful for understanding and designing embodied sonic interactions.

5.4.1 Retro-Active Listening

The first contribution of my research is the concept of Retro-Active Listening, which describes remembering ourselves listening to a sound from the past. Retro-Active Listening is a concept that can be helpful for researchers to understand the entire situation of listening when we re-evoke sound. This mode of listening helps us to perform a mental simulation of the act of listening itself and at the same time allows us to be present – with our personal experience – as a listener. It offers a way in which we remember ourselves as listening. Within this process we recall sounds we heard from our autobiographical memory and imagine re-listening to them again. It involves processes of simulation and affords "re-immersion" into a lived sonic experience, a form of embodiment as a re-appropriation and presentation of the experience itself. This process becomes a starting point for the evocation of the experience and the context. It exploits the subjective experience of a listener and it can be helpful to designers who wish to explore phenomenological, first person perspectives of users' sonic experience. By focusing on the subjective view of listeners, it lays a foundation for descriptive methods to investigate the embodied and kinaesthetic dimensions of listening.

Imagining and remembering sound can give us insights into other ways in which we listen. The philosophical writings of Ihde and Nancy, and from the fieldwork research of Henriques showed us different process of internal resonances in the listening subject, spanning from physical sensation to sense-making of an experience, across different temporalities and senses. Tuuri and Petitmengin described different aspects of the phenomenology of listening and how this is balanced as a pre-conscious and conscious encountering with sound. Evocation of sound involves an internal resonance between different temporalities of sound and associated meaning, bringing together conscious and unconscious aspects of listening that cannot be ignored if we want to bring further clarity to our understanding of sonic experience. Artists such as Brandon LaBelle and composers like Pauline Oliveros exploit the situational and affective aspects of remembering sound. Remembering sound becomes a way to listen to it again and a way to recount us as listeners. Remembering ourselves listening can extend our understanding of sonic experience, accessing its extra-auditory contextual aspects and other embodied, kinaesthetic qualities. As sound leaves traces in the memory of the listener, it may also leave an embodied trace that can be reactivated. Evoking listening experience has the potential for interaction design. In particular, there is a need to look at the specificity of a particular listening situation as evoked by listeners, starting from sound. Furthermore, in addition to the problematics of conscious/unconscious dimensions of listening and their role in forming the specificity of the "sonic" elements in everyday experience, another important dimension to consider is the temporality and presence of the sound that is listened to.

Exploring evoked sound from users' memories can help researchers in Sonic Interaction Design to better understand not only problematic and unique aspects of listening as experience per-se, but also the complexity of situations and actions afforded by sound. Listening can become a case-study to be enquired from the perspective of people's everyday, which we can draw upon to imagine design scenarios that exploit different levels of attentiveness and “embodied resonance” to sound. For this reason, the concept of Retro-Active Listening has a value in informing methods for research in SID. With Retro-Active Listening, we can access a past experience through thinking, imagining and remembering a sonic dimension. By sonic dimension, I refer to the complex configuration of experience that is characterised not only by sound itself, but also by our ability to listen and by the access and evocation of extra-auditory, embodied information. It is a turning towards the "sonic", rather than only the sound.

Designers wanting to address sonic experience in their designs also need to expand methods to understand other forms of listening - such as Retro-Active Listening - directly from participants, to evoke pre-linguistic and enactive ways of thinking of listening. Without this, designers miss the potential held within other bodily ways of representing sound, such as vocal sketching and sound tracing. Concepts such as Retro-Active Listening help to design "sonically" and to more fully draw upon the spectrum of sonic experience. Appropriate methods to explore the complex phenomenon of the sonic, from the sound itself, to listening, to remembering and imagining sound, could help us to investigate people's everyday sonic experience and their more embodied and phenomenological aspects. Listening itself can be further investigated as a generative method for design. If some of the conscious elements of listening have been widely explored, more affective, evocative and embodied aspects of listening have yet to be systematically incorporated and assimilated into the design process. This can open up opportunities for design in which we need to think about sound not necessarily in its presence but as a matter of embodied resonance with the social and ourselves.

5.4.2 Sonic Incident

The focus on embodied aspects of evocative dimension of listening has helped us to generate a set of methods and tools for enquiring about sonic experience in participatory design contexts. Developed for the Form Follows Sound Workshops, the Sonic Incident is a technique designed in this research which exploits the concept of Retro-Active Listening and it constitutes the second research contribution of this thesis. It helped our participants to focus on evoking episodes that have been characterised by a particular sound, vocalise them and imagine a bodily interaction with them. Derived by merging the Critical Incident technique from psychology (Flanagan 1954) and listening exercises from acoustic ecology (Schafer 1992), the Sonic Incident is a method that differs from Barrass's EarBenders as it focuses on considering the unconscious, embodied, kinaesthetic aspects of sonic experience. On a methodological level, evoking sound from their personal, autobiographical memory can be seen as opposed to an approach in which researchers choose a sound stimulus to evoke an experience. If an anamnesis as a method for listening would be based on choosing the auditory stimuli, evocation from personal memories implies a tuning of the listener's attention not only to the sound itself, but also to listening as an action.

The Sonic Incident technique helped us, as researchers, to discover ways in which a listening experience can be retraced step by step, through the strategy of first thinking about it and then describing it. Through this technique participants evoked problematic and yet unexplored aspects of their everyday sonic experience, which they may have forgotten or failed to notice. This technique helped us to include embodied aspects of sonic experience at an early stage of the design phase of our workshops, allowing participants to generate scenarios that were enacted by body movements, conserving a trace of the experience itself and going beyond pure sound mapping. We reported that participants were able to imagine scenarios of sonic interactions that were linked to their body movement. We noted that in the majority of cases they imagined narrative situations and phenomenological substitutions of the sound itself, which revealed an embodied, volitional relationship to sound in terms of immersion, agency and control afforded by this method. Additionally, we observed that the evocative aspects of using participants' memory of sound can be re-enacted using the whole body movement and proved to be successful in generating embodied interaction scenarios, sensitised by a felt and evoked sonic memory. This suggests that the technique is useful for sensitising participants in SID workshops using embodied interaction technologies, by forming an awareness and bodily sensitivity that can be retained during the design phases.

Finally, I suggest that the Sonic Incident technique can be useful to support ideation activities such as bodystorming in participatory design. It is helpful for brainstorming and generating ideas for the use of embodied sensor technology. The Sonic Incident technique, exploiting Retro-Active Listening, provides ideas for scenarios that are informed by participants' sonic experience, but which do not necessarily produce sound. Rather than exploring only sounds that may have been forgotten, the Sonic Incident technique helps to access forgotten embodied action-sound relationships and more contextual information from participants' everyday, informing not only a more "sonic" but also a more "embodied" approach to interaction design.

5.4.3 Gestural Sound Toolkit

The Gestural Sound Toolkit is a software which was designed during this research. It allows users to prototype gesture-sound mapping using motion sensors and digital sound playback. Based on Cycling'74 Max/MSP, it features a series of modules for human motion analysis, machine learning of gestures and various audio sample playback manipulation tools. The toolkit has been developed collaboratively by myself and Dr Caramiaux. My experience as a sound designer meant that I gave a technical contribution in developing the sound synthesis engines. I also contributed to the design of the toolkit, responding to the needs of greater usability of the graphic user interface and the overall workflow. Caramiaux's contribution focused on the implementation of the modules for machine learning and gesture recognition. The Gestural Sound Toolkit is available to download for free.[28]

The work on gestural-sound technology in this research has focused on the use of a miniaturised wireless accelerometer mapped to an interactive system that plays back sound in real-time. The use of this device derived from previous user studies I co-conducted which explored body gestures with musical interactive systems (Tanaka et al. 2012). There, the physical aspect and dimension of the object was considered by participants to be "neutral" or "minimal" or could even be "wearable", suggesting that this accelerometer as a good candidate to deploy in further studies. In the pilot user study in Chapter 3, we used the miniaturised and

[28] The Gestural Sound Toolkit is available to download from the following URL https://github.com/12deadpixels/Gestural-Sound-Toolkit. It is currently actively maintained by myself and Baptiste Caramiaux.

wireless accelerometer sensor from the 2012 study for its quality of being an anonymous object which could be attached to the body, without any immediate resemblance to a pre-existing object. The quality of being anonymous served the study on the typologies of sound stimuli we wanted to investigate in relation to their impact on affording human gestures. We used physical modelling synthesis to design the sound stimuli, modelling them to different types of spectromorphological qualities (Smalley 1997), based on the three categories of sound objects as defined by Schaeffer (Chion 1983). This enabled us to explore the idea of gestural-sonic affordances, following a model initially suggested by Godøy (2010). This system, composed of the miniaturised accelerometer and interactive sound playback modules based on human gestures, became part of the tools of enquiry used in this research regarding participants' action-sound relationships and gestural-sound mappings. This allowed us to focus on body and gestures, rather than manipulation of objects.

While the previous model of sound object was useful for the specific user study, this would not have been appropriate for usage in the participatory workshops. In Form Follows Sound we opted to develop a rapid prototyping toolkit which would enable participants to design their own gestural-sound mappings. This brought us to a complete reconsideration of the approach in designing the mapping between the hardware/software components of the system used before, including the introduction of a machine learning system that participants could use to facilitate their desired gestural-sound mappings. As in the ideation part of the workshops participants evoked sound from their memory, we wanted participants to find the sounds they evoked. Therefore we needed to change the type of sound synthesis deployed in the toolkit. We turned from physical modelling synthesis used to design the sound stimuli in the pilot study, to using sample-based sound synthesis to design the sound manipulation modules built in the toolkit. As the name of the modules (e.g. "scratching", "scrubbing" "hitting"). indicated their functionality, this implied metaphors which perhaps influenced the design of the gesture-sound mappings from the users. This was further complicated by the gesture-learning models, suggesting expectations of what possible gestures could be achieved. Despite the possible influence of our module names and functionality, it is interesting to observe that the vast majority of the prototypes produced by participants were developed around the sonic incidents evoked in the ideation phase, rather than being developed exclusively around the possibilities of the toolkit.

A further interesting aspect of the Gestural Sound Toolkit was participants' relation to the gesture recognition modules, based on machine learning techniques. Many participants were intrigued by the possibility of using specific movements of their body for designing very precise sound mappings. However, only 3 out of 14 participants were able to use gesture recognition entirely successfully. Instead – partly because of technical issues with the system itself – they favoured other algorithms for movement classification, particularly exploiting data about energy of movement, speed and position, rather than shape-like gestures. Interestingly, participants gave very little attention to the sound modules available in the toolkit, neither did they question the quality of the sound produced. This is surprising considering that some of the sound modules were very basic in terms of sound quality.

We can argue that design of embodied technology, particularly that which is non-visually dependent, can be informed by delving deeper into sonic experience, and the metaphors and techniques used to discuss it. This can be particularly helpful for designing embodied gestural interactive systems based on machine learning, taking advantage of evoked non-visual metaphors for kinetic and situated qualities of movement which are actively explored in motor-based activities, such as "embodying sonic imagination", in which participants reimagined a bodily interaction with the Sonic Incident. Exploiting embodied aspects of people's sonic experience, rather than only considering spatial and visual based references, is a worthwhile path for future research for prototyping systems based on machine learning of human gestures and movement, beyond the actual use of sound.

Beyond the specific case of the workshops, the Gestural Sound Toolkit is relevant to the community of designers who want to use human motion sensing and sound. Its modularity and the attention given to an easy-to-use graphic interface offers an advantage for non-experienced designers who want to work with interactive sound technologies. As I have reviewed in Chapter 3, by comparing it with the Sound Design Toolkit by Delle Monache and VOGST by Franinović and Bevilacqua, the toolkit developed in this research is one of the first being publicly and freely available which has specific modules for facilitating gestural sound mappings with the aid of machine learning possibilities, inside one single software library. During the final stage of writing this thesis, another promising gestural-sound sketching toolkit was made available for designers. This is SkAT Studio, the voice-gesture-sound sketching toolkit developed within SkAT-VG., a European research project led by Davide Rocchesso at IUAV (University of Venice) in collaboration with IRCAM and KTH (Stockholm Technical University)[29] It publicly appeared in December 2015, 18 months after the last Form Follows Sound workshop and the last development phase of the development of our toolkit. Differently from the Gestural Sound Toolkit, SkAT Studio focuses particularly on the analysis of acoustic characteristics of vocalisation and presents modules for sound synthesis (not sample-based) developed using the sound-design toolkit by Stefano Delle Monache.[30]

From being available from early 2014, our toolkit has been adopted in the SID community. Dr Cumhur Erkut and his collaborators have successfully used the Gestural Sound Toolkit in their workshops with design students, indicating its usefulness in these contexts (Erkut et al. 2015; Erkut & Serafin 2016). Dr Ana Tajadura-Jiménez used the toolkit for motor-rehabilitation research, as it provides researchers in her team with a quick way to design interactive sound mapping based on human movement (Tajaudra-Jiménez, personal communication, 2016).

5.4.4 Embodied Sonic Interaction Models

In Chapter 4, I presented three embodied sonic interaction models for action-sound relationships. These models emerged from an analysis of the workshop projects created by participants when we used the metaphor of "superpowers". We identified three models: (1) Conducting, in which the user interacts with the embodied interactive system, thinking of sounds as part of an event, often utilising discrete movements connected to the meaning of the sound, (2) Manipulating, in which there is a direct modulation of the sound through the participant's continuous movements and (3) Substituting, in which movements substitute the cause of the sound or the sound itself, ignoring the constraints of the interface.

The models are further distinguished by the way in which they can be evaluated: while conducting and manipulating may involve quantitative measures to compare interaction techniques (time completion, accuracy), substituting necessitates a

[29] SkAT-VG project website: http://skatvg.iuav.it
[30] SkAT studio is available at: https://github.com/SkAT-VG/SkATStudio

qualitative explanation of the relevance of chosen actions to an associated sound, its cause and its context. Further research on this would be valuable in the future.

These three interaction models provide operational guides which can be used by interaction designers or developers to build sonic interactions based on gestures and body movement. The analysis of literature in Sonic Interaction Design in Chapter 2 and the observation of previous SID experiments, user studies and workshops in Chapter 3 showed that there was a need to formalise models that could be adopted by designers interested in working with gestural-sound interactive technologies. These models provide a guide for interaction designers, as an interaction model can be characterised through its descriptive (incorporating existing interaction techniques), generative (facilitating new interaction techniques) and evaluative (comparing techniques) capabilities.

5.5 Sonic Affordances: Listening to Embodied Resonances

This section points to some considerations for possible future research on the subject of sonic affordances, which can help to explain how sonic experience supports bodily action. At the present stage, this does not constitute a developed research contribution as it goes beyond the scope of this research project, though it points towards a further line of development for future research.

As reviewed in Chapter 2, the concept of affordance relates to an ecological approach to psychology. An ecological approach to investigate a subject regards the entire components of the environment as somehow involved in the processes of the observed thing. The idea of sonic affordances can be described first as the potentiality of sound to afford a stream of specific actions from an agent. The word "afford" is particularly important in this case, more than the adjective "sonic". The original definition of affordance is a word coined by Gibson, created to explain a "furnishing" relationship – in terms of providing, supply, opportunity and causality – between the material world and the life of animals.

Affordances cannot be understood without considering the perspective of the subject for which something is afforded. Affordances are mappings of emergent functionalities between the perceiver and its environment towards emerging goals.

Affordances are special relationships. Rooted in an ecological perspective to psychology, the concept of affordances is based on the material quality of the world – its surfaces, substances, mediums of propagation of energy – and the specific sensorial apparatus of the animal in an interdependent relationship based on possible interactions. This has an affect both in terms of epigenetics of the individual and environmental changes. The concept of affordance helps to reduce the importance of intentionality of the willing subject in terms of its interaction with the world, by framing the question of action of an agent not necessarily in terms of decisions but in terms of action possibilities, which are specified by certain conditions – perceived or not – as they exist between the animals and the surrounding environment in a specific moment.

Regarding "sonic" affordance, a few questions arise. What is the "sonic" in sonic affordance? Is there a difference between how sound is perceived – if it is even perceived – for defining a "sonic affordance"? And when we say the words "sonic affordance", is there any specific sound we are thinking of, perhaps the sounds of an alarm going off or the one of a digital sinewave? Does it mean to think that sound has affordances (necessarily multiple ones) and even the possibility that it might not have one? Which sound? Does this, that or any sound make us do anything as a form of subtle irresistible synaptic reaction that activates our muscles individually and socially? This series of questions illustrates the complexity of dealing with the sonic component of an affordance. If sound can be considered a property of an object, we may argue that the sound of a violin does not necessarily afford the same thing as the violin as an object. A problem with the sound of the violin is that it can be understood to be a different subject to the "sound of a violin", in an archetypal sense. This difference is important in our understanding of affordances, as it unveils problematic aspects in terms of multiple hierarchies, perceivable and non-perceivable relationships, and non-hierarchies that this concept underlines. Affordances describe multiple actuated or unactuated relationships, an interconnection between the physical characteristics of the perceived thing and the cultural world, which simultaneously supports, surrounds and depicts it.

This analysis of sonic affordances centres around the idea of the "sonic" itself that I discussed earlier in this chapter, which I consider to be broader than the auditory consideration of sound. A sonic affordance will necessarily be derived from a similar view to sound, as sound affords listening, hearing, sounding, thinking about sound and other forms of human participation in the phenomenon of sound. The pertinence of discussing the concept of sonic affordances is particularly relevant to Sonic Interaction Design, as we have seen in Chapter 2. I suggested that affordances are involved in the process of automatization (Still & Dark 2013) of a user's physical action with interfaces, reducing the involvement of reasoning about the action itself. This idea suggests that sounds – but also a listening situation – can be designed in order to facilitate the users to do only some specific actions, in terms of human movement, in an intuitive way.

The concept of Embodied Resonator introduced by Tuuri, as reviewed in Chapter 2, is important to explain sonic affordances and their relation to the sense-making of embodied action-sound relationships. Tuuri's argument for the embodied resonator is that perception of sound, listening, sensorimotor abilities and experience, are connected to the creation of mental images of action-relevant clues in the world. In Tuuri's words, the "embodied resonator functions as a mediator which permits patterns of sensation to be inferred in terms of mental imagery being projected from the structured nature of experiences" (Tuuri & Eerola 2012, p.145). This means that the inference of action-relevant clues perceived in hearing and imagining sound is not a unique static relationship of a stimuli-reaction type, rather it "resonates" a range of possible actions that are based on the perceiver's experience. This concept explains why, in our pilot user study in Chapter 3, when participants were able to identify the sound stimuli – or at least they were able to give a satisfactory description for them – they described the sound in terms of similar sound producing sources (e.g. the sound of knocking on a door instead of a percussive digital sound). It also explains why, when participants failed to build an association between known sounds from their everyday, they described the sound in more abstract terms and sometimes figures relating to the movements they performed (e.g. drawing circles in the air for describing continuous sound). In the workshops in Chapter 4 the embodied resonator was constantly involved when participants imagined possible bodily sonic interaction. We can explain this by discussing Tuuri's view of a pattern of sensations which can be evoked by mental imagining, and which we found in other literature on auditory stimuli (Hubbard 2010). In our workshops the pattern of sensations is evoked by imagining a sound already heard, using Retro-Active Listening and to re-evoke sonic incidents. This leads to a process of resonance of emerging action-sound relationships that participants were able to draw upon in the imagery involved when they remembered themselves as listening.

Reviewing the results obtained in my research, I believe that Tuuri's concept of "embodied resonator" can provide a model in which sonic affordances are related to possible action-sound relationships as emerging in the context and experience of the perceiver, rather than exclusively in the sound in itself. We saw in Chapter 2 that Godøy proposed a model for the study of the relationship between gestures, sound and affordances. The gestural-sonorous interaction can be thought of as based on affordances of hearing sound for producing bodily gestures. These gestures follow trajectories and shapes linked to the spectromorphology of sound as it is mentally rendered. Tuuri's model extends this by relating the importance of the context and the experience of the listener, beyond the production of gestures.

If we now analyse the data about description of sound and gestures from our pilot study and workshops in Chapters 2 and 3, we can look at how some of the participants described a sonic incident that came from an unknown sound source. Some of them described sounds in terms of mechanical actions involved in the production of the sound, while others described the processes involved for the actual discovery of the sound sources. When participants described these unknown sonic incidents, they would refer to other similar actions involved in the production of sound ("sounded like") and physical feelings involved ("the sound was stabbing my hears", P10) so that they could communicate the most-likely impression of sound. This process can be seen as an embodied resonance of thinking sound, relating physical sensations, meaning and referential elements of sound. This forms a three-layered dimension of sonic experience in which possible affordances arise, stemming from each of these levels of the perceiver's consciousness, providing an excitement, through an "embodied resonance", of the relevant contextual actions that can be associated and/or performed. These observations are, at this stage, only preliminary and they could not have been possible without the research I undertook. Nevertheless, their inclusion in this discussion points towards a subject worth exploring in future research in embodied interaction with sound.

5.6 Chapter Summary

This chapter presented a general discussion of the results obtained by this research. It started by answering the core questions and then discussing the sound-centred approach and answering the methodological questions. I then presented and discussed the four main contributions of this research, consisting of the concept of Retro-Active Listening, the Sonic Incident technique, the Gestural Sound Toolkit and three models of embodied sonic interactions. I concluded this chapter by suggesting a possible line of further research in the field of Sonic Interaction Design. The next chapter concludes this thesis and will focus on more general considerations of my research and ideas for future work.

6 CONCLUSIONS

6.1 Summary of the Thesis

In this research I have worked with sound and interactive technologies in ways that I would not have anticipated at the beginning of this journey. Coming from a background in music, art and sound design, the way in which I worked with sound was often based on the idea of designing and playing out sounds with a series of technically sophisticated tools, and acoustic and software instruments. Although in previous artworks I have worked on creating forms of listening mediated by the specific design of objects and devices (Altavilla & Tanaka 2012), the shift that I observed in my practice was towards a consideration of the sonic, rather than sound. This encompasses ways of thinking about sonic methods, rather than exclusively using or designing sound stimuli.

In this thesis I proposed a sound-centred approach to investigate users' sonic experience in Sonic Interaction Design research. This approach originated from a need to better understand users' sonic experiences with interactive sound technologies based on real-time tracking of human movement through motion sensors. To do so, I intersected Sonic Interaction Design with theoretical investigations of sound from Sound Studies, listening methods from Acoustic Ecology and Sound Art, experimental studies of sound in cognitive psychology and musicology. The "sound-centred" approach focused on researching topics such as sonic experience and listening and designing participatory methods for studying Sonic Interaction Design. In Chapter 2 I reviewed current approaches in SID and presented an overview of how the experience of sound is considered in Sound Studies, Auditory Culture, Acoustic Ecology and Embodied Sound Cognition, discussing various forms of listening, such as imagining and remembering sound. In Chapter 3, after describing the research methodology of my project and reviewing research approaches, methods and techniques from interaction design and SID which could be adopted to investigate the "sound-centred" approach, I presented a pilot user study which served as a first step in this research. This helped me to gather a first account of users' perspectives and listening experience while playing with an embodied gestural sonic interactive system. Chapter 4 presented a series of participatory workshops that explored sonic experience as a starting point for designing interaction scenarios based on body movement, and designed specific methods which can be used for Sonic Interaction Design. Finally, in Chapter 5 I answered the research questions posed at the beginning of this thesis, discussed the research approach here undertaken, developed and discussed the contributions to research and outlined a possible subject for further research.

The thesis intertwined theoretical and practice-based research in Sonic Interaction Design, offering a way in which sonic experience could be explored in participatory settings. I began by tracing my observations on the topic of "sound" by reflecting upon my background as an artist working with sound, listening and interactive technologies. This foregrounded my personal journey from Sound Art to Sonic Interaction Design as an opportunity in which body movements, action-sound perception and cultural aspects of sound could be investigated. One of the key problems I identified was the need for a better understanding of the "sonic" in the field of Sonic Interaction Design, and to explore other aspects within the spectrum of sonic experience, including not only our ability to hear sound, but also reacting to sound, thinking, imagining and remembering it. With this work, I aimed to point towards a fuller, more nuanced understanding of the adjective "sonic" in SID. Looking at people's sonic sensitivity – our ability to feel, think and imagine sound and listening – has been key to opening up this possibility.

The literature reviewed showed us how Sound Studies and Acoustic Ecology provide an understanding of sound as a richer component of the range of human experience. The depth in which the sonic is explored within this literature motivated me to consider listening experience and how this can inform research methods in SID. I found that a focus on everyday and past experiences of listening offered a way to study the relationships between corporeal movement and sonic experience from the perspective of the possible user in SID, by focusing on the link between mental imagery, corporeal action and embodied sound cognition. Using this knowledge, I designed a pilot user study exploring sound-related affordances as a way to understand body movement in relation to digital sound feedback. Participants' morphological and associative descriptions of sounds that they heard disclosed information about acoustic and physical aspects of sound, and their cultural, everyday and situated qualities.

This led to Form Follows Sound, a series of participatory workshops based on methods that exploit everyday sonic experience to generate scenarios of bodily interactions with sound that could be successively developed with motion-tracking technology and digital sound feedback. I developed the Sonic Incident, a specific technique for SID research which exploits the mode of Retro-Active Listening. This technique helped us to explore participants' past sonic experience. This constituted the ideation phase of the workshops, providing cases for scenarios of bodily interaction with sound that were developed in the workshop using the gestural-sound prototyping technology. I then discussed the research questions in view of the results of the work undertaken and outlined the contributions of this research, the methods I used to explore this subject and its impact on research in Sonic Interaction Design. This conclusion chapter presents a summary of the main research contributions and closes by outlining opportunities for future research and practice.

6.2 Summary of Research Contributions

The research contributions to the field of Sonic Interaction Design were the result of adopting a methodology based on a sound-centred approach This approach consisted of a focus towards an enriched concept of "sonic" in SID and looking at aspects of sounds that go beyond sound feedback and technological augmentation with sound. The analysis of sonic experience and listening gathered from my literature review brought a focus towards phenomenological and embodied qualities of the sonic world. This knowledge informed the development of the methodological and technical contributions, and motivated the choices I undertook for designing the pilot user study and the workshops. It allowed an expansion of the methods used in SID for studying bodily interaction with sound in participatory settings.

The first contribution of my research is the concept of Retro-Active Listening, which describes remembering ourselves listening to a sound from the past. This mode of listening helps us to perform a mental simulation of the act of listening itself and at the same time allows us to be present – with our personal experience – as a listener. It exploits the subjective experience of a listener and it can be helpful to designers who wish to explore phenomenological, first person perspectives of users' sonic experience. By focusing on the subjective view of listeners, it lays a foundation for descriptive methods to investigate the embodied and kinaesthetic dimensions of listening.

The second contribution is the Sonic Incident technique, which can be defined as a technique for gathering participants' past sonic experiences and developing scenarios of bodily interaction with sound. Conversely to ideation techniques already applied in SID workshops, in which adding sound is thought as way to improve a problematic interaction with an artefact (Franinović et al. 2008; Houix et al. 2013), the Sonic Incident technique offered a way for participants to draw upon their everyday sonic experiences and provide us with a form of case-study for generating interaction ideas in which sound was central.

The third is a technical contribution, consisting of the Gestural Sound Toolkit. The purpose of this toolkit is to facilitate users in designing their own gestural interactions with sound using a computer and motion tracking technologies such as IMU (Inertial Measurement Unit) sensors. The toolkit consists of a software modular system in which gestures can be analysed and reused purposefully to the desired real-time sound mapping, providing participants with a rapid way to prototype sonic interactions.

The fourth contribution is the identification of three embodied sonic interaction models, which are based on Conducting, Substituting and Manipulating metaphors. These should not be considered as mapping, rather as ways in which users interact with digital sound using free body motion. The models can provide designers with specific metaphors for an early implementation of gestural-sound mappings to be applied in interactive contexts. Conducting models of embodied interactions can be helpful for scenarios involving direct control of digital sound, in which human gestures have a semantic relationship with the sound played. Substituting models can aid the design of explorative scenarios using the human body and sound feedback. The Manipulating model holds potential for designers who wish to characterise users' movements through variation of parameters of the sound synthesis engine, as in real-time sonification of human movement, for example. Future research can be undertaken in light of the evaluation of these models. While

Conducting and Manipulating may involve quantitative measures to compare interaction techniques (time completion, accuracy), Substituting necessitates a qualitative explanation of the relevance of chosen actions to an associated sound, its cause and its context.

6.3 Future Work

In Chapter 5, I discussed the possibility of combining the concept of sonic affordances with Tuuri's concept of embodied resonator for studying action-sound relationships. Further research and specific studies on consciousness of sonic experience can provide ways to study various aspects of meaning-making in sonic interactions. These studies need to be inclusive of the broader experiential spectrum of the sonic, such as modes of listening, evoking, imagining and remembering sound. In future work, researchers can study sonic affordances by identifying various stages in which action-sound relationships are considered in the lived context, and relating to the preconscious and conscious dimensions of sonic experience. The benefit of using this approach is that we can study a multi-layered approach to action possibilities and provide designers with a focus on specific dimensions of sonic experience. This can both address difficulties and give rise to opportunities to work not only with sound, but with the whole spectrum of sonic experience.

The Gestural Sound Toolkit provided us with a rapid way to sketch and prototype gestural-sound interactions using motion sensors, machine learning and real-time sound feedback. Although the current system is largely stable and it has been used by other researchers, further work is needed to expand the compatibility with different systems, such as mobile platforms and small single-board computers.

The union between the Gestural Sound Toolkit and methods exploiting introspective, personal dimension of sonic experience shows us the potential for investigating other domains of research. Of particular interest for future research would be the creation of a specific sound design toolkit for cinema and game sound designers based on the use of variable gesture recognition and methods based on sonic and extra-sonic imagination.

Finally, I hope that this research has contributed towards expanding the potential forms of sonic operations used by researchers in SID for designing interactions. These operations are not exclusively intended to be forms of sound designs for interactive systems, but as contributions towards finding methods for encouraging attention towards the sonic. This holds the opportunity for “sonic” researchers to be involved as stakeholders in complex research in designing interactions, not only as specialists in designing sound feedback, sound augmentation and its technological implementation. This is a specialism that requires further research on the understanding of sound, its phenomenon and its context, and of the whole spectrum of sonic experience, towards an exploitation of people’s sonic sensitivity as a method for generating novel and unexpected forms of design.

APPENDIX A: USER STUDY DATA

Table A-1 Grid Analysis of user responses to interview

Tables used for grid analysis. The data has been factorised for each question (q). Participants gave more than one single answer to the same question and/or describing sound and actions using multiple terms.

q1: Can you describe the sound you just played?

Impulsive	*Iterative*	*Sustained*
• Bouncing ball • computer error (2) • Computer sound (2) • drum sound (2) • knocking on the door, • videogames	• woodpecker • driller • bag of crisps • rattle (3) • insects flying (2) • interference noise; (3) • scratchy • grindy • shaking grain pepper • scratching vinyl	• finger on a crystal glass (2) • sine wave • UFO in cinema • Digital sound synthesis • "wavy" sound • interference

q2: Can you describe your action in terms of physical movement?

Impulsive	*Iterative*	*Sustained*
• Like playing basketball • a pushing movement. • Simple[small] movement with the hand • Moving sudden • Hitting (2) a surface with a tool (spoon on the pot/drum) / something with the hand • Moving the wrist faster and quicker. • Going down but also up	• Doing circles and waves with the hand • Movement with the arm: up/down/right/left. (2), changing speed (1) • Shaking of hand • Touching • scratching • Shaking/Vibrating the hand/fist (2) • Slashing the hand and arm • Swinging left to right. • Right arm movement Body was still.	• Drawing an 8 in the air • Like dancing • moving the arm (2) up and down, like falling | any directions, changing speed. • Shaking the hand • Moving the arm up to charge the sound, then realise it • Swinging, Drawing 8 • From bigger movement of the wrist to smaller ones. • Body was still, hands were moving UP and Down.

q3: Can you tell us how to play the sound?

Impulsive	*Iterative*	*Sustained*
• pressing • contact • percussive (2) • impulsive (2) • moving the arm suddenly • slamming the hands • hit drum/invisible objects (2) • banging hand in the air • shaking the hand • knocking	• moving the wrist/arm: combination of (left/right/up/down) • making waves • impact and continuity of impacts • using differences of movement • scratching • touching • rubbing • abruptly • shaking (2) • swinging movement created consistent sound	• moving the hand/arms	speed-sound {volume} (5) • movement of the arm: position-sound (2) • playing it harsher requires sudden movement • moving arm up and down

q4: How did you go about trying to figure out how to play sound?

Impulsive	*Iterative*	*Sustained*
Tried same strategy -> testing other characteristics of sound -> not enough precision; General movements -> Checking spatial conditions without success -> Remembering the previous experience -> Testing impacts -> Got sound; Realising sound NOT connected to movement -> hearing the sound -> using contact, touching the sensor, to trigger the sound ; Moving the arm -> All directions -> Different speed; Moving hands -> Triggered Sound was heard -> testing pitch by slowly moving hand -> no result -> moving hand up and down -> no doubt on trigger only; Testing movement of arm -> no sound -> closing fist -> sound came, but not always -> trying something different -> sudden movement worked; No strategy -> Surprise by different system -> Trying violent movement -> Found the sound -> hitting	Checking spatial conditions * -> Hitting the edge of the screen -> Discovered no relation with space -> movement of the wrist; Making circles -> Heard the sound -> Maxing waves; Testing general movements -> Up/Down/Left/Right -> Checking spatial conditions without success-> sound happened -> discovered that was about impact; Moving the arm -> All directions -> Trying different speed; Moving hands -> Shaking Hands -> Found it responsive -> trying different movement using shaking to trigger the sound -> perceiving a length in the sound -> testing it with movements -> adjusting the movement to get continuous firing of sound; No big movement -> Testing different movements with fists -> Test big movement of arm -> Testing wrist again -> Sound; No strategy / casually or by intuition -> moving hands produced sound -> exploring right-to-left movements -> moving quickly -> get more sound ;	Tried the 1st strategy -> no relation -> rotation of wrist -> exploration; rotating the wrist quicker produce more 'noise"; Started like the previous -> It worked immediately Moving arms -> Repeating movement -> Trying different heights of the arm -> no results -> using only energy of movement; Moving the arm -> All directions -> Trying different speed; moving hand to test the system -> different movement (sudden and smooth) -> hearing the sound -> continuous responsive movement to sound; Rotating the wrist -> Trying a big movement of arm -> Smaller and faster movement of the wrist-> Sound; Exploring -> up/down movements produces "intense" sound.

APPENDIX B: FORM FOLLOWS SOUND WORKSHOPS DATA

Table B-1: List of Sonic Incidents and Embodying Sonic Imagination Examples

This table presents the list of Sonic Incidents described by participants and the interactions they imagined with them (Embodying Sonic Imagination). This list was created analysing the collected graphical and/or written text from participants and audio-video documentation. Some of these descriptions may lack precision, but they are useful for providing a general idea about the content generated by participants. Further audio/video documentation can be found online at http://mgm.goldsmithsdigital.com/formfollowssound.

Participant	Sonic Incident	Embodying Sonic Imagination
P1	Dawn choir waking him up	Circular diagram, movement control different sound parameters
P2	Persistent tube announcement - beep beep - ignored sound of everyday (A)Her loudspeaker pops when online (B)Hum of airplane revealed by baby crying (C)	CONDUCTOR TRADITIONAL GESTURES Effect desired and Instructions Invert/Swap - Crossing arms Duet - Clasping hands together Dynamic - Raising / Lowering hands Ensemble - Gesture large circle with hands/arms Stop - Clap hands twice

Participant	Sonic Incident	Embodying Sonic Imagination
P3	Unidentified sound, very bizarre, some sort of air conditioning (A)Metro, beep before doors closing (B)	"The moment before the silence" sentence, Hammer on surface - visualisation of waves on a surface (B)
P4	Wind blowing through badly insulated windows in the hallway (A)Squeaking door in the bus (B)	Man controlling the sound of the noisy part in the bus - using limbs (B)
P5	Bubbling of vegetable oil while cooking (A)Wind blowing in the bathroom, squeaking door (B)	Breath (Inhale/Exhale) controlling the wind and the door (B)
P6	Leaves rattling in the wind while walking, trees (A)	Energy based - control of leaves, trees, environmental sounds (B)
P7	Cars racing in Greece wake him up	Sound of the engine and gears (inside the car)If listening - annoyingif producing - pleasant - not caring of disturbing others
P8	Train passing - rhythm description (A)Skype ringing/notification tones (B)	Gestural control of Skype notification sounds (B)
P9	Train crashing (A)kids asking for chicken (B)	Birds eating chicken rests in the pavement (B)

Participant	Sonic Incident	Embodying Sonic Imagination
	WORKSHOP 2	
P10	Unknown beep in room -from street	Unknown beep in room -from street
P11	*Unknown* sound caused insomnia - wong wong; (A)Children playing football - distracting conversation; (B)Three days of rain - different intensity ©	/Children playing football, ball hits listener (B)Rain, different intensities, hitting the ground (C)
P12	Strom trooper wake alarm. Impossible to stop	Arrows pointing down. Pushing mechanism
P13	Raindrop at train station, people steps (A)Air fan on the bed sheets while body wakes up (B);	Trains on rail, lines and arrow (A)Circular lines then segments (B)
P14	Chimes in the theatre (A);Subway train arriving masking hearing of conversation (B);	Bells, candelabra, musical notes (A)Old train passing (B)
P15	Squeaking ventilation in the workshop room (A)Elevator bell next door (B)	Man controlling characteristic of sound by moving (A)Man sitting on table manipulating something (B)

Participant	Sonic Incident	Embodying Sonic Imagination
P16	Sound of filling water bottle - changing (A)Fingernails on a touch screen (B)Key falling on floor (C)Squawky metal frame (D)Phone falling on the floor during night (E)	Bottle being filled with water (A)Finger on the touchscreen (B)Keys falling on the floor (C)/ (D)Phone falling from the night stand (E)
P17	Cats jumping after he step on it	Stepping on cat - cat reactions - movements
P18	Car's tyres on wet asphalt	Springs connected together playing “Jingle Bell
P19	Pigeons on the fire escape destroying foil	Birds action and Gabrielle reactions
P20	African Music in Union Square (A) Instrument under subway (B) Vending machine - water coming down (C). Software render finish (notification sound) (D). Friend’s phone Alarm (E)	Tap water incident - involved mechanical parts1. Tap2. Water flux3. Basin4. Water off the basin.
P21	Her Bike hitting manhole on bridge	Sequence of bike hitting the manhole, using Onomatopoeias
P22	Glasses hitting during party with friends (A)Bike crash, metal falling on pavement (B)	/ (A) Crash and the emotional reaction of people(B)

Participant	Sonic Incident	Embodying Sonic Imagination
P23	Squeaking of printer, similar to mattress squeak - young mice on bed - just imagination only the sound of printer (A) Grasshoppers sound heard in car (B)	1 inch Spring (A)Car, comic balloon coming from it with confused drawings and grasshoppers (B)
P24	*Participant left due to family reasons*	*Participant left due to family reasons*
	WORKSHOP 3	
P25	Duck honk on the bike - inappropriate sound	Being the duck - limbs control different qualities of squeaking - bathroom situation
P26	Train, notification sounds for distances and stops (pitch based or pulses)	Fingers tapping on table (waiting gesture) activate information about remaining distance of the journey - displayed by sound
P27	Everyday sound landscape - Bicycles, voices, riding areas, crossing	Brain, Voice, Body movement, Hearing controlling environmental sound,Gesture for silence and voicing out thoughts
P28	Train - Loud impact and release of air from below carriage (A) Empty moisture tube - squeeze as last drop (B)	Train - Becoming the mechanical components - removing/adding parts (A)Control train motion, alter perception of time using machine, hand pressure, friction Tube - becoming the tube, control/intensify airflow (B)Environment - reshaping the environment - room size - materialPress the tube in multiple ways - "polyphony" using different limbs.

Participant	Sonic Incident	Embodying Sonic Imagination
P29	Walking in the woods, snow cracks under his feet, breaking ground (A)Rhythmic Background sound, muffled (B)	Sound: Crack + "Swoosh + thud" (A)Action: "Crack"/Crush by moving the fist + slide and stop using legs Pressing a ball control reverb and filtering of sound (B)
P30	Wind moving leaves (A) Metro brakes sound before stopping abruptly (B)	Circle - Subtle sound composed of many movements, directions. Wind left a void before and after (A)Lower tone in the wagon brakes was a signal for the sudden stop (B)
	WORKSHOP 4	
P31	Warning beep of car lights left on	Remote control of lock. Open Hand interrogate if door is open with warning beep, if the hand closes the door is locked and the sounds goes off.
P32	Sizzling sound of oil in fraying pan, indicating that the pan was too hot.	Daredevil's batman. Sound to navigate through locations.
P33	Vibration ring of phone on a shelf while sleeping. Unexpected rhythm of vibration, wrong rhythm, it was like a call, instead it should have been like an alarm.	Snooze action to fall asleep again and creating a sound that would suggest him as being awake while still sleeping.
P34	Fireworks heard during New Year's day.	Control fireworks with gestures. Hand claps makes them explode

Participant	Sonic Incident	Embodying Sonic Imagination
P35	Train honking when approaching train station. Remembering one accident. Constantly waiting for hit when he heard this sound. Relieved when the accident doesn't happen.	Blasting an ultra loud sound with hand that will physically move people and cars away from the track.
P36	Annoying sounds of neighbours' children playing	Transforming children's' screams in music by conducting them as a musical conductor
P37	Sounds of opening a champagne bottle, sounds of the liquid sparkling and the cork falling on the floor	Superpowers to follow the cork in an impossible trip over the space
P38	Sounds of frying noodle. Left the frying pan alone while cleaning the room. Different sounds indicate different state of cooking.	Physical superpower to extend arms to reach far frying pans when sound is heard.
P39	Hearing an annoying repetitive melody from a nearby phone. Not easy to locate. Melody stuck in the head.	Moving limb, like being a conductor, change the melody of the nearby phone, to avoid repetition.
P40	Noisy unlocking hinge of a door heard every morning	Power to turn this unlocking action done by other people by slowing them. To reduce the sound.
P41	Phone alarm + Clock alarm failing to wake her up	Destroying loud alarm with laser vision explosion
P42	Hearing heating starting at 00:45 am at home after 10 days holidays. Feel like home	Every 00:45, snapping hands will slightly modify the sound of the heating allowing him to sleep.

Table B-2: List of Projects Realised

The following table shows the projects realised, with a brief description and their related sonic incidents and embodying sonic imagination scenarios from the ideation phase. The order shows varying degrees of links between the original sonic incidents and imagined interactions and the final projects realised. The letter G stands for Goldsmiths (Workshop 1), the letter P stands for Parsons (Workshop 2), the letter I stands for IRCAM (Workshop 3) and the letter Z stands for Zurich (Workshop 4). Further audio/video documentation can be found online at http://mgm.goldsmithsdigital.com/formfollowssound.

Group	Final Project Title	Sonic incidents	Embodying Sonic Imagination	Project Description (brief)
G1	Plane, baby crying	Persistent tube announcement - beep beep - ignored sound of everyday (A) Broken Loudspeakers (B) Hum of airplane revealed by baby crying (C)	CONDUCTOR TRADITIONAL GESTURES 1. Invert/Swap - Crossing arm 2. Duet - Clasping hands together3. Dynamic - Raising / Lowering hands4.Ensemble - Gesture large circle with hands/arms5. Stop - Clap hands twice	Conducting airplane sounds – Acting out the described situation, in different steps
G2	The Wind Maker	Leaves rattling in the wind while walking, trees (A)	Energy based - control of leaves, trees, environmental sounds (B)	Being the wind and slam doors at command.
G3	Car	Cars racing in Greece wake him up	Sound of the engine and gears (inside the car)If listening -	Simulating the Doppler effect of the car by acting on an

Group	Final Project Title	Sonic incidents	Embodying Sonic Imagination	Project Description (brief)
			annoyingif producing - pleasant - not caring of disturbing others	imaginary gearshift.
P4	Umbrella	Three days of rain - different intensity	Rain, different intensities, hitting the ground (C)	Interactive umbrella. Different kind of rain sound for different gestures
P5	*Test your mettle*	Raindrop at train station, people steps (A)Air fan on the bed sheets while body wakes up (B);	Trains on rail, lines and arrow (A)Circular lines then segments (B)	Performance instruments for two dancers, based on an augmented spring, reacting to the physical stress. Dilatation - no sound / Contraction - full sound
P6	Yoga corrector	Sound of filling water bottle - changing	Bottle being filled with water	Yoga corrector with sonic feedback related to position of the leg and the limb.
P7	Flap pen	Pigeons on the fire escape destroying foil	Birds action and Gabrielle reactions	Augmented pen that plays environmental sounds rhythmically according to the pen movement.
P8	Pneumatic step	Squeaking of printer, similar to mattress squeak - young mice on	1 inch Spring (A)Car, comic balloon coming from it with	Augmented shoe that plays sounds when it is not on contact with

Group	Final Project Title	Sonic incidents	Embodying Sonic Imagination	Project Description (brief)
		bed - just imagination only the sound of printer (A)Grasshoppers sound heard in car (B)	confused drawings and grasshoppers (B)	the ground.
I9	Inside the Duck	Duck honk on the bike - inappropriate sound	Being the duck - limbs control different qualities of squeaking - bathroom situation	Being the duck.
I10	The snow cracker	Walking in the woods, snow cracks under his feet, breaking ground (A)Rhythmic Background sound, muffled (B)	Sound: Crack + "Swoosh + thud" (A)Action: "Crack"/Crush by moving the fist + slide and stop using legs Pressing a ball control reverb and filtering of sound (B)	Amplification of a sliding experience, movement, interaction between feet, snow and ice. Presented as a form of sound storytelling.
Z11	*Snoozy Bed Linen*	Vibration ring of phone on a shelf while sleeping. Unexpected rhythm of vibration, wrong rhythm, it was like a call, instead it should have been like an alarm.	Snooze action to fall asleep again and creating a sound that would suggest him as being awake while still sleeping.	Moving in the bed modulate snooze melodies to alleviate abrupt wakening.

Group	Final Project Title	Sonic incidents	Embodying Sonic Imagination	Project Description (brief)
Z12	*Fireworks*	Fireworks heard during New Year's day.	Control fireworks with gestures. Hand claps makes them explode	Conducting fireworks on command, from the launch to their explosion.
Z13	*Super Champagne Man*	Sounds of opening a champagne bottle, sounds of the liquid sparkling and the cork falling on the floor	Superpowers to follow the cork in an impossible trip over the space	Being the cork flying after opening the bottle.
Z14	Swap sounds during sleeping	Hearing heating starting at 00:45 am at home after 10 days holidays. Feel like home	Every 00:45, snapping hands will slightly modify the sound of the heating allowing him to sleep.	Swapping distracting sounds when sleeping with pleasant ones, and change their volume.

Table B-3: List of Sound and Action Descriptor Cards

List of words for the provided Sound and Action Descriptor Cards. The ones added by participants are in italics.

Sound Descriptor Cards	Action Descriptor Cards
Loud	Hitting
Quiet	Scratching
Rough	Pouring
Soft	Pushing
Impulsive	Shaking
Continuous	Swinging
Close	Slamming
Far	Rubbing
Difficult	
Easy	
Simple	
Complex	
Personal	
Anonymous	
Pleasant	
Annoying	

Table B-4: Post-Workshop Surveys

The following table presents the post-workshop survey we sent to participants after Workshops 2, 3 and 4. We received the survey back from 15 participants out of a total of 33. The participants' answers are shown below each question, which are reported here in their original form. The survey was anonymous so it is not possible to associate the sentences with the participants. Each row corresponds to an answer given by one participant; in some cases they gave us multiple answers.

What did you find most useful from this workshop?

For me, leaning about gesture recognition is very useful since It's something that very delicate. Not only I need to do those actions slowly but also I need to practice doing it again and again before a real performance. So, practicing and team work is very important. More over, observing every day sound from every day objects and transforms to pictures is also fascinating for me because each person has different background and perspective to convey their sound (which is abstract things) to be something that everyone can see and understand.
It introduced me to people different than my background with different ways of seeing the world and technology
Everything from A to Z. *Working directly with outstanding and inspiring professionals was my favourite part.*
The gesture sensor; sound processing; the relationship between gesture and sound
I earned some knowledge about sound (to which I am not used) and became more open-minded about sound and its possible interactions with the body.
The team work, I found more balanced in our workshop this, everyone

was involved and proactive. Although everyone came from different field. It was a great experienced. *The development of a sound consciousness.* *The exploration of the things Max/Msp can do and what others still in improvement.* *The inspiration I've got from it, to keep working on those ideas I had on mind, as well to the discovering of more people working on these fields of sound.*
Exploring the inner workings of the patches. Finding out about different types of sensors.
Actually I liked the methodology. The way in which the workshop is structured and how it includes different approaches to sound. I was expecting something more technical and programming-oriented from the very beginning, so that was actually a good surprise. *The GDS toolkit for Max was also a vey useful tool.*
The first day of the workshop, by showing film extracts that use sound in various contexts and by seeking responses on this issue, it instigated a thinking that moves from the phenomenological to the empirical aspect of sound, from a reflective perception of sound to here-and-now experience. I found also interesting questions on the nature and relationship of memory and sound.
Thinking about a connection between gestures and sound.
Thinking about the soundscape around us and thinking about modifying it.
Reflecting sounds I heard but didn't notice and to see how much we can realize in just one day without having experience in sound design
Getting Max known

The workflow we used and the short introduction into Max.

the insight how important sound really is

What would you like to see improved in the workshop?

Yes, as I mention before it would be better that MAX path sound be finalized. And also It would be nice If the second day we have a nice quality of microphone to record our everyday sound and share to everyone for the 3rd day. Lastly, I would like to know more about gesture recognition and examples.

An extra day would be nice.

No comment.

First part was long and boring. I mean the first morning. I know it's necessary, but still boring.

Support of the library for other computers than Mac could be appreciated. And probably a short session (one hour) where everybody can test and implement small stuff with Max before working in groups (three people per computer is probably not so efficient).

Maybe, to try with different sensors, or to experiment with biosignals. Not only those gather from motion. But I guess is more complex and it will take more time the duration of the workshop.

More rigorous discussion and debate on metaphors and relationships in this field. More challenging tasks with the sensors and software.

It would be good to work with open source, cross platform software.

Possibly some questioning once the projects/tasks are selected, towards the way in which the selected sounds are part of an embodied experience and on how the participant understands sound as a body experience.
A small cheatsheet handout for Max/MSP would be nice to keep the knowledge for later!
Nothing comes to mind
(No answer)
The introduction into the toolkit was a bit difficult to grasp. I first didn't understand that it's like a framework, where you can take out different parts, like a palette of tools. I saw it more as an application in the beginning. And I found it difficult to understand what the exact output of the different outlets was. This would be good to understand what the program was exactly doing.
Little bit more time for the max part

Do you pay more attention to sounds around you now?

I would say, I usually put my ear phone while I'm walking, so I only hear my music. But If I sit in a quiet place, I'll pay more attention to sounds surround me.
I pay more attention to potential sounds now. Things that make no sound or very little sound and wonder what they could sound like being interacted with
Absolutely Yes

Yes.
Definitely. Probably not around me but in the work I am doing.
I could say I always put attention on sounds, but I didn't explore before and try to recreate those scenarios.
No more than I did before the workshop.
Definitely
I am more aware on the interactive aspect of the sound experience, and i am starting to think what does interaction with sound means. In this sense, what is embodiment of the sound, how visible it becomes, and how much it affects the environment that gave the sonic incident.
Yes
In every day life not, however there are some situations where i do pay more attention to sounds
yes
no
Yes, but I think this is more related to the workshop we're having now, the to weeks we're concentrating on sound as a whole.
just a little

Did the workshop help you to imagine interactions while listening to sounds?

Yes, it helped. Also I think that as my background is graphic design. I

was trained to imagine abstract things and then transform to be pictures.
Absolutely
Definitely Yes
Yes.
Definitely. We had quite a good imagination to be inside the duck :), and the project went a bit artistic with interesting interactions. So I guess I could imagine interesting and unexpected interactions while listening to sounds.
Yes, at least I could punctuate that UCD methodologies could apply to Sound Interaction Design.
It encouraged me to think a little more imaginatively about scenarios with sounds, through this idea of alternative interactions (the giant duck for instance).
At least in my case, the discussions around sound and action / sound and objects really encouraged new approaches to sonic interaction.
Yes it did, and also touched the issue of the psychological aspect of a sound, the one related to memory and personality.
No
YES
yes
yes
I don’t think so.

not really

Did the workshop help you to think about sound as a medium to understand everyday interactions? (Physical, Social, Technological, etc)

I think it helped.

In some ways yes. I do not think I was consciously aware of that as it was happening.

Yes

Yes.

Did the workshop help you to think about sound as a medium to UNDERSTAND everyday interactions? (Physical, Social, Technological, etc)

Probably not...

Sound probably has a more active role than that.I think sound can be a medium to understand everyday interactions, but this was not the purpose of this workshop.

We were actually actors of the sound, and not listeners (as could be the people watching our performance).

it Increased the way of thinking in sound and to explore more everyday actions and interactions of course.

Although there is some things I'm still trying to understand. And I'm divagating on it, something like social context/impact and anthropological approaches.

I already place a great deal of importance on sound in my own and general everyday interactions.
Somehow, but would't say that was directly tackled by the workshop.
Somehow yes, but maybe if there was a sound selection from these fields(social life, technology, etc) during day one then this aspect of sound as a medium of understanding in everyday life would be more obvious.
Well yes, but I think I did this before already
Yes
No
A little
Definitely. I think it really sharpened my perception towards that.
yes

Did the workshop make you consider sound as a medium for the design of everyday interactions?

Definitely, as I saw the final performance I can't deny that sounds and interactions are something that push each other to be something that interesting.
The questioning and drawing a sound from our lives did make me think about how sound makes us change and feel on a daily basis

Yes
Yes, but I don't really like to use everyday sound to create interaction, I am not narrative kind of person.
Yes.In our project, we began with a sound (sonic incident), and it gave us inspiration to design body interaction. We became actors of the sound and designed the interaction that fitted well.
I have been consider to work more on the field of Interaction Design. But the workshop gave me more ideas, and think about the possibility to apply for a PhD on this field.
Again, I think about this a lot anyway, but I was encouraged to think in a slightly different way, which will be useful in the future.
Yes.
Not so much as a design, I am more interested in sound as a way to visualize rehabilitative and improvisational paths.
Yes I see that this is important
Yes
yes
it was present before
Yes, I think in the future I will put more weight into this when I'm designing interactions.
yes

Did the workshop help to open up new ideas on relationship between everyday and sound?
Yes, with WAX I think it's a thing that connects our interactions and sounds together.
It made me think of a heightened reality of sound. Where sound is interactive
Yes
Yes
Did the workshop help to open up new ideas on relationship between everyday and sound?
Yes.That was a bit artistic and I did not think that such interaction could happen between everyday and sound (or probably more at a functional level).
Yes of course, every new thing you discover and learn give you the inspiration to keep going and think more. In this case about everyday situations, and how the sound play a role when it exists, and how it will be that particular context from different perspectives, if the relationship will change. And how to sound concatenate different sequences objets-actions-cognition-perception.
I liked the exercise with the different relationships between visual and sound (film clips). These were quite good examples to demonstrate what sound might or might not communicate when used in different ways. I was aware of these possibilities before, but the examples used conjured up quite vivid experiences of these relationships, and reminded me to consider all options.
I think the first session really achieved this goal.

Definitely yes.
(No answer)
Yes
yes
Not so much
Not particularly.
No

The following question has been asked only in Workshop 3 and 4.

How did the process of going from thinking, remembering and enacting sound in the everyday (Sonic Incident) influence the final prototype your presented?

We began with a really weird sonic incident (rubber duck horn on a bike). That was not easy to deal with this incident but it was simple enough to give some freedom in the final implementation of the prototype. We first thought of being the duck itself, and then being inside it. This thinking process actually went in a logical way, and I guess the final result is quite good: touching different materials around us. Anyway, I really liked the process to go from a sonic incident to implement a final prototype!
At the beginning was complex to figure out how that sound it is, now exactly to understand what the sound it's, but maybe in how to fit in what other expect you see ("hear") on it. What actions were representing on the clips, or if there is relation with the context or not. After that you start to think, ahh maybe this was the intention, or the intentions is don't have any

relationship between visual and audio stimulus. Then the process of remembering incidents let you get the change to open that sonic memories and how sound still there.

The impact of this process had an effect on the final prototype, from 3 ideas we converge in one prototype, merging concepts, way to narrate to have one sonic discourse and ways of approaching embodied relationship.

I thought this process of development worked reasonably well, but had I known our interesting sounds from the first 5 minutes of the workshop were going to be developed into prototypes, I would have thought more carefully/differently about what I chose!

I think the process encouraged less obvious sound mappings for the final prototype.

The process defined the prototype in the way that the sonic incident was seen as an augmented memory. And its practice and research let to an improvisation and research into the psychological aspect of the prototype.

As our idea was based on such a sound, it was very influencing.

It was a very interesting approach to start with thinking about sounds and creating something based upon this.

The final idea grew out of this reflecting

We haven't presented it yet

It was very good to have such a "strict" workflow from the beginning and not just "do something with that tool". That really helped to focus on the idea we already had, to shape it and build a prototype.

I thought it was really helpful that we had like different approaches towards the idea and the sound.

It didn't ... we just chose the only possible prototype!

How much do you feel the prototype you realised in the group fits your needs and expectations you had attending the workshop?

The prototype we realised was purely imaginary (we were inside a rubber duck!), so it did not really fit any specific need and was just for practice.I was glad we used gesture recognition with machine learning for real-time mapping of a gesture towards a sound, since this is what I am most interested in.
As I mentioned before I was expecting to work on Electronics a little bit more, maybe I created that idea on my mind. But at the end, I'm very satisfied with the idea we presented. It was more useful to think about memories, sonic incidents, affordance, sound sketching than expend time on some electronic exploration.
I'll be honest, not very much! I have my own preferred (quite systematic) way of working with sensors and live DSP but this was never going to work well as a development technique with my group who were very unfamiliar with the software and some of the sound concepts. As a result, the development process was a little more shambolic than I would have preferred, and I felt the final product lacked substance. It did something, but not in a very interesting way.
I think it fitted well, as it allowed me to explore expressive mappings between body and sound, and also learn more about using body gestures for live performance.
It offered me a different hearing of sound, the one that has more a manipulating aspect and does not suffice on its reception and instant body response.
It was more kind of fun. Maybe there should be also a part where we try do

design a very specific, realistic or useful sound.
Very much. However, i didn't expect to create super champagne man.
We could realize more than i thought before the workshop
So far, it seems to fit my expectations
I was really surprised what we could achieve in that single day workshop. So my expectations were more than fulfilled. I think the prototype we built didn't really fit a need, but it really helped to get the whole idea of the workshop.
I didn't have expectations

The following and final question was asked on Workshop 2, 3 and 4.

What information from this workshop are you going to apply in your future work/projects?

I would like to learn/know more about gesture recognition and how to record sounds.
I may make future projects with this work. I think it has high implications in street theatre especially
A storyboard will be one of the key elements of creating my future works. After this workshop I realized even a simple 2D painting needs a storyboard. Also I would like to create sound as viewers' eyes browse around the artwork. I was thinking of a sensor that can catch viewers'

eye movement and create sound according to the direction of the eyeballs and the colors they are viewing.
Granular sound effect; gesture/movement, instead of using that expensive sensor, maybe I will prefer openCV.
In my field (virtual reality), I am used to building worlds with computer images in which the users interact (with no sound). With this workshop, I became aware that we can build virtual worlds with only sounds, and that interaction and immersion may be enhanced with that.
I didn't realise to much how to approach sound into my HCI field before, not from the side of Design Methodologies. But I discovered how I could start to design Interactions, how to move through Sound into my field of studies. The idea I have is to converge Electronics, Acoustics, HCI and Anthropological Studies into my research field. Look for PhD studies that suit to me covering my expectancies on interdisciplinary fields and to offer me enough freedom to work in experimental approaches.As well, to find the way to live through these participating in multidisciplinary projects, get the inspiration to work more on technical tools that will help me to build projects.
I'm going to try and dissect the patches and find ways to improve my own system. There were some nice ideas at the end of day one on the 'position' of the subject in relation to the sound (e.g. being acted upon, acting on etc.) and I think I'm going to try to think more about that in my own work.
The methods based on thinking, remembering and enacting sound are very interesting and I think it could be very useful for my teaching (e.g. real-time interaction). Also, I'm looking forward for the multi-platform version of the GSD toolkit.
My research has been influenced from the suggestion of contexts and

environments the workshop provided.
I learned something about Max/MSP and maybe gonna use that or use PureData, which is similiar I guess.
Thinking about sound as an essential part of a design, not an additional part.
The library we got for Max
Max
Probably the workflow we used. And that sound can really support everyday interactions.
To plan more time for the sound-parts of the project

APPENDIX C: ETHICAL STATEMENT

My research project has been developed as part of the wider project "MetaGesture Music" funded by the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. FP7-283771. I followed the ethical assessment form submitted as part of the MetaGesture Music project, which has received ethical approval from the Goldsmiths Research Ethics committee and the ERC. The ethical procedures were based on the EU and UK norms. The project conforms to privacy and confidentiality guidance from the UK ESRC "Research Ethics Framework" (REF). The ethical considerations in my research project follow the guidelines and the methods established in the wider MetaGesture Music project.

Adult volunteers were recruited to take part in this research with the sole aim of gathering their views, opinions and data related to research activities which comprised the user study and four workshops. Participants were recruited through a call for participation in academic institutions and student communities, via digital message boards and mailing lists. The call for participation outlined the objectives of the study and the activities participants would be involved in. Participants volunteered by email to take part in the research activities and studies.

Once their participation was confirmed, I informed them of the aim of the research, the nature and usage of the data they provided within the user study and in the workshops. With the outcome of this research potentially reaching the public through papers and public presentations, I made participants completely aware that data collected during such research activities, including their writings, drawings, photographs and videos could potentially reveal their identity to others. All participants agreed of their own accord to take part in my research and they were asked to sign an Informed Consent form, which explained the nature of the studies and gave the participants the possibility to withdraw from the research at any time, including in the period after its conclusions by contacting me or the hosting institution. On 21/01/2018 no requests of withdrawal have been received from any of the participants. I anonymised the written content of participants' data, such as texts and answered questionnaires using a tag code for analytical purposes. The following is an example of the informed consent form distributed to participants taking part in my research activities. All the fields have been anonymised, excluding the printed names of the researchers, for inclusion in this thesis.

GOLDSMITHS, University of London

Participant Information and Research Agreement

Aims of the study

Our research area is musical and sonic interaction, in particular the relationship, if any, between movement and sound.

The logistics of the study

The study will observe how each participants produce movements and digital sounds. An interview is following this activity. All the activities during this study, from the start to the end will be filmed. This includes every gestures and sound produced, electronically and not, and any spoken words.

Research agreement

I the undersigned agree to take part in the aforementioned research project. I understand that I am free to terminate my involvement in the research project at any time but understand that by doing so I will invalidate any of the data provided by my involvement. I agree to participate in completing questionnaires and engaging in a documented discussion where the results are published anonymously. I am aware that the filmed material may be used for further documentation on all possible publishing platforms (printed, digital). I reserve the right to approve or deny the authorization for this specific usage of my image, after examination of the edited filmed material.

Printed Name:

Date of Birth:

Place of Birth:

Full Address:

Email:

Gender:

Signed Participant: Date:

Signed Researchers: Alessandro Altavilla Date:

Baptiste Caramiaux

Workshop

Godsmiths College, University of London
Organizers: Alessandro Altavilla, Baptiste Caramiaux, Atau Tanaka

Full Name:

Gender:

Age:

Occupation:

Consent form
I declare to accept to participate to the workshop organized by Alessandro Altavilla, Baptiste Caramiaux and Atau Tanaka. I am free to accept or decline this participation.

Part of the workshop will be recorded using a video camera. The captured video data will not be used for commercial purposes but only in academic context (presenting at conferences or mentioned in scientific papers). I declare to agree with the use of this data in the mentioned context. I am free to accept or decline this participation.

Name/Signature of one of the organizer

Name/Signature of the participant

Goldsmiths
UNIVERSITY OF LONDON

APPENDIX D: PUBLICATIONS

This section features two full papers I have authored, which have been published during this research.

The first paper reports on the user study on gestural sonic affordances I discussed in Chapter 3. The paper was published in the proceedings of the international conference on New Interfaces for Musical Expression (NIME), Seoul, 2013.

The second paper reports on the Form Follows Sound workshops I discussed in Chapter 4. This paper was co-authored by Baptiste Caramiaux (Goldsmiths, University of London), myself, Atau Tanaka (Goldsmiths, University of London) and Scott Pobiner (Parsons, The New School of Design, New York). The paper was published in the proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, held in Seoul in 2015.

Full bibliographic references

Altavilla, A., Caramiaux, B. & Tanaka, A., 2013. Towards Gestural Sonic Affordances. In *Proc. of the International Conference on New Interfaces for Musical Expression (NIME)*, pp. 61–64.

Caramiaux, B., Altavilla, A., Pobiner, S. & Tanaka, A., 2015. Form Follows Sound: Designing Interactions from Sonic Memories. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pp. 3943-3952.

Towards Gestural Sonic Affordances

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ABSTRACT

We present a study that explores the affordance evoked by sound and sound-gesture mappings. In order to do this, we make use of a sensor system with minimal form factor in a user study that minimizes cultural association. The present study focuses on understanding how participants describe sounds and gestures produced while playing designed sonic interaction mappings. This approach seeks to move from object-centric affordance towards investigating embodied gestural sonic affordances.

Keywords

Gestural embodiment of sound, Affordances, Mapping.

1. INTRODUCTION

Affordance is a concept in interaction design dealing with the kinds of usage an object invites of the user [14]. The concept, however, originates in the field of ecological psychology where it describes qualities an environment offers to subjects [8]. Our working definition of affordance relates to this ecological three-way relationship between subject, object, and environment. This provides us a framework within which questions of perceptibility, scale, user, and finally interaction can be examined. Sound is a fundamental property of everyday interactions as it contributes to perceiving complex affordances [7]. Therefore, we might gain insight into our embodied interaction with sound. Can sound by itself exhibit affordance? Can certain qualities of sound afford certain kinds of gestures? Could this approach help guide sonic interaction design?

We present a follow-up study of an earlier pilot experiment that looked at gestural affordance of sound with accelerometer-based devices [17]. We designed an experiment that minimizes object-based device effects and cultural associations to concentrate on the embodied reactions that sound itself could invite. This paper first presents related work in the field, then describe the experimental design and user study, and finally discuss interview-based results.

2. RELATED WORK

Concepts linked to affordance have found application in various types of NIME research, from screen interfaces [13], to network music collaboration [10], to mobile music [18]. Most of this work uses affordance from a design object or user interface perspective.

NIME'13, May 27-30, 2013, KAIST, Daejeon, Korea.

Sound as a physical property can contribute to the affordance provided by an object [7]. Object manipulation by auditory feedback is explored in Sonic Interaction Design (SID) [16]. Franinovic et al. [6] explored the latent possibility of action within sonically augmented everyday objects. Lemaitre et al. [11] showed that continuous sound feedback helps users in manipulating tangible interfaces. These previous works investigated the action of auditory feedback on the design of an object and its resulting manipulation.

Other works take a behavioral approach to examine the direct link between the sound and resulting human gestures without facilitating objects. Leman et al. [12] showed that gestures performed along with a Guqin music performance are correlated with player's movements. Inspired by Schaeffer's reduced listening, Godøy et al. [9] investigated the link between gestures and abstract sounds arguing for an intimate link between morphologies of both gesture and sound. We showed that gestures performed while listening to environmental sounds mainly depend on the level of identification of the sound source [2]. Van Nort evokes Chion's categories of sound objects [3] to propose an approach informed by morphological characteristics of sounds to create *perceptual, embodied control design* of gestural mappings [15].

Principles of affordance have been applied in music interface design. Magnusson uses affordance as a critical design factor for screen-based music interfaces [13]. Affordances of network music collaboration have been explored by Gurevich [10]. We present an overview and review of musical affordance with applications in mobile music instrument design in [18]. In a previous user study [17] we explored the gestural musical affordances using consumer devices with built-in accelerometers. The production of gestures was influenced by the form factor and familiarity of the devices (Nintendo Wii-Remote, iPhone). Another factor was the recognizability of musical instrument sounds, which created cultural associations that influenced the perceived affordance by users.

3. USER STUDY

In the present study, we designed an experiment that minimized both object-based affordance and cultural association to investigate the potential gesture afforded by synthetic sound and gesture-sound mappings. We were interested to find out:

- Whether embodied interaction producing sound parallels corporeal response in sound listening
- If gestural mapping could impart affordance to sound in the absence of a physical object
- Whether sound by itself, free of cultural associations, can exhibit affordance to suggest gesture.

We conducted a user study, with 7 non-musicians (4 women, 3 men), between 24-40 years old. A series of gesture-sound producing tasks was followed by interviews with participants.

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3.1 Technical apparatus

We used the Axivity Wax, a miniature, low power, wireless 3D accelerometer, to capture user gesture. The sensor is about the size of a thumbnail and was housed in a Velcro-band (Figure 1) strapped around the hand. This minimized the physical form factor of the sensor as an object. Data rate from the accelerometer rate is up to 2 ksamp/sec. The device sends accelerometer data in OSC format over ZigBee to a dedicated receiver unit which in turn was connected to a laptop computer via USB. The computer runs a Max/MSP patch reading the sensor data, and maps them to sound synthesis control parameters. Two speakers, set to a double mono configuration, output the sound produced by the Max patch.

We produced synchronized audio-video recordings of the performances and the interviews of the participants using standard audio/video recording equipment.

3.2 Scenarios

We designed three scenarios corresponding to Schaeffer/Chion's categories of sounds: *Impulse, Iterative and Sustained* [3]. These categories have been a standard basis for previous studies by ourselves and others cited in Section 2.

We worked with synthesized sound rather than samples in order to minimize association of the sound with known objects. The Impulse sound was designed with a physical model of a generic percussion instrument (STK [4]) using the Percolate objects in Max/MSP. The Iterative sound uses the physical model of a shaker (PhISEM [5]), while the Sustained sound was built using amplitude modulation (AM) synthesis.

We created the following mappings between accelerometer input and sound output:

Impulse sound control, based on percussive action. Sound is triggered once when the instant energy of the movement exceeds a set threshold. We use a reset hysteresis of 200 ms to avoid multiple triggering.

Iterative sound control, based on shaking of the hand. Sound is articulated by accumulating energy. It is first actuated with a minimum movement of the hand. Increasing the frequency of periodic movement controls amplitude of the overall sound and three parameters of the physical model such as: decay, shake away energy and resonant frequency of the filter.

Sustained sound control, based on continuous movement of the hand or arm. The overall amplitude of the sound is directly proportional to the amount of movement produced. The vertical tilt of the hand, in both directions, controls the depth of the tremolo. A small amount of vibrato (+/- 20hz) is controlled by horizontal rotation. The reference frequency of the oscillator is 420hz. The amplitude of a third sine oscillator set to 880 Hz is exponentially mapped to the speed of the movement.

3.3 Procedure

We created a task-oriented experiment in order to investigate whether participants could play three different sounds based on three different mappings we designed. Task performance was followed by an interview.

We first informed the participants that the movement of their arm and hand would produce electronic sounds. They were simply told that there would be three scenarios without details on the kinds of sounds or mappings. They were told that they were not being evaluated or judged.

The order of the scenarios was randomized and counterbalanced across participants. For each scenario, the participants were given up to 1m30s to explore and try to figure out how to play the sound.

We then interviewed the participants first with general questions, followed by a more detailed review of the activity. Two general questions were asked to each participant: *Was this way of producing sounds natural? Was it easy or difficult?* We then performed an auto-confrontation interview [19] where participants watched a video of themselves performing the tasks and were asked to base their answers on specific moments in the video. The interview was guided by a series of questions reported in Table 1 below

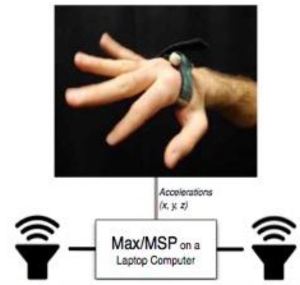

Figure 1. The Wax fitted into a Velcro hand-band. Acceleration data is mapped to different parameters for controlling sound synthesis.

Table 1. Auto-confrontation interview questions

Q1	*Can you describe the sound you just played?*
Q2	*Can you describe your action in terms of physical movement?*
Q3	*Can you tell us how to play the sound?*
Q4	*How did you go about trying to figure out how to play the sound?*
Q5	*Can you show us at what point you got it?*

4. INTERVIEW RESULTS

The audio-video recordings of the interviews were transcribed and annotated using Inqscribe software. We noted the timing of the participants' gestures and added descriptive notes tagged with video timecode. Interview data was factorized to each specific question and used to build different grids for thematic analysis.

The general experience was classified by the participants as "natural" and "intuitive". Some participants explained this as an ease with which they perceived a link between sound and movement. Another element which made the experience "natural" was the lack of external interfaces. The experience as a whole was also classified as "easy". Participants felt that it was "*easy to find how it works*" (U3), having one sound for each scenario helped (U4), and acoustic feedback facilitated his experience (U6). It was also classified as "*fun*" (U4, U7) and the freedom of playing with the body was also here considered to be a positive aspect (U5, U7). The time needed by participants to explore the three different tasks was on the whole shorter than the 1m30s they were accorded. The average timing for impulsive sound was 1m10s, for the iterative sound it was 1m15s and for the sustained it was 1m05s.

Description of sounds (Q1)

The Impulse and Iterative sounds were often described using similar and known sound sources from everyday life and musical instruments. Impulse sounds were described using words such as "*bouncing ball*", "*drum sound*" (2 times), "*computer error*" (2 times). Iterative sounds were described as "*rattle*" (3 times), "*interference noise*" (3 times) "*insect flying*" (2 times), and "*driller*". Sustained sounds were described less precisely. Two participants described them as "*finger moving* *on the ring of a crystal glass*", but generally this category of sounds was described using abstract and ambiguous references, such as "*U.F.O. in cinema*", "*wavy sound*" and "*digital sound synthesis*". Sometimes our participants mimicked gestures in order to reinforce words that were difficult to articulate.

Description of action (Q2)
For Impulse(s) actions participants used terms such "*like playing basketball*", "*pushing*". Iterative actions were described using words as "*touching*", "*vibrating*", "*shaking*" or "*scratching*". Sustained control was described using information on the spatial sequence of movement (up/down/left/right, horizontal, vertical, drawing a circle).

Explaining how to play the sound (Q3)
In most cases participants were able to explain what were the most effective movements needed to play the three different sounds. Their descriptions linked the imagined object of Q1 with the action described in Q2. For the impulse sounds they used action verbs such as "*pressing*", "*pushing*", "*percussive*" (2), "*moving the arm suddenly*", "*hitting*" (2), "*knocking*". For the iterative sounds, participants used words such as "*impact and continuity of the impacts*", "*scratching*", "*rubbing*", "*shaking*" (2), "*swinging*". For sustained sounds they referred to arm position as somehow affecting the sound (2), while the speed was seen as changing the amplitude of sound (5). One participant described that the sound became "*harsher*" as a result of moving energetically the arm, correctly identifying the presence of a third, inharmonic oscillator in the sound engine, activated only when an energy threshold was crossed.

Understanding how to play the sound (Q4)
Participants used different approaches to understand how to play the sounds. Two participants used a fixed sequence of movements as a reference for the production and control of sound. Two other participants tested general random movements until they could hear some sound and then started a gestural exploration. Finally, the remaining participants declared not to have used any strategy but relied on intuition.

When did you get it? (Q5)
Table 2 reports the times indicated by the participants as the moment they understood how to play, during the auto-confrontation with the video recording. The second row reports the Standard Time Deviation.

Table 2. Average timings reported for Q5

	Impulses	Iterative	Sustained
Time	24 sec	25 sec	16 sec
STD	22.4 sec	13.02 sec	11.55 sec

5. DISCUSSION

For each scenario, participants had a tendency to describe sound production in terms of causality. If the sound source could be identified, people described it as the physical object producing the sound, for example, drums or rattle. On the other hand, a blurry identification of the source led to a description related to digital and electronic processes ("*computer error beep*", "*interference noise*", "*sine wave*"). Participants described the physical movements (Q2) they performed in a manner consistent with their description of the sound. If the physical object that would have produced the sound could be identified, such as the "*bouncing ball*", the participants described their physical movements as the actions associated with this object. For sounds not associated with a real world object, participants instead used spatial indications (e.g. "up/down/right/left") or geometric figures to describe their movement.

Question 3 forced the participants to articulate a link between the action (Q2) and the sound (Q1). They described the *impulse* mappings with the correct mapping: "*hitting*", "*knocking*". These are the simplest sound/action relationships, caused by quick movements, and the answers to the 3 questions are essentially the same. For the *iterative* sound control, participants were less able to directly describe the mapping and instead tended to describe an action that would have produced the sound, e.g. "*scratching*". In this case the answer to Q3 resembles that of Q2. Finally, for *sustained* sound control, participants described the sound/action relationship in an analytic way, e.g. "*wavy sound*", without relation to concrete physical actions. Here, the answers to Q2 and Q3 complement one another, where Q2 actions were described in spatial ways, and Q3 in abstract, analytic terms that correspond to these geometric descriptions. These results indicate that if the sound can be identified as a physical object that can be manipulated, the control gesture is related to the action interacting with the object to produce the sound.

In a previous experiment, we studied embodied listening – gestures invoked in the act of listening to sound [1]. Gestures were performed in response to a sound stimulus, and did not involve interactive control of sound production. There, the link between the level of identification of the sound source and the gestural description was shown to either mimic the action producing the sound or trace the sound frequency/amplitude profile [1].

With the present study, we shifted from evoked gestural response during listening to sound production through gesture facilitated by sensing and mapping. Similar to the aforementioned study on embodied listening, participants used action verbs, such as "hit", to describe gesture produced when sound sources were identified. In case of non-identification of the sound sources, the description is mainly spatial ("up/down"). This comparison is based on qualitative analysis of the interview data, however we can suggest that embodied responses while listening can be transposed into similar actions in making sound. We can draw upon terminology from language acquisition where *passive vocabulary* (vocabulary of words understood when listening) is distinct from *active vocabulary* (words mastered for speaking or writing). Using these terms, we can consider the experiment on embodied listening [1] to be an example of *passive* gestural response and the present experiment to be a study of *active* gestural sound production.

In another previous study [17], we looked at sound production using commonly available consumer devices such as a Nintendo Wii-mote and Apple iPhone. There, we found that musical affordance is a complex construct comprised of physical object-based affordance, cultural association, and sonic affordance [17]. In the present study our aim was to strip away the object and cultural factors to focus on the affordance that sound itself might provide.

The fact that participants tried to describe the sounds and gestural interaction in terms of familiar objects from the real world indicate that people have a tendency to look for association in order to understand sound. Even in the absence of an object, they describe the sound in terms of objects. In the absence of cultural referents, people try to describe their gestural relationship with sound grounded in present-day culture (drums, computer beeps). In order to answer the question of whether sound itself can exhibit affordance, one answer may be that sounds afford a form of memory recall to cultural and physical referents that themselves afford certain kinds of actions.

In this sense, we can consider sounds, or certain types of sounds, based on a Schaefferian typology, to manifest themselves to the user through Gaver's notion of *complex affordance* [7]. Comparing the verbal description of sounds (Q1) with the gestures produced (Q2) some particular typologies of sounds *afford* the production of different movements. The gestures produced can be related to the identification of a possible sound source. However, this may also be related to the visibility of the designed mappings. One could ask whether it was the sound or the mapping that afforded gesture.

The process of understanding how to play these sounds differed from person to person. We noted several different approaches to figuring out the sounds: *Strategic, Explorative* and *Intuitive*. Participants were internally consistent, in that they typically used the same strategy to explore all three sounds. Strategic users had a methodological way of trying different inflections in sequence to try articulating the sounds. Explorative users quickly tried very different gestures, honing in once sound was produced. Intuitive users would follow initial tentative sound production by producing gesture corresponding to the imagery suggested by the sound, perhaps being closest to an affordance-based style of sound-gesture learning.

Participants' recognition of the moment when they understood how to play the sounds (Q5) evidences some contradictions worth further exploration. The analysis of the video recordings, compared to the timings reported in Table 2, showed us that participants tended to indicate the first occurrence of sound heard rather than their recognition of how to play the sounds (Q3). This raises questions of comprehension and intentionality that will need to be studied in future work.

6. CONCLUSIONS

We have presented a study that explores the possible notion of sonic affordance – whether sound can suggest gesture. This experiment builds upon likening two previous studies on embodied listening and musical affordance. The first study investigated gestures induced by sound listening [1]. In the second study on musical affordance, we looked at musical gestures suggested by culturally familiar sounds in conjunction with familiar techno-culture devices [17]. In the present study we explored the viability of transposing passive, receptive sound/gesture responses to active, sound producing scenarios to investigate sonic affordances By removing the object-based affordance and the musical cultural association from the stimulus, we found that sound still suggests gesture.

Similar to the study on production of gestures during passive listening [1], the use of active gestural control of sounds in this study showed that the description of gestures was influenced by a possible identification of sound source. In fact, participants describe sounds as resultant from an action in the case of impulses and iterative sounds, while sustained sounds were described referring to perceivable modulating characteristics. This parallels to the present case of active gestural control of sound.

Gestural mapping had an influence as well. The gestures produced were influenced by the modulating parameters we superimposed in the mapping. This suggests that the gestural mapping, as relation between movement and production of sounds, contributes significantly to the perceived affordance of a sound.

Despite the absence of object and cultural referents, participants looked for associations to help ground their understanding of the sound and associated mapping. This points to the interesting possibility that abstract sounds and gesture mappings may afford the recollection of known sound producing objects and situations. In addition, the simple recollection of imagined sound-producing objects might afford movement even in its absence.

The recognition of a possible sound source characterizes the gestures produced. However, acoustic characteristics of sound also have an impact, especially when this recognition fails. In the sound stimuli designed for the experiment, temporal perceivable modulations of sounds drove participants to change their gestures.

Considering gestural-sonic affordances may provide insight into designing future interactive and gestural music systems that balance the morphological characteristics of the sound with its potential cultural identification.

7. ACKNOWLEDGMENTS

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Form Follows Sound: Designing Interactions from Sonic Memories

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ABSTRACT

Sonic interaction is the continuous relationship between user actions and sound, mediated by some technology. Because interaction with sound may be task oriented or experience-based it is important to understand the nature of action-sound relationships in order to design rich sonic interactions. We propose a participatory approach to sonic interaction design that first considers the affordances of sounds in order to imagine embodied interaction, and based on this, generates interaction models for interaction designers wishing to work with sound. We describe a series of workshops, called *Form Follows Sound*, where participants ideate imagined sonic interactions, and then realize working interactive sound prototypes. We introduce the S*onic Incident* technique, as a way to recall memorable sound experiences. We identified three interaction models for sonic interaction design: *conducting*; *manipulating*; *substituting*. These three interaction models offer interaction designers and developers a framework on which they can build richer sonic interactions.

Author Keywords

Interaction Design; Sonic Interaction Design; Methodology; Gesture; Sound.

ACM Classification Keywords

H.5.5. Sound and Music Computing: Methodologies and techniques; H.5.2. User Interfaces: User-centered design; H.5.2. User Interfaces: Interaction styles; H.5.2. User Interfaces: Auditory-non speech feedback.

INTRODUCTION

Sound has a long history in Human-Computer Interaction, often as a supporting function in the user interface as a way to notify the user about their actions. An early example is the SonicFinder [17], that introduced auditory icons defined as "everyday sounds meant to convey information about computer events by analogy with everyday event". Sound as a medium for interaction has recently emerged through the discipline of Sonic Interaction Design [16] making use of continuous interaction between user actions and sound feedback to help in accomplishing a task while performing it. While this approach has found several promising applications; for example, in rehabilitation [3], sport [33], or music, few insights have been given to interaction designers to allow them to realize such interactions. In this paper, we propose a participatory approach to extract insights for novel and rich sonic interaction designs.

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Sound can be thought of as an information medium, one that conveys clues about materials, substances and their environment, and reveals a sense of the physical dimensions of a space and its surfaces [2]. At the same time, sound is an affective medium evoking memory and emotion. High amplitude sounds, rich in low frequencies, can be physically felt by humans, as in the case of powerful sound systems [21]. Sound can even be used as a weapon using high frequencies and narrow beams [19]. Most importantly, sound is a temporal phenomenon and "exists in time: It is an inherently transient phenomenon" [17]. Listening becomes a critical activity for Gaver, who distinguishes *musical listening* from *everyday listening* [18], the former emphasizes musical qualities of sound while the latter focuses on causal and contextual aspects of a sonic event.

Sound is powerful in that it can provoke a visceral response and influence action. In cognitive neurosciences, couplings between the auditory and motor systems have been reported at the level of the brain [39]. The body is not passive in listening – human actions have been shown to have an effect on auditory perception [29]. Behavioral approaches of sound–action coupling have examined how a physical gestures can represent the sound it accompanies [27]. Considering environmental sounds, recent studies showed that corporeal representation of sound depends on the user's level of identification of the sound source [7]. This points out the possibility that sound sources, and possibly sounds themselves, can take on qualities we can think of as *affordances*, inviting accommodation, response, and possibly use, on the part of the beholder.

In this paper, we propose an approach for the design of sonic interaction where sound and the user's sonic experience serve as the starting point from which action–sound relationships are envisaged. We consider the perception–action loop as a fundamental design principle that facilitates forms of embodied interaction [8,10]. We introduce a methodology based on critical incident technique and workshopping to aid users in accessing memorable sound events, and use scenario building to aid them to prototype sonic interactions. Advanced interactive sound and gesture capture technologies are introduced to allow groups of participants to elaborate novel, functional action–sound relationships. From the insights we gained, we derive interaction models for continuous interaction with sound that could be useful for interaction designers to conceive rich sonic interactions for future products and interactive systems.

The paper is structured as follows. In the next section we review the state of the art in sonic interaction design and interaction models in HCI. We then present the workshop procedure and describe its evolution across four iterations. The Results section reports on outcomes from the workshops and insights they provide. The Discussion uses analysis of the results to frame our proposed interaction models for sound. We conclude by indicating how this research might inform the work of interaction designers and frame future research directions.

RELATED WORK

Sound as an interface

The use of sound in the user interface arises from the need to transmit information through a different medium than the visual (*sonification*). Sound HCI research has resulted in techniques such as audification (raw translation of data to sounds), earcons (audio messages made of short rhythmic sequences of pitched tones with variable timbre), auditory icons (sounds from everyday conveying information about events). For a review see [23]. Sound as a display for information communication has also been the core of the International Community for Auditory Display (ICAD) [26].

Sonic interaction design

Sonic Interaction Design (SID) brings together research and design works that use sound as an "active medium that can enable novel phenomenological and social experience with and through interactive technology" [16]. In this context sound is used to provide information about the nature of the interaction itself, helping the user to refine her actions under a given task [22]. SID also extends the use of sound in an interaction setting for non-task oriented and creative activities. For instance, previous works combined sound design and interaction design techniques to explore sonic augmentation of everyday objects [32,34].

According to Franinović et al. [15], a central element in SID "is the role that embodied action and perception plays, or how action can be guided by sound in a concrete, lived manner" based on theories of embodiment in cognitive sciences [38] and interaction design [10]. The authors added that embodied sonic interaction is a critical notion as "the body is continually navigating through space, attending to cross-modal phenomena […]" ([15], p.43). Embodied actions are crucial in sonic interaction. However, the field lacks an operational framework for designers to realize such interactions.

Techniques for sonic interaction design

Techniques for teaching Sonic Interaction Design are broad and often exploratory. Such techniques are: performing soundwalks [13], listening exercises, cinema sound effects foley analysis [25], and the writing of sonic dramas [31]. Vocal sketching is a technique that uses the human voice as a sketching "tool" for interaction design [11] and, according to Rocchesso, can be thought of as an extension of bodystorming, or "physically situated brainstorming" [6].

Workshops, and processes of *workshopping* are gaining acceptance in HCI as a key methods in qualitative and user-centric research [36]. Franinović et al. [14] propose the workshop as a means to investigate sound in the design of everyday products and to set the methodological basis for this practice, which includes elements of auditory display, product interaction design and ubiquitous computing. A recent study by Houix et al. [24] proposed the use of a participatory workshop to generate prototypes using sounds associated to manipulations of physical objects and prototypes implementing certain gesture–sound relationships. There, the workshop was used as an exploration to test gesture–sound relationships in object manipulation. There is a need, therefore, to formalize some of the very subjective methods in sonic interaction design and to extract insight from them to be transferred to interaction designers wishing to create new products and systems that make robust use of sound as a central part of human-machine interaction.

Interaction Models

Interaction design research has provided a number of different frameworks through the notion of interaction models. Beaudouin-Lafon defines Interaction Model as "an operational description of how interaction proceeds" [5]. Examples of interaction models in HCI include the instrumental interaction from the same author [4] or the direct manipulation model by Shneiderman [35]. While several interaction models have been developed for computer-based interaction through graphical interfaces, interaction models for sonic interaction still remain to be proposed.

METHODS: WORKSHOPPING SONIC EXPERIENCE

We designed and delivered a series of participatory design workshops that focus on participants' memory and direct experience of sound in the everyday. We used a two-phase structure, Ideation followed by Realization, as a way to move from the description of an affective experience to the elaboration of a functioning interactive sound prototype. Since the design process is driven by sound through sonic memories, we called the series of workshops *Form Follows Sound* (FFS), in reference to the idiomatic "form follows function".

We carried out the workshop 4 times in an 8-month period, with a total of 43 participants of varying degrees of experience with sound and music:

- **New York**. A two-day workshop at Parsons The New School for Design. 15 participants (8 female and 7 male), aged 22 - 44. Participants' background included graphic and interaction design, theatre and dance performance, music.
- **Paris.** A two-day workshop at IRCAM Centre Pompidou as part of the European summer school, Human-Computer Confluence (HC2). 6 participants (2 female, 4 male), between 24 and 35 years old. Participants were from a wide range of fields including engineering, rehabilitation, music technology, physics, bioengineering, and art.
- **London.** A one-day workshop at Goldsmiths College. 9 participants (2 female and 7 male). Their background was various including art and technology, social science, film studies, sound design and computing.
- **Zurich.** A one-day workshop at the ZHdK academy of art as an activity within a teaching module in Sonic Interaction Design. Participants were 12 students (4 female, 8 male) aged between 20 and 24 years, with beginner's experience in sound design.

Phase 1: Ideation

Phase 1 of the workshop was called *ideation* as the goal was to generate ideas for action–sound relationships based on memories of sounds from participants' everyday lives. This phase does not involve technology.

Sonic Incident Technique

Critical incident technique is a set of procedures in psychology that elicit specific memories related to particular recent moments lived by the subject [12]. This technique has then been used in HCI as input for design [28] and in evaluation [20]. As a design input method, it facilitates participants recalling situations, describing why they may be atypical, and highlighting the desired normal operation of an interactive system.

With the *Sonic Incident,* we have adapted critical incident technique to specifically address sound-based memories and experiences. We start by asking workshop participants to remember a particular incident that occurred within the last two days for which the sound was memorable. We guided the participants by encouraging them to think of incidents where the situation was frustrating, surprising, or funny, in which the sound contributed to that situation being memorable. The participants were asked to describe the incidents, the reason why they remembered them, the situation they were in while they heard them, and finally how those particular sounds were related to themselves.

The participants were asked to write a text and/or graphical description of the sonic incidents. As text, it might be a narrative of the event, or a textual description of the sound. As drawings, they could be a pictorial representation of the sound, or a storyboard recounting the incident. In all cases, the exercise required participants, independent of their level of prior experience with sound, to represent the sound in its original situation in words or pictures, and in a non-technical way.

The participants then shared their sonic incidents with the group through vocalization, a standard technique from Sonic Interaction Design. Each participant imitated the sound using their voice and the rest of the group tried to guess what the original sound was. This provides an interesting converse to the text/image description of sound. It required the participant to describe a sound by using sound. The activity remained without technology, and, by using the voice, exploited an intuitive and corporeal mode of sound production.

Imagining sonic interaction

In this part of the workshop we asked participants to imagine possible gestural interactions with their sonic incidents. They did not need to be realistic, and rather could be situations in which they could act upon the sound through their movements, or conversely allowed themselves to be moved by the sound. For this activity, we adopted two strategies to invoke corporeal engagement with sound in different iterations of the workshop.

A first strategy was based on the actions in sound (Parsons workshop). We gave the following task "*To see what actions and reactions the sound may provoke in you or in the space around you.... getting from the sound itself to its effect and to the actions that may cause it.... Sketch this interaction between the sound and your actions ... and how do you think this can happen.*" This task encouraged participants to focus on sound and action, and to explore interaction beyond volitional control.

A second strategy encouraged participants to think about having agency over sounds from their sonic memories (Paris, London and Zurich workshops). We introduced the metaphor of "*Superpowers*" asking participants to imagine themselves as all-powerful beings who could create and act upon sounds. The task was: "*Imagine you have super powers and through action with your body, you can manipulate the sounds/situations described previously in the sonic incident. So, look at your sonic incident, and imagine what happens and how it happens. It doesn't have to be realistic.*" This version of the task intentionally introduced volitional control as a mode of sound/gesture interaction.

Phase 2: Realization

The second phase of the workshop was an activity where the participants created functioning technology prototypes to play out their imagined sonic interactions. We created breakout groups where each group selected one imagined scenario from the set of sonic incidents described in the ideation phase in order to implement it.

Gestural Sound Toolkit

We provided a hardware/software toolkit to realize gestural sound interactions (Figure 1). The toolkit includes gesture sensors, and software tools for motion data processing, mappings and sound synthesis. The system affords real time, continuous interaction where sound is sculpted and modified live as movement is performed.

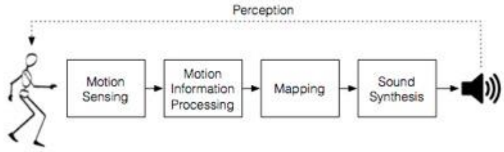

Figure 1. Architecture of the Gestural Sound Toolkit

The sensing hardware was chosen to minimize object-based affordance and cultural association [1,37]. To do so, we chose to use a small sensor to provide a suitable representation of the gesture, not too complex in order to be understood by the participants, non-specialist in motion sensing. We used the Axivity Wax[1], a miniature (the sensor is about the size of a thumbnail), low power wireless 3D accelerometer (see Figure 2) with a sampling rate of 100Hz.

Figure 2. Sensing hardware used in the workshops

The software part of the toolkit was designed to allow participants with no background in interactive sound design, programming, or working with sensors to author forms of continuous sound manipulation through gesture. The software is a collection of high-level modules that can be freely linked to each other. These modules are the following:

- *Receiver module:* receives motion data from the sensing hardware.
- *Analysis modules:* analyze and process the accelerometer data. A Filter module can be used to reduce noise. The Energy module extracts gestural energy from the incoming signal. Velocity was calculated by computing the derivative. A Machine Learning module performs gesture recognition and neural network regression [9]. An Impact Detector, senses percussive gesture from the accelerometer signal.
- *Synthesis modules:* allow pre-recorded sounds (from the sonic incidents) to be played and manipulated. The toolkit integrates temporal modulation (scrubbing). A trigger module allows for triggering a sound from a sound bank. A manipulation module allows sound to be sculpted and modified live as movement is performed.

The toolkit uses the Max/MSP visual programming environment[2]. Our library is available online and open for contribution[3] and is based on the FTM[4] and MuBu[5] libraries. A screenshot is reported in **Figure 3**. This architecture allows sound selection, triggering, and most importantly continuous manipulation of amplitude, pitch, and effects, articulated from user or object movement as captured on the sensors. The sensors are mounted by workshop participants on part of the body, on objects, or in the environment, as imagined in their scenarios.

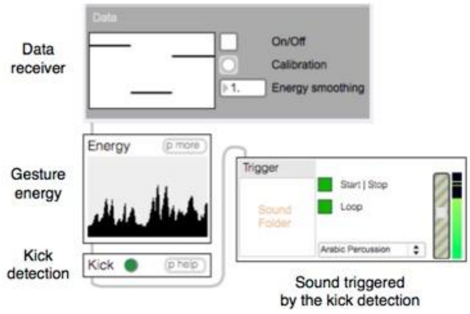

Figure 3. Gesture Sound Tookit software, showing modules which can be interconnected and reconfigured

Group Activity

The Gestural Sound toolkit was presented in a tutorial introducing general notions of gestural sound interaction followed by a short session where participants build simple interaction examples. With this basic guidance, each group created a storyboard of their chosen scenario and implemented using the toolkit. The participants were asked to define, find, or record sounds to be used, and define the actions or gestures involved in the interaction, and the consequences of these gestures on the sounds based on the imagined situation that has been chosen. This was done with minimal guidance from the workshop facilitators, who guided the participants in basic operation of the system and

[1] http://axivity.com/v2/index.php?page=product.php&product=wax3

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

[3] https://github.com/bcaramiaux/Gestural-Sound-Toolkit

[4] http://ftm.ircam.fr/index.php/Main_Page

[5] http://imtr.ircam.fr/imtr/MuBu

its technological constraints. The workshop ended with live performance and demonstrations of the final prototypes to the group, and a general discussion.

Data collection and analysis

All workshop activities were filmed. We collected graphical and textual descriptions from participants of their sonic incidents and scenarios. Two authors performed the analysis and annotated the videos against the graphical and textual descriptions. They then generated a table describing each step from sonic incidents (columns) to the realized project for each participant in each group (rows). This table was the basis to identify emerging interaction strategies. Finally, each participant completed a questionnaire at the end of his or her workshop.

RESULTS

Phase 1

This section presents results from the ideation phase of the workshop, participants' sonic incidents and imagined sonic interactions.

Sonic incidents

All participants across the four iterations of the workshop were able to describe one or two sonic incidents, with several describing more than three incidents.

Of the 61 total sonic incidents, and 57 were sounds produced by non-human events from the everyday. Of these, 20 sonic incidents referred to transport situations: "beep before tube's doors closing", "squeaking doors in the bus", or "bike hitting a manhole". 14 sonic incidents referred to domestic situations: "bubbling of oil while cooking", or "stormtrooper wake up alarm impossible to stop". Two other categories are: environmental sounds such as "wind" or "rain" happening in a particular situation such as "rain at the train station"; and electronic sounds such as "Skype ringing" while not being in front of the computer. Human-produced sonic incidents mostly involved social situations (8 sonic incidents) referred to such situation, for example "children playing football.

Every sonic incident involves a sound that was not produced by the participant but that happens in a situation in which the participant was an observer.

Interaction scenarios with sonic incidents

The second activity encouraged participants to imagine scenarios where they could actively interact with the sounds evoked in the sonic incident. We used two different strategies to invoke corporeal engagement with sound: 1) Sound interaction without volitional control, and 2) Volitional control using the superpowers metaphor.

From the set of 15 interaction scenarios generated by the first strategy, we took the textual description of the sound incidents and the subsequent interaction scenarios and traced their evolution.

- 9 scenarios are (graphical) **representations** of either the cause of the sounds or the actions on the sound on the participant. For example, reported Figure 4, a sonic incident was a "*Stormtrooper wake up alarm impossible to stop*" for which the interaction representation was a sketch with arrows pointing down and a pushing mechanism, an abstract view of the effect of the alarm on the participant.

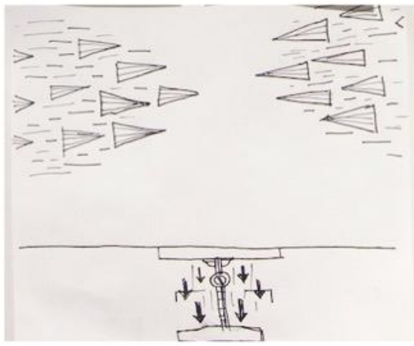

Figure 4. Sketch of sonic incident: *Stormtrooper Alarm*, showing effect of being awoken by an alarm clock

- 3 scenarios described **reactions** of the participants after hearing the sound from the sonic incident. For example, a sonic incident was "*cats jumping after [the participant] steps on it"* and the interaction scenario was "*stepping on cat, cat reactions* [sound], *my movements in reaction to the cat's reactions*" (Figure 5). These produced reaction scenarios kept the same situations in which the sonic incident occurred.

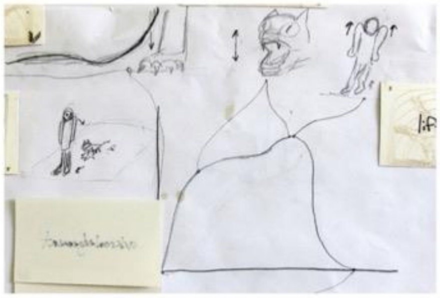

Figure 5. Sonic incident as reactions: *Stepping on Cat*, a series of reactions, first by cat, then of the user to the sound

- 1 scenario describes the **manipulation** of sound from body movements. The sonic incident was "*Squeaking ventilation in the workshop room*" and the imagined was a "*man controlling characteristics of sound by moving*"
- 2 are scenarios that are not related to the earlier sonic incidents. For example the sonic incident was "*Car's tires on wet asphalt*" and the imagined scenario was "*Springs connected together playing Jingle Bell*".

From the set of 26 interaction scenarios generated using the superpower strategy, we performed the same analysis, tracing the evolution from textual description to interaction scenarios. We observed differences across the scenarios imagined, finding that 22 scenarios involve both the sound and the situation in which the sound takes place in the corresponding sonic memories, while only 4 used just the sound, isolated from its initial situation. Of the former, we found differences in how the participants relate body movement to the sound material.

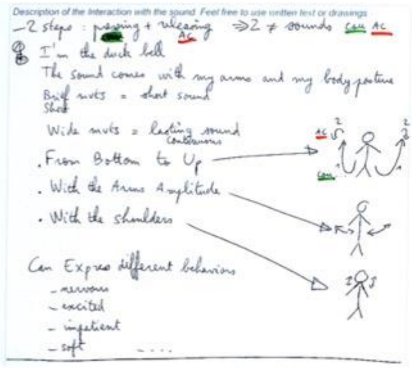

Figure 6. Substitution as interaction scenario: *Duck Honk*, user becoming the duck

- 3 scenarios described movements that **substitute** the sound or the cause of the sound. For example, a sonic incident was "*Duck honk on the bike that was inappropriate"* and the interaction scenario was "*Being the duck, limbs control different qualities of squeaking*" (Figure 6).
- 7 scenarios described gestures that **manipulate** sound parameters. For example, a sonic incident was "*Walking in the woods, snow cracks under his feet, breaking ground"* and the interaction scenario was "*Sound: Crack + Swoosh + thud; with actions: Crack/Crush by moving the fist + slide and stop using legs*" (Figure 7).

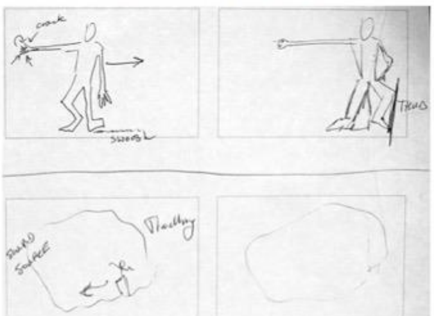

Figure 7. Manipulation in interaction: *Snow Cracks*, limb movements crushing snow, zooming into imagined actions

- 7 scenarios described movements that **conduct** sounds. This differs form the previous case by the existence of an explicit gesture vocabulary. For example, a sonic incident was "*Annoying sounds of neighbors' children playing"* and the interaction scenario was "*Transforming children's screams in music by conducting them as a musical conductor*".

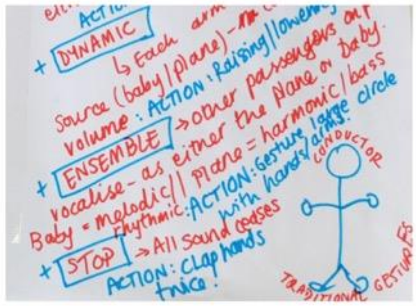

Figure 8. Reaction in interaction: *Laser Destroy Alarm* where a user's gesture conducts sound in reaction to sonic incident

- 3 scenarios described **reactions** of the participants after hearing the sound from the sonic incident (similarly to Workshop 1). For example, a sonic incident was "*Phone alarm + Clock alarm failing to wake her up"* and the interaction scenario was "*Destroying loud alarm with laser vision explosion*" (see Figure 8).
- The two last scenarios involved **unrelated relationship** to the actual sonic incident even if using the sound and situation. For instance, a sonic incident was "*Sizzling sound of oil in fraying pan"* resulted in the unrelated the interaction scenario, "*Sound to navigate through locations"*.

The strategy used in facilitating embodied sonic interaction, therefore had an impact on the action–sound relationships imagined by workshop participants in their interaction scenarios.

Phase 2

In the realization phase, each breakout group chose one scenario from their group to develop into a functioning prototype. They first created a realizable interaction scenario by storyboarding it, describing actions, sounds and interactions. They then recorded or searched online databases for sounds that approximated the sound of the incident. With this, they authored a movement/sound interaction using our hardware/software toolkit.

Despite the potential difficulty of working with interactive sound software, the high level abstractions and workflow of our gestural sound toolkit was generally well understood by the participants. During all the workshops, the participants were highly independent and asked for help from the facilitators only when they wanted a software feature that was not included in the toolkit, for instance a sound synthesis engine such as sine wave generator (IRCAM). This was facilitated by the modular architecture of the toolkit and also by working in breakout groups.

During the four workshops, 14 projects were realized. In 13 cases, participants produced fully working prototypes that were presented to the whole group, while in only one case participants were not able to complete a final implementation. In complement with this, only one project was realized without using sound material from the sonic incident activity in the first phase. Although all the 12 other projects made use of a recalled sound from sonic incidents, the final projects made different uses of the situation in which the sound from the sonic incident occurred.

There were two types of project – those that implemented a scenario, or part of a scenario, from the ideation phase, and others that implemented a scenario that used only the sound from the sonic incident and implemented a totally different situation and interaction than originally imagined.

Of the first type of project (8 total), an example includes: "*Hum of airplane revealed by baby crying*" and imagined "*conductor gestures, e.g. dynamic responding to raising/lowering hands*" as interaction mode. The prototype recognized three gestures. The first one triggers the hum of airplane, the second one start a baby crying, the last one stops the sounds. In this case, the participants found sounds in the Freesound[6] online sound database. During the demonstration, the participants placed the sensor on the hand. Accelerometer data was low-pass filtered to take out noise and then sent to the gesture recognizer. The recognized gesture was used as a selector for a sound in a playlists and subsequently played. This shows a conducting situation.

In another example, the sonic incident was "*vibration ring of phone on a shelf while sleeping*", which was characterized as "*wrong rhythm, it was like a call, instead it should have been like an alarm*". The imagined interaction was the "*Snooze action to fall asleep again and creating a sound that would suggest me as being awake while still sleeping"*. The group implemented a scenario in which after the clock alarm is heard, moving (mimicking the movement in the bed) against the clock activates a "snoozy melody". Subtle movements change the speed of the melody played back to help waking up. When moving towards the clock, the alarm sound plays back to wake up the user. Here, participants substitute the alarm mode of operation through actions related to sleep.

Of the second type of project (4 total), examples include a sonic incident "*Sound of filling water bottle, changing*" where the participant represented the action linked to the sound as "*Bottle being filled with water*" changing the pitch. The implemented prototype gives different sound feedback (based on the recorded sound sample of water poured in a bottle) according to the position of the arms. This resulted in an application, the "Yoga corrector" that facilitates adapting body position during a yoga exercise according to sound feedback similar to the rising pitch of the filling water incident. The sensor was strapped on the arm or on the leg. They used the variations in orientation of the sensor to control the reading cursor and pitch transposition. This shows how participants manipulated sound parameters through their actions.

From the 12 projects, of the two types, we found that the prototypes involved actions that conduct the sound, substitute to the sound cause or manipulate the sound. No interaction scenario from the first phase that involved actions in reaction to sounds was retained for implementation. Interestingly, all were from the workshops where the superpowers metaphor was used. We infer from this that the use of technology to realize scenarios has an effect on previously imagined action–sound relationships and is dependent on the metaphor (actions in sound or the metaphor of superpowers) used in the task from the first phase.

DISCUSSION

We have presented a series of workshops that investigate participatory and sound-centered methods for the design of sonic interactions. This approach proposes the sonic incident technique, and the notion of sonic affordances, as parts of an ideation process for generating ideas for embodied sonic interaction. Importantly, the methodology leverages on a non technology-centered approach for authoring action/sound relationships. From the proposed methodology, we highlighted three types of actions-sound relationships in the final prototypes: actions that conduct sounds, substitute the sound source, or manipulate sound parameters. Here we discuss the methodological contributions presented in this paper and we show that the workshops provide interaction models for sonic interaction design.

Sonic incidents and sonic affordances

The sonic incident technique was successful in facilitating users' thinking about sound in context. Participants tended to describe sounds that happen to them rather than sounds that they cause. The technique makes the participants aware of why sound was an important part of the incident, why they remember it and what would be the normal situation with this sound [28]. Each sound is thus contextualized in an idiosyncratic situation from participant's everyday life. Engaging the everyday of the participants is an important conceptual aspect of the technique as it can provide a context of use through the sonic incident itself. As such, sonic incident can be thought as a technique that could facilitate the design of situated interaction (as defined in [5]). With Sonic Affordance, we propose the notion that sound can invite action. It was explored in the second part of the Ideation phase of the workshops by asking participants to imagine corporeal engagement with the sonic incident.

The small, non-descript, sensing technology became a "non-object" that served a function without carrying a physical affordance. Objects afford user actions based on their form factor, shape, size, and textures. Similarly, sound can have prior cultural association, such as musical context in identifiable instrument sounds. By using a miniature sensor, the sensing technology itself did not offer physical

[6] http://freesound.org

affordances to influence the interaction imagined. By working with sound from the everyday, we minimized musical association that may have colored the resulting gestures. In so doing we were able to use the workshops to drive participants to focus on the affordances from the sound itself and not the interface used, hence, *Sonic Affordance*. The concept of a Sonic Affordance is useful as a way to think about the corporeal response that a sound may invite on the part of its beholder.

Participants in general were not accustomed to imagining interactive scenarios with sound. A critical aspect of the ideation process was therefore to aid the participants to think about acting in the situation of the sonic incident. Mentioning actions in relation to sound did not lead the participants to involve the body in the interaction. The metaphor of superpowers was more successful in generating physical action–sound relationships in the imagined sonic interactions. We used this metaphor in three workshops (Goldsmiths, IRCAM and Zurich), and interestingly faced questions about the meaning of the task. Participants were questioning from which perspective they have to imagine the interaction: "*Can I be the sound?*" or "*Am I listening to the sound?*".

Methodological contribution

In our workshop procedure, the ideation phase takes place without computers. This encourages participants to focus on sounds and their context, without influence of technology. Interactive technology is introduced only in the subsequent realization phase, after sounds, incidents, and scenarios have already been imagined. The sonic interactions imagined, therefore, were not technology-driven. The creation of the scenarios has been grounded in the concepts of sonic incidents, resulted affordances and imagined interaction scenarios.

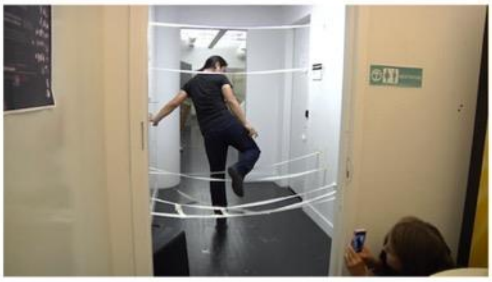

Figure 9. Physical constraints in the use of the Gesture Recognition System, the sensor is placed on the foot

Workshop participants were able to take the sonic interactions imagined in phase 1 and implement them using our toolkit. They overcame limits in their own technical knowledge to nonetheless use machine learning techniques in their prototypes. They were also tactful in working around limitations and constraints of the technology. For example in one prototype, participants transformed the physical space, creating an obstacle course to walk through to more clearly send distinct foot gestures and slowing down the user's walk to aid the recognition module of the toolkit in distinguishing gestures to trigger different floor crackling sounds (Figure 9).

It was a challenge to present advanced sound programming and interaction authoring techniques as just one part of a workshop program. Given that the workshop participants had no prior experience with the Max/MSP software, we were mindful that the workshop not become a tutorial on use of that software. The library of high-level modules we designed is effective in giving access to powerful, reconfigurable sound interaction functionality in a highly accessible manner.

Emerging interaction models for sonic interaction design

In the three workshops where volitional control of sound was explicitly mentioned, the scenarios that were generated showed interaction scenarios involving movements that *substitute, manipulate,* and *conduct sounds*, and their technology implementations capture user movements that reflect this. We propose these action/sound relationships as interaction models for sound. More precisely, these interaction models are described as:

- **Substituting**: the movements substitute the cause of the sound or the sound itself. Possible actions are defined by the sound itself and not constrained by an interface. Then there is a direct modulation of some aspect of the sound (volume, brightness, playback speed) by the participant's actions.
- **Manipulating**: where movements manipulate the sound. The possible actions in interaction should be let to the choice of participant/user. They can be constrained by the interface. Then there is a direct modulation of the sound through the participant's actions, similar to the previous model.
- **Conducting**: there is a semantic relationship between the participants' gestures and the sound. The gestures should be free to be chosen by the user but they are, eventually, part of a finite set of gestures (a vocabulary). Then there is a direct relationship between a symbolic feature of gestures (what gesture, how it is performed) and the sound.

These three interaction models provide respectively unique operational descriptions that can be used by interaction designers or developers to build innovative sonic interfaces that respond to particular contexts. Further, interaction designers can use these models to characterize interaction according to descriptive (incorporating existing interaction techniques), generative (facilitating new interaction techniques) and evaluative (comparing techniques) powers [5] and therefore to enhance the specificity with which they respond to a given sonic interaction design problem.

These models enhance the design process by describing distinct approaches to the design of a sonic interface, establishing criteria that can be used in the early stage assessment of a sonic design problem. The substitution model focuses the designer on sound and its source; manipulation addresses controllable aspects of sonic artifacts, such as instrumental control; and finally conducting introduces the symbolic and semantic meaning of gestural interaction with sound.

The models are further distinguished by the way in which they can be evaluated: while conducting and manipulating may involve quantitative measures to compare interaction techniques (time completion, accuracy), substituting necessitates a qualitative explanation of the relevance of chosen actions to an associated sound, its cause and its context.

Innovation in sonic interaction design

Norman and Verganti [30] argue that human centered design tends to produce incremental innovations that are constrained by users' past experiences. They further argue that radical innovation requires technological change or meaning change. The work presented does not introduce technological change: accelerometer sensors are commonly available and gesture recognition algorithms in the toolkit had been developed in our prior research. Meaning change, however, is explicitly addressed, by encouraging participants to think about, discuss, and manipulate sound through our methodology. Our method aids workshop participants without specialist audio engineering or musical training to work with sound, representing a change in meaning of sound for those participants. The process identifies sonic incidents and translates them into embodied interaction concepts and prototypes. Differences in the emphasis in the task (volitional or non-volitional), led to different interaction scenarios and models. This method can be replicated, and leveraged, by designers to expand the meaning and utility of sound in consumer device interaction.

CONCLUSION AND FUTURE WORKS

In this paper we presented a series of four workshops that explore the rich potential of action–sound relationships and their use in designing interactive systems where sound is a fundamental part of the interaction. The workshop structure is comprised of ideation activities including the *Sonic Incident* technique as well as graphical, textual and vocalized sound representations; followed by realization activities including scenario building and prototyping. Participants generated final projects that implemented three principal interaction models: *conducting*, *manipulating* and *substituting*. These three interaction models can be operationalized by interaction designers and developers building innovative sonic interfaces and products.

Sound in the user interface has heretofore been made up mostly of sound bites, events and triggers. The sonic interactions of the sort presented here involve continuous interaction between physical action and sound, putting the user in an action–perception feedback loop. Each of the three models described above is the basis for an interaction strategy within this feedback loop, which can help designers build better sonic interfaces that respond to specific circumstances and contexts. Together, these methods an interaction models can help designers to address sound as continuous and informative phenomenon in the interfac rather than as a simple display mode for alerts.

The research presented in this paper will be useful fc interaction designers to conceive future products th integrate sound in the interface in a robust and continuou fashion. The proposed interaction models are not limited t sonic applications and might be considered for interactio with other continuous phenomena, such as light, and movin image. These interaction models fit into interactio paradigms that go beyond the desktop to object environments, and sounds, in our everyday lives.

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APPENDIX E: GLOSSARY OF TERMS

Accelerometer: An electromechanical device measuring static or dynamic acceleration forces on a body, calculated by the change in speed divided by time. Accelerometers are used in various applications, from medical research to engineering and product design, and are useful devices for measuring motion, vibration and orientation of an object or body in space.

Acoustemology: A concept developed by the ethnomusicologist and anthropologist Steven Feld, who describes it as the union of acoustics and epistemology, which investigates the "primacy of sound as modality of knowing and being in the world" (Feld 1996).

Acoustic ecology: A discipline which emerged in the late 1960s with the work of Raymond Murray Schafer and collaborators at Simon Fraser University, Canada. It focuses on studying sound as a way to understand relationships between living beings and their environment, including the impact of human technologies and cultural practices.

Affordance: Affordance is a concept originating from ecological psychology by James Jerome Gibson (1979). It describes the possibilities of actions that are latent in the environment which are available to a capable animal. These are dependent on the environment and by the specific sensorial and physical characteristics and capabilities of the animal. This concept has been exploited in design for usability purposes.

Bodystorming: A technique used in interaction design research. It provides a focus on users' imagination of planned gestures and body movements involved in the intended scenarios of interactions. It helps to provide in-depth information about experiential, contextual, embodied and enacted aspects of the scenarios. It is useful for early phases of design, such as in problem-definition and to imagine interaction scenarios as a replacement for, or in addition to, textual and graphic descriptions.

Critical Incident Technique: A set of procedures in psychology that elicit specific memories related to particular recent moments experienced by the subject, focusing on aspects of failure and/or success of such experiences. Created by psychologist John Clemans Flanagan (1954), the critical incident is useful in research for collecting and analysing data regarding behaviour, emotions and actions undertaken in particular situations.

Cycling'74 Max: Formerly known as Max/MSP, is a programming environment for interactive media. Rather than writing lines of code, Max is based on a visual, modular-like system. Programs are coded in Max "patches" by interconnecting "objects" using virtual cables. Each object is a self-contained program which computes individual functions and operations. Currently licensed by Cycling'74, it is widely popular among artists, musicians, composers and interaction design researchers due to the large availability of modules specialised in creative programming and real-time analysis of sensor data.

Embodied cognition: A theory which sees cognition as deeply dependent on the physical features of the agent's body and rooted in its sensorimotor system. In interaction design, this form of cognition is involved with "the creation, manipulation and sharing of meaning through engaged interaction with artifacts" (Dourish 2004, p.126).

Ensounded: A concept conceived by anthropologist Tim Ingold (2011), which describes our life as being constantly immersed in the continuity of the presence of sounds around us, literally *within* sound.

Ergo-audition: A mode of listening described by Michel Chion (2010) which reveals our sense of agency in the production of sound as a direct consequence of our own bodily actions and the physical interactions with surrounding materials and objects.

Gesture to Sound Mapping: In an interactive system, a designed relationship between the variation of a movement performed by a user and the playback of a sound through a sound synthesis engine.

Human-Computer Interaction (HCI): A research field that studies how humans interact with computer technology. The Association for Computing Machinery (ACM) defines HCI as a "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewett 1992).

Interaction scenarios: Past, present or future descriptions of interactions between users and systems, as recounted and imagined by users and/or designers. These descriptions may include actions performed by a user, imagined reactions, the expected goals, behaviours, emergent problems and situations.

Machine Learning: A field of computer science which studies the creation and programming of algorithms that can automatically be learnt from a set of input data and make predictions and decisions about the possible outputs.

Modular Design: A design approach in which a system is seen as a collection of interconnectable blocks of functionality (modules) and in which their order can be chosen arbitrarily by the designers and/or users.

Participatory Design: A co-operative approach to design, in which designers seek to actively involve all the possible interested subjects (e.g. institutions, end users, researchers, policy makers and others) in the design process.

Phenomenology: A philosophical discipline that studies processes of consciousness and experience through an analysis and philosophical discussion of perception and interpretation of phenomena, considered from a first-person perspective. It deals with interpretation of experience, with an emphasis on perception, bodily activity and context. Also, a philosophical movement originating from the 20th century and discussed by Edmund Husserl, Martin Heidegger, Maurice Merleau-Ponty, Jean-Paul Sartre, et al.

PhISEM: Physically Informed Stochastic Event Modelling is an algorithm developed by Perry Cook and Gary P. Scavone (1996) for generating sound through a computer simulation of the collision of multiple independent sound producing objects. It is used for generating shaker-like sounds.

Physical Modelling synthesis: A sound synthesis technique based on mathematical models of sound production mechanisms. These models attempt to replicate the laws of physics involved in the interactions between the different materials generating a sound, such as for example, a finger softly picking a nylon string of an acoustic guitar with a wooden sound board.

Sample-based synthesis: A type of sound synthesis which is based on the playback of a previously recorded sound stored into an accessible memory of the hardware or software synthesiser. Different types of playback operations can be performed, such as slowing down its playback speed, jumping between different portions of the recording, reversing the playback, as well as many others.

Sonic Interaction Design: Sonic Interaction Design (SID) is a design field which triangulates sound design, interaction design and computing to exploit the opportunities given by the relationships between auditory perception and human movement. It provides focused ways in which sound is considered as a design medium, which is particularly meaningful for aiding a desired human-computer interaction.

Sonification: The process of translating data into audio, with the purpose of aurally communicating information about the data itself. It exploits auditory perception and helps to retrieve temporal and spatial relationships within the data. An example of sonification is the principle of the working mechanism of parking sensors fitted in some cars. The increase in the rate of the beeping, heard by the driver while manoeuvring the car, indicates that the car is moving closer to an object.

Sound object: Term originated by the French composer Pierre Schaeffer. In electronic music analysis and composition, a sound object describes a basic unit of analysis of an acoustic or recorded sound (Chion 1983). For composer Curtis Roads, a sound object is a sonic entity that has a perceivable unique singularity defined by a set of defining acoustic properties varying over a period of time (Roads 2015).

Sound Studies: A field of research which studies the concept of "sound" and how this is treated across different disciplines, such as sociology, anthropology, musicology, political studies, sound art, medical science, architecture, cinema and many other fields.

User-Centred Design (UCD): A methodological approach and design attitude in which the end-users are involved in the process of design. The origin of the term is attributed to Donald Norman who in 1999 described it as a design "philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable" (Norman 1986). An understanding of users' opinions, needs and context is the central core of UCD research, alongside with their identification and modalities of involvement

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