Amplifying Actions
Towards Enactive Sound Design

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Abstract

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Recently, artists and designers have begun to use digital technologies in order to stimulate bodily interaction, while scientists keep revealing new findings about sensorimotor contingencies, changing the way in which we understand human knowledge. However, implicit knowledge generated in artistic projects can become difficult to transfer and scientific research frequently remains isolated due to specific disciplinary languages and methodologies. By mutually enriching holistic creative approaches and highly specific scientific ways of working, this doctoral dissertation aims to set the foundation for Enactive Sound Design. It is focused on sound that engages sensorimotor experience that has been neglected within the existing design practices. The premise is that such a foundation can be best developed if grounded in transdisciplinary methods that bring together scientific and design approaches.

The methodology adopted to achieve this goal is practice-based and supported by theoretical research and project analysis. Three different methodologies were formulated and evaluated during this doctoral study, based on a convergence of existing methods from design, psychology and human-computer interaction. First, a basic design approach was used to engage in a reflective creation process and to extend the existing work on interaction gestalt through hands-on activities. Second, psychophysical experiments were carried out and adapted to suit the needed shift from reception-based tests to a performance-based quantitative evaluation. Last, a set of participatory workshops were developed and conducted, within which the enactive sound exercises were iteratively tested through direct and participatory observation, questionnaires and interviews.

A foundation for Enactive Sound Design developed in this dissertation includes novel methods that have been generated by extensive explorations into the fertile ground between basic design education, psychophysical experiments and participatory design. Combining creative practices with traditional task analysis further developed this basic design approach. The results were a number of abstract sonic artefacts conceptualised as the experimental apparatuses that can allow psychologists to study enactive sound experience. Furthermore, a collaboration between designers and scientists on a psychophysical study produced a new methodology for the evaluation of sensorimotor performance with tangible sound interfaces.

These performance experiments have revealed that sonic feedback can support enactive learning. Finally, participatory workshops resulted in a number of novel methods focused on a holistic perspective fostered through a subjective experience of self-producing sound. They indicated the influence that such an approach may have on both artists and scientists in the future. The role of designer, as a scientific collaborator within psychological research and as a facilitator of participatory workshops, has been evaluated.

Thus, this dissertation recommends a number of collaborative methods and strategies that can help designers to understand and reflectively create enactive sound objects. It is hoped that the examples of successful collaborations between designers and scientists presented in this thesis will encourage further projects and connections between different disciplines, with the final goal of creating a more engaging and a more aware sonic future.

Contents

List of Figures

List of Tables

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Chapter 1

Introduction

This chapter introduces the need to expand existing design practices with an alternative approach grounded in enactive theories. The premise is that a shift from reception-based to performance-grounded sound design can be achieved only if scientific and artistic practices are better integrated within design. I outline the conceptual background for an enactive approach to interaction design, present the overall aims and methodology of this doctoral thesis and provide a short overview of chapters.

1.1 Doing with Sound

Each of our movements generates sound, sometimes loud, sometimes quiet, sometimes inaudible even to ourselves. As we step on the gas pedal in our car, the roaring machine responds to our pressure, as we walk down the street, the rhythm of our steps resonates in our body, as we chop carrots, the knife cuts through the vegetable to hit the cutting board. In each of these everyday situations, we are the cause of the sound, the reason for its sounding. We are not only listening, but immersed in and guided by the sonic responses of the world; we are *doing with sound*.

Yet, this essential part of our everyday life has been sparsely considered within scientific and design communities that have preferred to focus on the listening subject (Chion 1998; McAdams and Bigand 1993). Artists and musicians, however, have explored *doing with sound* in expert performance contexts as well as in installations engaging non-expert participants (Cadoz 1988; Kahn 1999). More recently, researchers developing musical and haptic interfaces have been using enactive approaches to human-computer interaction or HCI (this and other term can found in the Glossary at the end of this dissertation) in order to better integrate users' sensorimotor experience in their design (Enactive Network 2004; McGookin and Brewster 2006; Poupyrev et al. 2001; Essl and O'Modhrain 2006; Leman 2007). Scientists have been working to prove that sonic feedback tightly coupled to user movement can increase user control over an interface (Williamson and Murray-Smith 2005), a tool (Rath and Rocchesso 2005), and a physical activity (Effenberg 2005).

Still, these efforts of the artistic and scientific communities remain rather disconnected due to their different methodologies and approaches (see Figure 1.1). On one hand, artists develop situations that engage physical activity through sound, and, by doing so, gather tacit knowledge about the subject. This type of implicit learning ('knowing how') can be contrasted with explicit knowledge ('knowing that'), the one which is based on a collection of data that can be codified and stored, rather than on bodily performance (Dienes and Perner 1999; Polanyi 1967). However, such embodied knowledge, acquired through processes of creation of an artwork and observation of its use, is implicit and hard to structurally organise and to transfer. On the other hand, scientists continue to provide new facts about the complexity of body-mind-environment

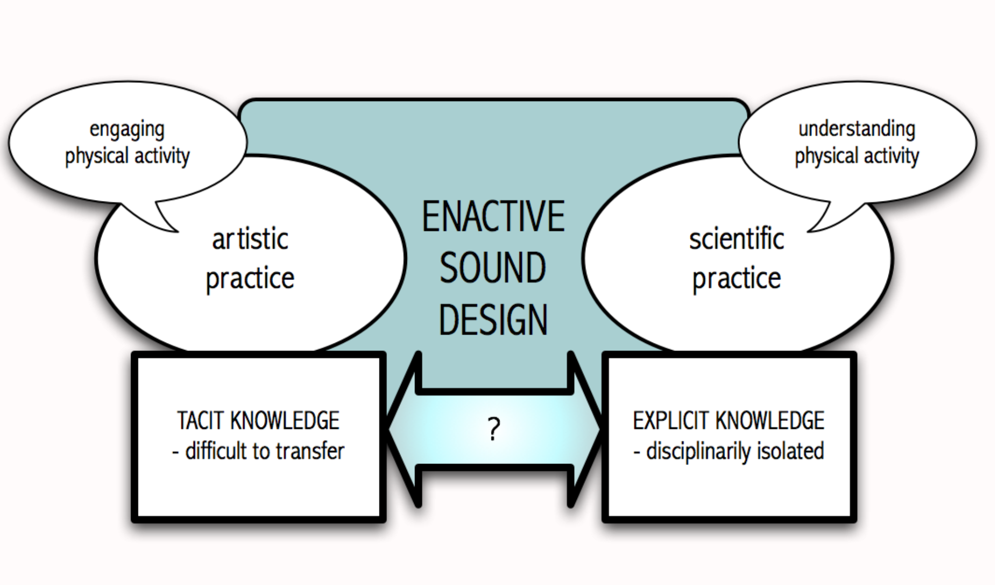

Figure 1.1: Whereas artistic practices engage physical activity and build upon the tacit knowledge of the artist, the scientific disciplines explain the working of sensorimotor processes resulting in concrete factual knowledge. The exchange between these domains is weak.

relationships. But these findings often remain isolated due to specific disciplinary languages and narrow research questions, making it difficult to connect them into a larger design framework.

As a result of this gap, strategies for creating sound that engages bodily movement are sorely lacking. While a few pioneering examples of sonic artefacts that foster enactive audience/user participation do exist, and while scientific research continues to make progress on the topic, design practice and education are still bound to a traditional understanding of sound. In order to enable new generations of designers to practically address the transdisciplinary questions that the self-produced sound poses, a more solid foundation of design methodologies needs to be developed. I argue that such methodologies must draw on different bodies of implicit and explicit knowledge in order to put the focus on performative, rather than solely listening aspects of self-producing sound.

1.2 Premise and Conceptual Foundation for Enactive Sound Design

> We propose as a name the term enactive to emphasize the growing conviction that cognition is not the representation of a pregiven world by a

> pregiven mind but is rather the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs. (*The Embodied Mind: Cognitive Science and Human Experience*, F. Varela, E. Thompson and E. Rosch 1992, p.9.)

In this dissertation, I introduce the notion of **Enactive Sound Design** in order to shift the research perspective from the dominant reception-focused sound creation towards an understanding and engagement of the experience of *doing with sound.* The main premise is that such a shift can be best enabled through methods that bring together scientific and design practices.

The goal of such an enactive approach is *to engage bodily action* by closing, enhancing and extending the sensorimotor loops of user experience. I argue that this is different from the *responsive* design that focuses on the property of the medium, and from the HCI approach grounded on a cognitivist approach to user experience. By contrast, the *enactive* design works with users' embodied experience and its loops of sensorimotor activity. Thus, rather than developing an interface, enactive design is about shaping an embodied sensorimotor process that is supported by the object that enables it. Such an approach is directed towards challenging the technical understanding of interaction as input triggering some form of output, and towards supporting a more directly situated, less abstract, and hence, highly experiential framing of the world.

Thus, in this thesis, I follow an enactive prospective in order to enable a physically more engaging use of interactive objects through self-produced sound. While concepts such as enaction are elaborated within the main text of this dissertation, the Glossary that can be found at the end of this document, helps the reader refer to different ideas and approaches.

The conceptual basis for enabling this alternative approach to sound design can be found in theories of embodiment and enaction within the disciplines of psychology, philosophy and biology, among others. The psychologist James J. Gibson's ecological approach to perception was among the first to posit a theory of 'perception as action', in contrast to past views of perception as a purely cognitive process of a priori, informatic-based representations (Gibson 1968, 1979). Following his work, the philosopher Alva Noe stated:

> Perceptual experience acquires content thanks to our possession of

> bodily skills. What we perceive is determined by what we do (or what we know how to do). (Noe 2004, p. 5).

Thus, the central argument is that the perception, and thus the acquirement of knowledge, is possible only if explorative action is engaged.[1]

Such an explorative and performative relationship between the physical world and an agent, Gibson argues, is grounded in the environment that through its affordances invites an agent's action. For example, a stone of a large size makes it possible for a human to sit on it or to break it with a hammer, but due to its weight does not allow it to be moved with bare hands. Because affordances emerge through the relationship between agent and environment, many of them are unknown and yet be discovered. The psychologist Donald Norman (Norman 1988) was aware that engaging such discovery was an exciting challenge for designers who shape the world of artificial affordances. He argued that the perceived affordances, those that tell the user what can be done with an object, were the most important for designers, because through them the user's activities could be guided and novel meanings could be created.

It was the cognitive scientist and biologist Francisco Varela who suggested that meaning was an act in which the perceiver's interaction with the external world was guided by direct action in local situations:

> In a nutshell, the enactive approach underscores the importance of two interrelated points: (1) that perception consists of perceptually guided action; and (2) that cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided. (Varela 1999, 12)

In his theory of enactive cognition, interaction was predicated not only on a body responding to a specific, concrete circumstance, but also through spatio-temporal processes in which that body came to act within and onto the world (Varela 1999; Varela et al. 1992). Thus, the concept of enactive cognition can be seen as dependent on how the world helps guide or modulate action that, in turn, continuously results in the body realigning and remaking that world.

[1] Important findings in this area come from child development psychology, as discussed in the following chapter (see for example (Piaget 1954; Bruner 1966; Gibson 1988)).

Such close coupling between action and perception is at the conceptual basis of enactive design.

Following Varela's and other enactive theories, and with the aim of fostering a new, enactive approach to HCI, a number of researchers formed a European network of excellence called ENACTIVE. They described enactive experience as 'characterised by a closed loop between the natural gestures of the user (efferent component of the system) and the perceptual modalities activated (afferent component)' (Enactive Network 2004). Their goal was to exploit bodily action in order to store and acquire knowledge and to enable the development of interfaces which can: 'recognise the gesture of the user at the beginning of the action and are able to interpret the gestures (in terms of intentions, skills and competence) and to adapt to them in order to improve the users performance'. (Objectives, Enactive Network website, 2004). The network conducted a number of perceptual experiments and developed novel instruments fostering research in haptic and musical interface design (Luciani et al. 2005). However, the overall methodology was grounded in traditional perceptual methods and control engineering, and thus made the integration of novel approaches to studying and designing enactive experience difficult.[2] While the network argued that 'enactive or sensorimotor feedback loop makes the interaction a process, a practice, a behaviour rather than an accomplishment of the task', (Enactive Network 2004), most evaluation methods followed precisely the time efficiency in accomplishing an experimental task as the measure of the performative qualities and often disregarded the basic principles of enaction, such as situatedness, in order to satisfy the already established rules of scientific disciplines. Thus, the effective application of enactive principles to interfaces has been arguably limited by a lack of suitable creation and evaluation methods.

1.3 Aims

This lack of methods grounded in an embodied approach informed the aims that guide this doctoral investigation:

- Aim 1: to expand the existing frameworks for reception-centered sound design through an enactive approach

[2]During the 4th Enactive conference, several discussions on the appropriateness of the research methods used have been raised by artists including Simon Penny, Ted Krueger and myself (see website for the conference program http://acroe.imag.fr/enactive07/).

- Aim 2: to identify critical issues that could foster an alternative design approach focused on engaging bodily action
- Aim 3: to formulate and test methods for conceptualizing and creating enactive sound artefacts
- Aim 4: to integrate design and evaluation methods for enactive sound artefacts
- Aim 5: to explore and evaluate the role of the designer within interdisciplinary teams and projects
- Aim 6: to develop participatory methods based on an enactive approach to sonic interaction
- Aim 7: to evaluate if the developed participatory exercises helped construct necessary bridges between artistic and scientific communities

Each of the chapters addresses one or more of these aims within the general premise of the thesis that the foundation of Enactive Sound Design can be best developed if grounded in combining suitable scientific and design methods that integrate an embodied perspective (see Figure 1.1 that provides a synoptic overview of aims and methods) .

1.4 Methods and Methodology

> If the same methodology was used generally in all fields we would have the key to our age: seeing everything in relationship. *Vision in Motion*, Moholy-Nagy 1969, p.96)

As interaction designer working within a scientific context, I conducted this doctoral research stimulated by the potential of self-produced sound to engage a more physical interaction with our world. The methodology was informed not only by design, but also through an ongoing discussion and collaboration with artists, psychologists, performers and computer scientists. As a result, the development of methods for engaging enactive sound experience presented in this thesis was informed by scientific, artistic and design disciplines.

The design theorist John Christopher Jones described design methods as

AIMS	METHODS	CHAPTER
1. expand the existing frameworks for reception-centered sound design through an enactive approach	◉ literature survey on enactive theories and scientific findings on sensorimotor experience ◉ comparative analysis of projects using sound to engage physical movement and audience participation	Introduction Chapter 2
2. identify critical issues that could foster an alternative design approach focused on engaging bodily action	◉ literature review of sound interfaces and products ◉ comparative analysis of existing sound design strategies	Chapter 2 Chapter 3
3. formulate and test methods for conceptualizing and creating enactive sound artefacts	◉ desktop research on basic design and interaction gestalt ◉ video documentation and analysis ◉ adapted task analysis ◉ functional prototype development	Chapter 4
4. integrate design and evaluation methods for enactive sound artefacts	◉ psychophysical auditory perception experiments ◉ functional prototype development	Chapter 5
5. explore and evaluate the role of the designer within interdisciplinary teams and projects	◉ participatory observation and group discussions ◉ informal interviews with psychologists and workshop co-organizers	Chapter 5 Chapter 6
6. develop participatory methods based on an enactive approach to sonic interaction	◉ participatory and direct observation within workshop setting ◉ video ethnography and interviews with workshop participants and organizers	Chapter 6
7. evaluate if the developed participatory exercises helped construct necessary bridges between artistic and scientific communities	◉ questionnaires for workshop participants ◉ group discussions at the end of the workshop	Chapter 6

Table 1.1: Overview of aims, methods and chapters

> ...techniques which enable people to go beyond their first creative ideas, to test their designs in use or simulated use, to collaborate in creative activity, to lead design groups and to teach and to learn designing. (Jones 2001)

Currently, within the field of interaction design, there is a gap between hard measurement-based methods and soft creation-based practices.[3] The former deal with the evaluation of usability, emotion and performance through psychophysical experiments, while the latter follow non-transparent creative processes. Indeed, as others have argued:

> most sound design methods for non-speech sounds in auditory interfaces are based on empirical knowledge, often resulting in sounds derived from random selection or the personal preferences of the designer. (Murphy et al. 2006)

Thus, the structured processes for understanding and designing the material qualities of an interactive object (its behaviour, shape, colour, sound, texture ...) and ways in which those affect physical and social context, are lacking (Maze and Redström 2005). Therefore, I propose that the development of successful enactive sound artefacts may depend on the successful combination of hard measurement-centred methods and soft creative practices.

While conceptual tools exist to address similar transdisciplinary issues, they are difficult to transfer to the design of sound for action. Thus, the practical portion of this thesis called for the development of new design-centred methods (for an overview of methods used, see Figure 1.1). Those practical issues can be divided into three areas of practice-based research: the creative methods presented in Chapter 4, the evaluation methods discussed in Chapter 5 and the educational methods described in Chapter 6. These steps allowed me to accomplish identified aims and to showcase the possible practices for Enactive Sound Design.

The first area of the practical research concerned ideation processes. It was grounded on basic design methods adapted to self-produced sound experiences and combined with classical usability methods. Following the predecessors of

[3]Note that this dissertation explores basic perceptual and methodological questions, and thus I am not discussing ethnographic practices that must be applied in projects with a specific socio-cultural context and a defined user group.

basic design, an existing kitchen setting was used to acquire an analytic and embodied knowledge of self-produced sound. Different kitchen activities were analysed using task analysis in order to facilitate the reflective process for the designer and to identify design materials. These were than combined in a matrix resulting in a number of abstract sound artefact concepts. At this stage, physical prototyping methods were used to identify the best technical and design solutions. One of these was further developed into an experimental apparatus called Spinotron that was used in the next evaluation stage.

The second part focused on the evaluation of the physical performance of the user guided by sonic feedback. While key questions emerged from design concerns, they had to be adapted to the existing experimental methodology from the auditory cognition field. Because of the highly experimental and risky character of the psychophysical procedures defined, constant feedback between the scientific and design team was necessary. Thus, although many experimental steps were defined in the beginning, the specification of the methodology was an emergent process which resulted in a case study for the evaluation of enactive sound performance, showcasing the problems encountered and their solutions.

Finally, the third area of the practice-based research explored participatory methods for Enactive Sound Design within different educational contexts involving participants of different age and professional background. During the six years of this doctoral research, a number of exercises and methods were iteratively evaluated using interviews, questionnaires and video ethnography. Existing participatory methods were extended to include the senses of sound, touch and movement, as well as contextual and situated experience. In addition, the evaluation of the workshops allowed for identification of practices that enabled a temporary dissolution of disciplinary boundaries and a deeper understanding of the designer as the facilitator of an interdisciplinary collaboration.

1.5 Chapter Overview

- Introduction

  The premise, the aims and the methodology of this doctoral thesis are introduced. I outline the conceptual background for enactive design and provide a short overview of the following chapters.

- Chapter 1: Self-Produced Sound

  What is an enactive sound experience and what is its relationship to digital technologies? This chapter unpacks the notion of enactive sound experience by examining current scientific research and by reviewing artistic explorations that exemplify ways of engaging bodily interaction through sound. A number of key aspects for the design of enactive sound are identified. Selected projects demonstrate how technology can increase the materiality of sound and how sonic feedback can change our perception of material world and thus strongly affect the way we act on and within it.

- Chapter 2: Existing Design Approaches to Interactive Sound

  This chapter asks why embedding sound in everyday objects and how has this been done in the past. A comparison of the existing design practices presented shows the practical issues that block a more performative and physical uses of sound. I identify challenges that remain to be addressed in order to establish the basis for an alternative approach to sound, which is focused on engaging physical action. The functional and social benefits of sonic medium for such physical and exploratory engagement are identified.

- Chapter 3: Creative Basic Design Methods

  The creation of enactive sound interfaces has not yet been addressed in a structured way, and this chapter aims to practically tackle this problem from a design perspective. I propose and evaluate a set of methods that can allow the designer to tacitly engage with self-produced sound in order to explore the complex relationships between sound and action.

- Chapter 4: Psychology Evaluation Methods

  Most perceptual experiments in the field of auditory cognition are carried out in the context of passive listening, and methods to evaluate *doing with sound* are lacking. How can designers contribute to defining new evaluation strategies for enactive sound? This chapter presents the experiments on sensorimotor performance and demonstrates a close collaboration between designer and scientists that resulted in evidence supporting the argument that sound can support enactive learning.

- Chapter 5: Participatory Education Methods Creating contexts for collaboration and the inclusion of designers in research on enactive interfaces is still a challenge. Structured scientific and engineering approaches are intimidating for young design researchers whose knowledge is still mainly tacit. How can this tacit knowledge be shared with other disciplines? The chapter presents methods that allow participants from different fields to explore their subjective experience, to observe social and physical phenomena and to find an expressive way of imagining sonic futures.

- Conclusion

  The last chapter sums up the results of this doctoral dissertation and outlines future steps and research areas to be further explored. I present results of practical experiments, namely novel strategies and methods for designing, evaluating and teaching Enactive Sound Design that have been formulated and evaluated in this dissertation. I show that a new methodological basis for Enactive Sound Design can begin to take shape by working with a challenge of connecting scientific and creative practices.

Chapter 2

Self-Produced Sound

In this chapter, I explore the experience of producing sound through the use of analogue and digitally-augmented objects. I analyse aspects of enactive experience and discuss how it can be engaged through interactive sound technologies. The notion of enactive sound is unpacked by discussing sensorimotor learning, willed action, multisensoriality and continuity involved in sound production. Through an analysis of selected projects, I show that interactive technologies have the potential of increasing the malleability of sound as material and thus, enhancing the physical engagement of the user with this medium that is usually perceived as ephemeral. Finally, I propose that by modulating user perception through sound, designers can affect user action and that such enactive loops have been scarcely used in design.

2.1 Introduction

The contemporary cultural and commercial forces that shape the conditions of sonic experience limit users' interaction to listening. Consider the highly constrained cinematic context: the audience is confined to a chair, intently focused on the screen and almost completely immobile. Nobody is involved in sound creation; rather, sound is consumed as a part of the movie. The architecture of the concert halls, opera houses and cinemas, and associated social habits constrain human movement so that maximum attention can be given to the reception of auditory and visual stimuli. In other words, sound has been designed to be listened to, rather than interacted with.

However, performative aspects involved in the self-production of sound are highly relevant for interactive contexts and have not yet been explored in design. In this chapter, I propose that an enactive perspective is needed in order to enable the use of self-produced sound to its full potential. To accentuate this perspective, I delineate the notion of enactive sound by identifying the perceptual and experiential aspects that make such sound unique. I then examine how these qualities have been addressed in a number of projects using computational artefacts. I show that self-produced sound is suitable for supporting existing physical movements, and propose that it may be deployed to teach new gestures. I argue that continuous feedback caused by willed action plays an essential role in such learning, and that this can be (and needs to be) shown on a practical level.

The chapter is divided in two parts in which:

1. I propose Enactive Sound Design as an alternative design framework and discuss the experience of self-produced sound in manipulation of analogue objects;

2. I examine how technology has been used in art and design projects, to shift the focus from listening to doing through sonic feedback.

The main contributions presented in this chapter are:

- framing and definition of Enactive Sound Design

- identification of key qualities of enactive sound: sensorimotor learning, willed action, multisensoriality and continuity

- analysis of projects exemplifying how those qualities can be shaped

- evidence that interactive technologies can increase materiality of sound and thus engage embodied action

The methodological and conceptual challenges identified in this chapter constitute the motivation for this doctoral research.

2.2 What Is Enactive Sound Design?

2.2.1 Listening to Self-Produced Sound

In the past, various types of listening have been proposed within scientific and design communities. They can be generally grouped into semantic and causal types of listening (Schaeffer 1966; Chion 1998).[1] During semantic listening, a person uses a code to interpret the meaning of sounds, as for example in an alarm sound that communicates urgency. In contrast, a situation in which a listener attempts to gather information about an event is labelled as causal listening. The latter occurs when we listen to the ebb and flow of daily life or perform activities that cause sound. Thus, it is also called everyday listening (Gaver 1993).

2.2.1.1 Psychophysics of Everyday Listening

During such listening, we recognise physical events that take place in our surroundings. Information about how an event has occurred is carried through air disturbances to reach our ears (e.g. From which location? What was the intensity?). The way in which listeners perceive their sonic worlds, extract information from heard sounds, and interpret them to identify a specific event can be examined through psychophysical experiments. Psychophysics is the scientific field that explores the relationships between physical stimuli (the properties of a physical object or event) and the sensory attributes perceived by

[1] These terms have been used by the composer Pierre Schaeffer, while others such as the sound theorist Michel Chion called them figurative and/or coded listening. Other types of listening include musical listening, in which certain structures are contemplated by the listener, and reduced listening in which a listener perceives sounds without reference to their source or meaning.

a human (perceptual sensation) (Gescheider 1997). The main goal of psychophysics is to *quantitatively* define the response of an organism to a physical event. More specifically, the psychophysics of sound explores the relationship between the mechanical properties of an object involved in sound production and the perceived attributes of that same object (see Figure 2.1 with the auditory processing diagram from (McAdams and Bigand 1993)). The relationship between physical and perceptual is the key to understanding the impact of newly designed objects on the human experiences they engender.

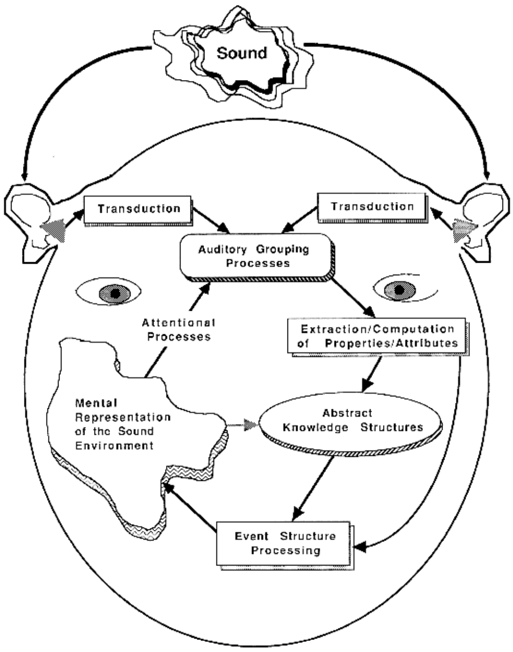

Figure 2.1: Diagram showing the main types of auditory processing and their interactions. Reproduced from (McAdams and Bigand 1993)

This relationship affects the interpretation of auditory information based on perceptual invariants that can be divided into structural and transformational kinds (Gibson 1979). Structural invariants communicate the properties of an object that do not change during its use, such as its material essence, while transformational invariants specify the temporal changes in an object involved in an event, such as the speed of its movement. Auditory experiments, such as those on bouncing and breaking events by psychologists Warren and Verbrugge, showed that it is the temporal structure of sound that carries information about how an event has occurred (Warren and Verbrugge 1984). For example, the sound of someone bouncing a ball can communicate the strength of his or her action, the distance between the hand and the ground, the speed and other information. These findings about the decoding of events through perceived sound can be exploited in design; for example, they can help communicate certain metaphors or affect user response during the manipulation of an object.

2.2.1.2 Listening to Actions

A specific kind of everyday listening takes place when a person listens to sounds produced by human action. The listener may recognise specific qualities of such action. For example, during a tennis match, the sound of the ball hitting the racquet, and subsequently the ground, communicates to the listener something about the quality of action: the intensity and even the precision of the player's movements. Sounds caused by human action are the result of the physical interaction between a person and its surroundings. In this thesis, I will call such listening, *action listening.*[2]

To perceive a sound caused by a human, therefore, is to perceive an action. Brain imaging techniques show that sounds generated by human actions are processed differently from other sounds. When recognising an action that caused a sound, our brain produces neural activity similar to that activated when we perform that same sound (Keysers et al. 2003). These neurons that discharge both when performing an action and when perceiving it are called mirror neurons.Mirror neurons were firstly discovered in experiments on visual-motor relationship in monkeys performing and seeing the action of grasping (Gallese et al. 1996). The suggestion by the neurologist Krakauer and Ghez that mirror neurons ‘may have a role in transforming the dimensions of an object in visual space into motor signals" (Krakauer and Ghez 2000) resonates with the notion of affordance proposing that action and perception are far more closely linked in the brain then previously thought. Initial findings about mirror neurons suggests that *doing with sound* and listening to actions are far more closely linked in the brain than previously thought. But what is specific to the experience in which one is listening to the sonic effect of one's own actions while performing them?

2.2.1.3 Ergoaudition

> There is (...) ergoaudition when a listener is at the same time, completely or partially responsible, whether or not he or she is aware of it,

[2] Action listening is not to be confused with active listening in which a person is attentively focused on sounds heard.

> for the sounds that he or she is hearing: playing an instrument, conducting a machine or a car, creating noises - of the steps, or the clothes - through his or her displacement or actions, but also when he or she speaks.[3] (*Le Promeneur Ecoutant: essais d'acoulogie*, Chion 1993, p. 98)

Michel Chion, one of the most acknowledged sound design theorists, coined the term *ergoaudition* in order to describe the experience of listening to self-produced sounds (Chion 1998). As he states, a listener is responsible for the sounds that he or she hears but may not be aware of them. However, he or she does not differentiate between internal body sounds and sounds that are produced through manipulation of the physical world. One of the main differences is that sounds such as heartbeat or breathing are hard or impossible to stop, while sounds such as cooking or walking can be easily controlled because they are produced through intentional actions onto the external world. Although sounds generated by both intentional and non-intentional actions are most often placed in the perceptual background, they deeply affect our experience and interaction with the world.

Thus, there is a difference between what is heard by a person who produces sounds and by another, external listener. For example, our own voices are perceived differently when we speak compared to when we listen to the playback of a recording. The sound source, one's own vocal cords, is situated inside the body itself. Sound waves propagate through the bones and body tissues, and not only through air, as is the case with an external sound event.

Our auditory perception is further transformed when we move, as our body predicts the sensory consequences of a motor command and compares the expected sensory effects with the actual ones. The central nervous system sends motor signals to the periphery (so-called efferent signals), but also makes a copy of the same signal, called the efference copy, which allows us to better combine movement and sensing (Kandel et al. 2000). For example, visual signals are dynamically changing as we move, but we perceive our surroundings as static. This results in an attenuation of sensory effects of self-produced sound. For example, it has been shown that we can ignore the sensory input of vocal

[3] Original text: Il y a (...) ergoaudition lorsque l'auditeur est en meme temps, totalement ou partiellement, le responsable, conscient ou non, du son qu'il entend : jouant d'un instrument, commandant une machine ou un vehicule, emettant des bruits - de pas, de vetements - dans ses deplacements ou ses actions, mais aussi lorsqu'il parle.

sounds, as the auditory cortex has not been activated when producing a short 'Ah' sound (Ford et al. 2010). These findings suggest we hear ourselves less, but are highly debatable as many parameters, such as attention, types of sounds and context, have to be taken in account.

When objects are used to produce sound, for example hitting a nail with a hammer, the perception is further modulated. A person will feel additional tactile inputs resulting from being in touch with a sounding object, and kinaesthetic inputs resulting from moving in order to generate sound. In contrast, a passive listener will have a different spatial relationship to the sound source and will be able to experience and interpret only auditory sensations.

2.2.1.4 Foley: Objects in Sound Design

In the production of the sound for cinema, physical objects are often used in order to create sound effects for screen. The original soundtrack can be substituted or augmented through a real-time sound making by the so-called foley artists. In this sound design technique, named by Jack Foley, an early developer of sound effects for film, a foley artist uses his or her body in interaction with physical surfaces and objects in order to produce sounds that accompany various events in a movie. On a foley stage, various materials can be found, from shoes to fabrics and different ground surfaces. By using these materials and objects, the foley artist aims to synchronize human movements that he or she sees on the screens, such as walking, with the sounds he or she produces (Sonnenschein 2001). However, the way in which a sound is created by the foley artists may have nothing to do with the actual production of that sound. For example, the twisting of the celery is often used to create the sound of bone crunching (Ament 2009). As the sound designer David Sonnenschein put it:

> Combining this with the fact that some realistic sounds do not play nearly as dramatically as sounds created by totally different sources then seen in the film, foley artists have made careers by pinching steaks for a boxing match and squishing cornstarch for walking in snow. The lesson is: Listen for the sound that works not necessarily looking for an authentic source.. and have fun with your discoveries! (Sonnenschein 2001, p.35)

Foley techniques and the use of the physical props is important for generating sound ideas. These techniques have been combined with interaction design practice and were integrated in the methods developed in this thesis such as the Action-Object Matrix and Soundstorm described in Chapter 6 of this dissertation. Moreover, foley artists have a large amount of tacit knowledge about sounds caused by objects and thus may provide valuable knowledge to product designers who are developing sound for object (see the online resources such as filmsound.org/foley and http://www.marblehead.net/foley/). However, the final goal of the foley technique is sound for screen, not for physical objects. Therefore, while learning from foley artists, the practice has to be extended with the concerns specific to physical manipulation of sounding object, namely the self-produced sound as a part of holistic experience with a product, rather than sound as a part of an audio-visual reception experience.

2.2.1.5 Listening and design

Similarly Chion, disregarded these tactile and kinaesthetic aspects of the *ergoaudition* present in the creation of sound with objects. Even its etymological origin (Lat. ergo: me, and audire: to hear) embodied Chion's focus on the reception of self-produced sound, rather than on its creation. This is because his work concerned sound design for the cinematic context, within which people take on the role of listener rather than that of performer. The so-called *audiovision*, Chion's framework relating the sound to the moving image, explored the impact of different audio-visual couplings, peculiar media relationships that can be creatively shaped and can cause different emotional or narrative experiences for the cinema audience.[4]

His approach was innovative, in that it was first to consider the multisensoriality of an audio-visual experience and offered valuable insights for cinema and the media art. However, it excluded any performative potential of sound and supported quiet audience reception. While suitable for cinema, where behaviours are predefined and predictable because the audience is *exposed* to an audio-visual presentation, his approach cannot be applied to situations within which the action of a user plays a central role. Thus, the design of self-produced sound requires a perspective different from the reception-based approach: the one in

[4]For more details on the idea of audio-visual coupling, see Chapter 10: 'Le couplage audio-visuel' in his book *Le Son* (Chion 1998)).

which tactile and kinaesthetic aspects and human exploration are at the core of the design and research process.

2.2.2 Enactive Sound Experience

Enactive Sound Design aims to shift the perspective from listening and from reception-based approaches towards performance-based approaches to sound design. The goal is *to design sound for action* or, in other words, *to create sonic feedback which can affect, guide and support the physical movement of the user who generates sound.* Thus, **enactive sound** can be defined as *sound which affects a sensorimotor activity of the user who willingly produces that same sound.*

This definition of enactive sound may be unpacked by discussing its qualities:

1. Enactive sound can affect **sensorimotor activity** of the user:

   No self-produced sound is possible without self-produced movement, and therefore some kind of existing or emergent sensorimotor knowledge is always present.

2. Enactive sound engages the user's **willed action**:

   The user should be aware of his or her sonic interaction in order to acquire new bodily knowledge.

3. Enactive sound enhances **multisensory experience**:

   Ergoaudition is not separable from the other senses, especially the haptic sense which encompasses vibration, touch and proprioception.

4. Enactive sound responds **directly and continuously to the user's movements**:

   No bodily experience is discrete, and so the physical interaction with sound always provides continuous feedback of different intensities.

Designing sound for action requires an understanding of these qualities and ways in which they can be shaped. What is the value of sensorimotor interaction for design? What can continuous feedback be useful for? What is the difference between willed and habitual actions generating sounds? Is multisensoriality an obstacle or a fruitful challenge for design? By analysing and working with these questions, a foundation for Enactive Sound Design can begin to be formed.

2.2.2.1 Sensorimotor Activity

Sensorimotor knowledge is acquired and maintained by the act of 'doing', through physical interaction with our surroundings. Activities such as drinking or biking must be learned through the body, and once this knowledge is acquired, they appear as intuitive and natural. Swiss philosopher and psychologist Jean Piaget was one of the first to associate sensorimotor learning with the early stages of cognitive development (0-24 months) during which the child learns through physical interaction with the world (Piaget 1954). According to Piaget, from age 2-7 magical thinking predominates, followed by concrete logical thinking from age 7-12, and entering the world of abstract reasoning after the age of 12. In 1966, psychologist Jerome Bruner called sensorimotor learning *enactive* because of the importance of the physical engagement with the environment for cognitive development. In contrast to Piaget, he proposed that the acquisition of different types of knowledge, which he labeled enactive, iconic and symbolic, was age independent (Bruner 1966). Bruner suggested that enactive learning not only happens in the early stages of human development when a child learns to walk or to drink, but also later in life when humans engage in new bodily experiences such as dancing, skiing and dough making. Thus, enactive knowledge is situated and grounded in our physical surroundings.

Such exploration, however, is sadly lacking in adulthood, during which we are constrained by social and cultural norms as well as personal beliefs and habits. Notwithstanding, the dynamic relationship between the human body and its surroundings offers unending possibilities for exploring, discovering and acquiring new bodily skills. Designers shape this relationship by creating everyday objects and spaces, thereby affecting users' modes of behaving and learning. When the design principles are grounded on efficiency and neglect such explorative potential of the physical world, the relationship between the user and his or her sourroundings may become static and enactive learning may diminish. The neurologist Alain Berthoz criticises rational architectural design and how it has affected our brains in his book *The Brain's Sense of Movement* (Berthoz 2000).

Similarly, designers of computing devices have often neglected the role of the body in interaction. Activating sensorimotor exploration through technology is a demanding challenge, particularly if the goal is to learn new physical movements. The difficulty of reproducing something as simple as walking has been witnessed within AI research, which has begun to embrace and to struggle with the embodied knowledge as the basis for designing interactions between the agent and the world (Pfeifer and Scheier 2001). However, only by confronting this challenge of engaging the sensorimotor activity, can we rethink the design of sound devices beyond functionality and reception. The enactive knowledge that humans already possess is grounded in the physical environment and may be a starting point for developing new embodied experiences.

2.2.2.2 Willed Action

Clearly, sensorimotor skills vary for different people: some know how to ski or to swim, while others have never learned it. As a new physical activity becomes a part of one's embodied knowledge, one learns to perform previously unfamiliar movements with ease, quasi automatically. But how does an unknown bodily movement become a habit?

Cognitive scientists have been studying the human control of actions in order to explain our behaviour. The psychologists Donald Norman and Tim Shallice argued that the control of action depends on two types of cognitive processes: automatic and willed (Norman and Shallice 1986). The former engages effortless routine operations such as avoiding people while walking on a crowded street. The latter, willed action control, occurs when automatic responses are not sufficient, such as in accomplishing new complex tasks. However, when a novel situation is encountered, willed acting is supported by automatic actions that are already a part of the person's embodied repertoire. Therefore, physical interaction with novel interfaces is a mix of willed and automatic processes whose balance affects the learning of new action patterns.

Among these, the willed action plays an important role, because learning processes occur faster when a person acts consciously and exploratively (Lotze et al. 2003). Yet, much of human action is unconscious. Findings in social psychology show that people are most often unaware of the habits which guide their behaviour (Bargh and Chartrand 1999). We are unconscious of the consequences of our actions, and increasingly so in a technologically augmented world where automaticity dominates. Thus, it may be proposed that increasing awareness of user's actions through sound may improve and enable learning by building on habitual actions and by stimulating novel ones.

Enactive learning can be seen as a process of transformation of an unknown action control pattern into a familiar one. In interactive systems, the familiarity of an interface depends not only on the way it is manipulated, but also on the feedback that the system provides. For example, an unusual sonic response may disturb the movements of the user. Imagine chopping vegetables and hearing the sound of the water splash (or a scream!) every time you hit the board. Thus, the design of the action-sound couplings can shape an enactive experience in multiple ways. If the expected auditory feedback is removed or substituted, the experience may become uncomfortable or surprising, thus, affecting the performance. The question, then, is how do different types of feedback and types of sound affect the user's enactive knowledge?

2.2.2.3 Multisensoriality

Any manipulation of a physical object is a deeply multisensorial experience. When cutting an apple, for example, we see and feel the knife and even smell the apple, we feel the movement of our hands engaged with the object and we hear the sonic effects of the cutting action. In addition to the auditory sense, the sense of touch and proprioception are inevitably stimulated when using an everyday object.[5] Thus, an enactive sound experience is a result of an interaction between different sensory inputs whose perceptual effects cannot be simply additive.

This process of merging of information coming from different senses is called multisensory integration (Calvert et al. 2004). Multisensory neurons, located in the centre of the brain, are identified as those neurons that respond more intensely to the crossmodal[6] stimulus combination than to any of individual sensory stimuli (Stein and Meredith 1993). The auditory-proprioceptive interaction takes place in the principal midbrain nucleus of the auditory pathway, called the inferior colliculus, where multisensory neurons receive input from somatosensory nuclei and from the auditory cortex (marked with red in Figure 2.2). The multisensory integration happening in this area appears to be

[5] In so-called untethered gestures, the sense of touch is not that important. For example, with the Theremin, an early electronic instrument invented around 1918 by Russian Leon Theremin, the movement of hands between two antennas controls the frequency and the volume and no tactile sensations occur (except for the air movement). Sile O'Modrain's doctoral thesis elucidates the problems with free or untethered gestural interaction using the Theremin as one of her main case studies.

[6] Crossmodal refers to stimuli activating more then one sensory modality.

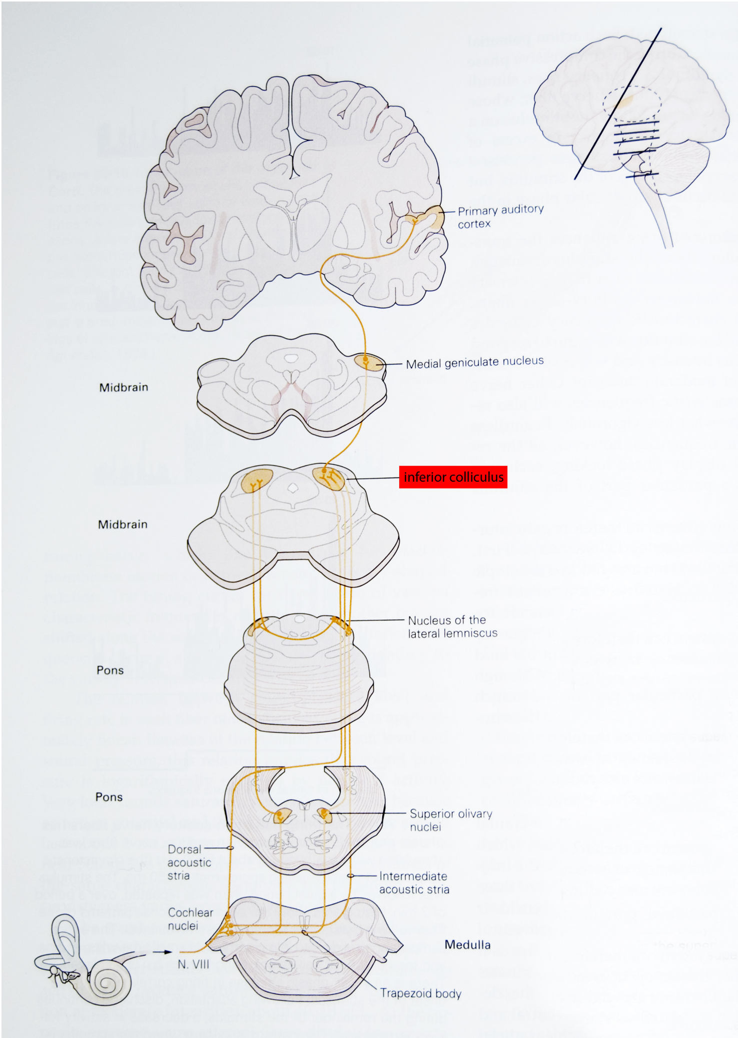

Figure 2.2: Diagram showing the auditory paths and the inferior colliculus (in red) which is responsible for attenuating the perceptual effects in self-produced sound (Kandel et al. 2000)

responsible for the perceptual effects of reduced awareness in self-produced sounds; for example, the sounds of speaking or breathing seem to be automatically attenuated.

By tracking the activity of multisensory neurons, neurologists defined the spatial and temporal rules of multisensory integration. If sensory stimuli are separated by large spatial gaps and long temporal gaps, the response of the multisensory neurons is weakened (Occelli 2010). As the spatial and temporal difference between the two stimuli is reduced, the mulitisensory integration becomes higher. While these findings result from research on audio-visual feedback, audio-haptic integration studies are expected to provide similar insights (Spence 2007).

Thus, we may conclude that multisensory integration can be best enabled if the stimuli pertaining to different sensory channels are activated simultaneously and at the same location. The expected experience may be disturbed if the coupling between the sonic feedback and its generating action is not synchronous and not collocated. In other words, the user may become confused if the sound is not emitted from the object manipulated or if the feedback to gesture is provided with a temporal delay (for example, if while the user is pouring the water, the sound emanates from a different location). However, breaking such user expectations can also be a design strategy worth exploring (Rocchesso and Polotti 2008).

Another multisensorial aspect is that speakers embedded in objects create vibratory sensations when in contact with user's body (Ballas 2007). These tactile effects may also be used as haptic feedback. However, the considerations for haptic stimuli are different from those for sonic ones due to the different nature of the tactile sense (e.g., different frequency responses of related neurons). Although Enactive Sound Design does not necessarily include the design of haptic interfaces, it is important for designers to be aware of the audio-tactile interplay present when using sounding objects.

Last, but not least, multisensoriality poses challenges for scientific evaluation of enactive sound. Perceptual studies most often focus on one sense only, mainly due to the complexity of the experiments, whose variables become increasingly harder to control as the number of senses observed increases. One early example of such experiment was performed by the psychologist Susan Lederman, who studied auditory and haptic interplay in identification of surface texture (Lederman 1979). However, guidelines on perceptual multisensory experiments, particularly those involving motor action, are lacking.

2.2.2.4 Continuity

Multisensorial feedback is *continuously* provided to the user who manipulates a sounding object. Think of pouring ice cubes from one glass into another: the sonic feedback of the ice cube hitting the glass is discrete, but the action which determines the response, as well as the tactile and propriceptive responses, are continuous. Under the influence of these, the user adjusts his or her hand in order to modulate the speed and the height of pouring. With the change of the material properties of the sound source, the same experience may change: if the user pours water, instead of ice, out of the same glass, both the action performed and the auditory feedback are continuous. Sounds communicate something about the pouring process at every instant of the user's performance. The user can better adjust his or her movements while continuously hearing the changes effected by his or her actions. The continuity of sonic feedback allows the user to perform and to combine existing embodied patterns in order to accomplish a given task.

This loop between sensing and action is perceived as continuous, because, on a neurological level, it occurs extremely fast. In reflexive responses such as keeping balance while standing, the stimuli do not even reach the brain. In higher cognitive processes, our afferent neurons (with motor and sensory subgroups) carry nerve impulses towards the brain, where auditory information is processed. The nerve impulses are sent away from the brain through the efferent neurons towards glands and muscles. In addition to motor nerves, there are efferent sensory nerves that serve to adjust the sensitivity of the signal relayed by the afferent sensory nerve. Because such sensorimotor processes happen extremely fast and concurrently, the user perceives the activity as continuous.[7]

Continuity of sonic feedback has proved to be essential for the expressive engagement with musical instruments. For example, a violinist bows a string to produce a good tone and adjusts his or her bowing action by listening to the continuous sound that is produced. Thus, the feedback guides the player's control of the instrument, allowing him or her to modify bow speed, pressure, angle, and so forth. Feedback of this type can be regarded as part of a continuous sensorimotor loop: a user continuously controls an object; this manipulation produces sounds that vary in a coherent way with the user's actions, and in turn the sounds affect how the user is performing. This suggests that suitable continuous sonic feedback can encourage, guide or correct the physical movement of the user.

[7]Scientists are struggling to understand complex enactive processes and to show the way in which the perceputal and multisensory activities interact. The traditionally separated sensory and motor research communities have been starting to work together to address current research questions (personal discussion with one of the perceptual psychologist Max Ernst at Eurohaptics Symposium 2010).

In interactive objects, however, the feedback is added and does not result from natural interaction with the physical world. Thus, the designed relationship between gestural input and the sound is a crucial issue for enactive experience. Following the principles of physical manipulation and learning with analogue objects, it can be suggested that using continuous responses will result in a more natural interaction. Therefore, by correct coupling between physical activity and sounds, designers may guide physical movement and can enable users to acquire new embodied knowledge.

2.2.2.5 Implication for Design

Each of the qualities of enactive sound poses design challenges that can be summarised as follows:

1. Enactive sound can affect the sensorimotor activity of the user:

   Thus, designed objects should first engage existing knowledge and then guide the user into learning new enactive knowledge.

2. Enactive sound engages the user's willed action:

   Thus, enactive interfaces should responds only when willingly activated by the user, in order to raise awareness of his or her actions.

3. Enactive sound enhances multisensory experience:

   Thus, we should design the perceptual effect of multimodal stimuli, rather than individual media, following spatial and temporal constraints of multisensorial integration.

4. Enactive sound responds directly and continuously to the user's movements:

   Thus, a more direct and continuous relationship between action and sonic feedback should be designed in order to engage enactive learning.

Enactive experiences take place when we create, shape, manipulate and act on, that is *interact*, with sounding objects. Given this direct connection between interaction with and within the surroundings and corporeal experience, we can ask what role technology has played in engaging enactive interaction. Although traditional paradigms still govern the design of digital sounding objects, a number of artistic and design explorations bear witness to the potential of interactive technology for shaping the enactive sound experience.

2.3 How Can Digital Technologies Foster Enactive Experiences?

Historically, technologies have often been blamed for disembodying sound and reducing music performance to minimal and machinic movements (Sterne 2003; Kahn 1999; Miranda and Wanderley 2006; Schafer 1994 (1977)). However, a number of artists have worked with interactive systems to engage performative experiences with and through sound. In this part of the chapter, I identify a number of exemplary cases, focusing on projects in which the user is in direct contact with the sounding object. These works come from different research and creative fields, such as sound art, interaction design, new musical instruments and engineering, but they all enable physical exploration and multisensoriality. They challenge the dominant disembodiment view of interactive technologies and show that these may increase the malleability of sonic material under the force of human action, thereby stimulating explorative and creative acts of *doing with sound*, both in everyday and musical contexts.

2.3.1 Actions Mould Sound

The separation of sounds from their original acoustic sources, enabled through recording devices, has fostered new artistic explorations, starting from the mid-twentieth century. On one hand, such technologically catalysed dissociation has fostered the creation of imaginary sonic spaces in electroacoustic music.[8] The acousmatic sound (the sound heard without seeing its source) created through the advent of magnetic tape recording, and later, the manipulation of electronic signals, led to electronic music's rapid integration into concert hall formats in the 1950s, where seated listeners would *let their ears be guided* into fascinating sonic landscapes. On the other hand, the temporal or spatial fracturing between a sound and its source allowed for treating sound as a material medium.

Sound captured on a material support such as magnetic tape enabled a more direct, physical manipulation of sound. Experiments with audiotape in the 1950s and 1960s by composers like John Cage, Pierre Schaeffer and Steve Reich, among others, made sound malleable in a novel way. Such artists explored the

[8]The french composer Pierre Schaeffer with his Music Concrete was one of the pioneers of electroacoustic music. For his approach see (Schaeffer 1966).

potential of cutting and splicing tape and reassembling it anew, creating startling sonic effects and new forms of music through repetition and modulation of parameters such as speed or phase. For example, in his 1963 *Random Access Music*, trained composer and video artist Nam Jun Paik de-contextualised the technical apparatus of a tape recorder by removing the tape head from the recording device. Visitors could 'interactively' run the tape head over the audiotapes arranged in abstract shapes on the wall (see Figure 2.3), while generating sounds that varied based on the speed of manipulation, continuity and intensity of gesture.

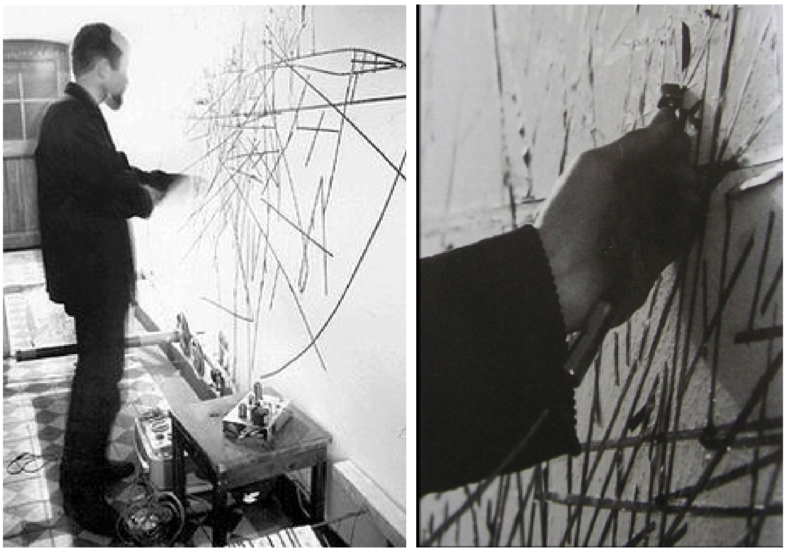

Figure 2.3: Random Access Music (1963) by Nam Jun Paik

The self-produced sound resulting from the interaction with the *Random Access Music* installation was unpredictable for both the performing visitor and the artist. It could not have been created based on prearranged compositions and fixed relationships such as those of Chion's framework, for example. The explorative nature of the installation engaged visitors in a discovery process through a direct contact with sonic material, namely the tape. This was achieved by changing the control of the head from an automatic mechanism to the human hand; a functional piece of technology was thus converted into an expressive instrument. The new materiality of sound, provided by the magnetic tape could be directly transformed through human action, thus enhancing the audience's enactive experience.

Paik's unpacking and rearrangement of a technological device served to offer

Figure 2.4: The Hands instrument (1984) by Michel Waisvisz

visitors a rich sonic experience through their manipulation of sound material, and yet new computational technologies soon radically advanced such experimentation. However, focused on algorithmic techniques, these new devices tended to neglect the human gesture, reducing it to discrete, robotic movements and the repetitive, automated machine-like quality of audio sequencers. The sound was digitally generated and modulated, but the creation of the audio materials was taking place in black computing boxes, accessible to users through buttons and knobs. Whereas Paik took the technology out of the box to physically manipulate it, the electronic music community used technology as a tool in order to achieve a desired result: an acousmatic sound that was to be presented to an audience in the listening situation. Perhaps this reduction of human action reached its apex in the so-called laptop music at the end of the 1990s. As composer Bob Ostertag argued: 'the physical aspect of the performance has been further reduced to sitting on stage and moving a cursor by dragging one's finger across a track pad in millimeter increments' (Ostertag 2002, 12). Thus, the relation between the performative movement and the sound produced became arbitrary and the musician's presence superfluous.

As a new minimal aesthetics of performance, found in early German electronic bands from the 1970s such as Kraftwerk and Tangerine Dream, dominated popular and research communities, an alternative approach based on sensing and actuating techniques resulted in the development of hybrid musical interfaces that demanded gestural virtuosity. Sound, in the work of many composers/performers, became once again a material to play with through the medium and force of bodily gesture. For example, in *The Hands* (1984) developed by the late Michel Waisvisz, sound was literally placed between the musician's fingers: catching, stretching and compressing it as the same sound transited through the air (see Figure 2.4). His work was crucial for the development of STEIM, the Studio for Electro-Instrumental Music in Amsterdam, and contributed to the formation of a research community around new interfaces for musical expression or so-called NIME community (for more discussion about NIME, see next chapter Section 3.2.4 Augmented Musical Instruments).

Figure 2.5: Crackle Family (1976) by Michel Waisvisz

While the musical and expressive richness of *The Hands* could only be achieved and explored by an expert user such as Waisvisz himself, his other devices were accessible to all, including children. Waisvisz's *Crackle Family* project (1976) presented a vision of the future dining experience in which a number of actions with everyday objects such as pouring tea or using cutlery were sonified (see Figure 2.5). The use of everyday, rather than expert, musical movements allowed Waisvisz to enable intuitive interaction for all. The *Crackle Family* project showed how existing enactive knowledge and familiar behaviours can aid the users' intuition and inclination towards exploring the physical world, the process that is at the basis of human cognition and intelligence.

Figure 2.6: Mark Hauenstein and Tom Jenkin's *AudioShaker* (2004). Courtesy of the artist.

Similarly, interaction designers Mark Hauenstein and Tom Jenkins used an ordinary looking container resembling a cocktail shaker to mix sounds rather than liquids. With their *Audio Shaker* (2004) device, users could open the object, speak into it to record sounds, shake it to mix them, and then literally, pour out the sound mix (Figure 2.6). The sounds kept the reference to the recorded sound but were transformed according to the intensity and repetition of the shaking gestures. When pouring the sounds out of the shaker, the speed was directly mapped to the tilting of the object and the sound emanated from the speaker situated within the object, providing the user with the sensation that the sound actually dripped or flowed out of the vessel and thus making the interaction easy and natural. The *Audio Shaker* device can be seen as an expressive instrument that turns immaterial and ephemeral qualities into malleable and the tangible ones, particularly when the sound shakes and vibrates between the user's hands, and pours out like water. Directly and continuously mapped to gestures such as shaking and pouring, the resultant sonic feedback makes the object easy to use and yet, meaningful, expressive and physically engaging.

A project that well exemplifies how the materiality of sound can be felt through gestural interaction is *The Sound of Touch* by designers David Merrill and Hayes Raffle. They developed a wand for capturing, storing and manipulating sounds by touching textures such as wool, a metal screen, or a broom bristle (Merrill and Raffle 2007). This palette of textures could be touched with a number of wands in various ways by hitting, caressing or brushing the materials (see Figure 2.7). The sounds produced could be captured with a microphone inside the wand. The recorded samples could be manipulated in real time by moving the wand in contact with the texture, this time using the palette as a tool for modulating the sample. Each sound embodied a gesture, and was brought to sounding by another gesture. In addition to the materials in the palette predefined by the designer, the wands could be used with any other physical texture. In *The Sound of Touch*, one does not create simply with a palette of sounds - the expressive material is instead a palette of sonic actions, which are designed through the relationship between the gesture, the artefact and the sound. Soundings emerge from the materiality of the world around us and that of our own bodies moving through and touching that world.

Figure 2.7: David Merrill and and Hayes Raffle's *The Sound of Touch* (2004). Courtesy of the artist.

The above projects use everyday objects as a starting point for interaction, thus taking advantage of gestures that the users already know. They explicitly relate the materiality of sounds to objects and to the gestures that produce them in a kind of metabolic, open-ended process. The direct continuous feedback creates a seamless experience comparable to natural interaction with an analogue object. Such ease of interaction is particularly important when the designer's goal is to engage a broad range of users.

2.3.2 Sound Moulds Actions

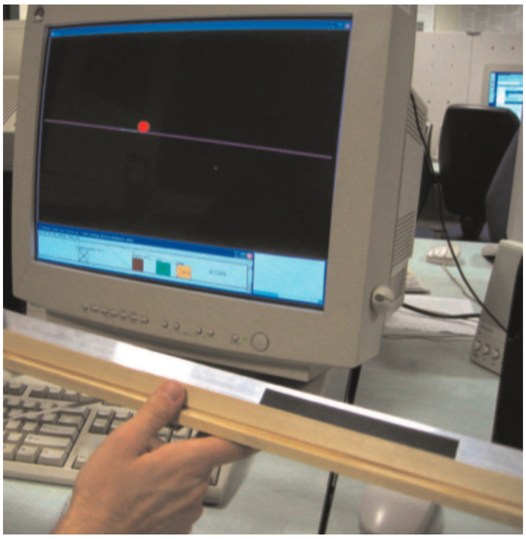

Figure 2.8: The Ballancer (2005) by Mathias Rath and Davide Rocchesso. Courtesy of the authors

Sound can be moulded by our actions, which in turn can modify our auditory perception, consequently enabling us to act, move or dance. In such action-perception loops, sonic feedback is capable of generating mental metaphors that may guide the user to accomplish challenging physical tasks. This has been show in *The Ballancer* project, in which users could balance a virtual ball on a physical stick by listening to the ball rolling across an identical virtual stick presented on screen (Figure 2.8). The rolling sounds were continuously coupled to the tilting of the stick and were generated by the means of physically-based models that simulated the sound of a rolling ball (Rath and Rocchesso 2005). Users could identify the speed and the movement of the ball across differently roughed areas of the virtual stick, by listening to the sounds shaped through their motion. They could immediately adjust their movements to keep the ball stable. During the course of the experiments, the task of balancing proved to be easier when sonic feedback was added (Rath and Rocchesso 2005).

This result supports the argument that human performance can be strongly affected by sound, and shows that sound can play a very important role in providing continuous feedback in sensorimotor interaction. As it shapes the action continuously, *The Ballancer* interface requires the user's attention and bodily response at every step of the interactive experience. Movements of balancing the ball are influenced by the sound and are, at the same time, the influence of it. Therefore, the enactive experience may be supported through a continuous coupling between action and sound.

Such a direct and synchronised relation between the user's actions and sonic feedback can not only affect the movement of the user, but can also transform the perceived properties of a physical object. This is exemplified in the *PebbleBox* project (2004) developed by Georg Essl and Sile O'Modhrain (Figure 2.9). The user can move her or his hand inside a box full of pebbles, and can generate the sounds of different materials such as ice cubes or sand (O'Modhrain and Essl 2004). The device is equipped with a contact microphone which picks up the impacts of the stones and uses this input to generate sonic feedback through granular synthesis. Depending on the sound heard, users feel the tactile sensation of immersing their hands inside a box full of fluid or ice cubes, despite the fact that only the pebbles are being touched. Such modulation of users' tactile perception through sound may be used by designers to inform the aesthetic aspects of an interactive product.

Figure 2.9: The PebbleBox (2004) by Georg Essl and Sile OModhrain.

While sound can influence perception of the material, it may also be used to directly generate tactile sensations due to its vibratory nature.[9] The perceptual effect on vibratory feedback during walking motion has been explored in the *EcoTiles*[10] project developed by Yon Visell, myself and Alvin Law during the course of this doctoral research (Visell et al. 2008, 2007). It is a floor-tile platform that can simulate different types of ground when one walks across it. The movement of the feet is captured through force-sensitive resistors attached to the tiles. Depending on the pressure of the user's body, the vibrating actuators attached to the tiles respond with different sonic signals. These vibrations, activated and sensed by the feet, appear to lend new material qualities to the floor and perceptually turn the wooden floor tiles into sand or snow surfaces.[11] This happens only when interactive response is temporally synchronised to users' actions, because then the sonic and haptic sensations acquire meaning grounded in the existing embodied knowledge of the user. In other words, when the stimuli are simply presented to the person standing on the tile, he or she feels as if the floor is shaking or as if someone is hitting on the tile from beneath. But, if the stimuli are interactively and synchronously coupled to the user's movements, the floor acquires new material properties for the user. The vibrations turn the wood into a responsive and dense matter, which becomes a different material only when being acted upon. Moreover, the meaning of the sound is associated with previous walking experiences. Through this activation of existing bodily knowledge, the experience appears more natural, situated and intuitive.

In the *EcoTiles* project, interaction is a process of active discovery, in which the perception of material reality can be continuously changed, adapted and reinvented. The feedback must be presented in a timely fashion at the moment when the user steps on the floor or moves from one foot to another. The wrong timing of the response displaces the agency from the user to the system, causing him or her to perceive something or someone else hitting the floor rather than to experience different grounds.

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[9]The latter was discussed as early as 1930 in the essay 'The Vibratory Sense' by David Katz, one of the first scientists to argue that the cutaneous sensations provoked by vibrations activate sensory channels different from other tactile inputs.

[10]The name of the device references J.J. Gibson's ecological approach to perception (Gibson 1979).

[11]For a detailed description of the interface and related perceptual experiments, consult Yon Visell's doctoral dissertation (Visell 2011).

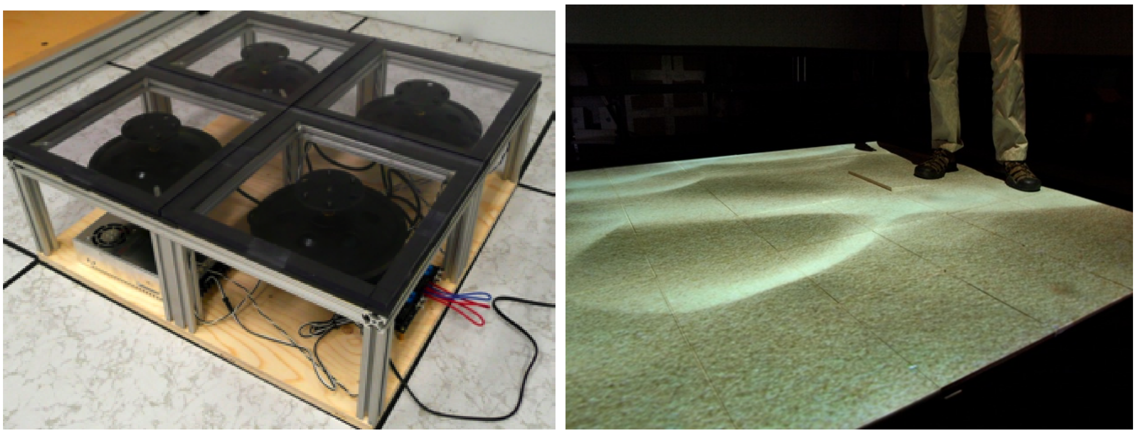


Figure 2.10: EcoTiles (2007-2010) by Yon Visell, Karmen Franinović and Alvin Law.

While the *PebbleBox* demonstrates the ways in which haptic and auditory senses interact, *EcoTiles* exemplifies how vibratory feedback can affect perception of the ground. Most recently, my colleagues have conducted experiments that show that vibration can automatically induce sensations of compliance under the force of our feet (Visell et al. 2011). The subjects felt that they were sinking into the ground while stepping on tile with vibratory feedback. Because walking across differently compliant surfaces results in adjustment of the muscles in the legs that compensate for the compliance of the ground material,the results of these experiments suggest that vibrational feedback can induce proprioceptive sensations, which may also stimulate the user's motor response involved in adjusting posture. These muscular micro-responses are a kind of 'felt proof' that the sensorimotor loop can be affected through interfaces such as *EcoTiles* or the *PebbleBox*. Currently, within the ModuLoc: Modulating Locomotion through Tactile Feedback project (2011-2012) and in collaboration with ISIR group at University Pierre et Marie Curie: Paris 6, we are conducting experiments to show that the legs and the posture physically change due to the perceived sensation of sinking. We hope that the results will prove our hypothesis and that this novel enactive interface will be able to support a more natural walking rehabilitation.

In summary, these recent projects show that the perceived properties of a material object can be altered by combining the physicality of gesture with changing sonic feedback. The wooden tile can be perceived as being as soft as snow, or as granular as sand. What we see and what we feel may not coincide, and yet our body combines different sensorimotor information and produces sensations that are deeply and physically felt. As in interaction with non-augmented objects, these sensations emerge when the user acts with the interface. If one does not move across the *EcoTiles*, one will not feel the morphing of the ground matter under one's feet. If one does not move their hand in the *PebbleBox*, one cannot feel the liquidness or softness of the pebbles. In response, these perceptual effects or illusions influence the way in which we then act, because the material world acquires new qualities and affrodances through interacting with sounding objects.

2.4 Conclusion

In this chapter, I have argued for a shift of research perspective from audio-visual reception and listening towards the experience of *doing with sound*. Starting from existing scientific and design approaches, I showed that self-produced sound has been mainly addressed from a listening perspective and that, beyond the music research, performative aspects have been neglected. I introduced Enactive Sound Design as the practice of creating sound for situated physical action, and unpacked its definition by discussing the qualities of the experience of *doing with sound*. The issues presented in this chapter outline the initial considerations for an Enactive Sound Design framework and for the development of practices that aim to engage and create enactive sound experience.

A review of selected projects showed the potential of interactive technology to support such experience by shaping the perceived materiality of sound. Historically, there has been a shift from manipulating sound support (e.g., tape or vinyl records) to modulating the perception of the user through interactive feedback (e.g., material properties). The first set of projects exemplified how sound can acquire tangibility through digital technology, while the second, more recent examples demonstrated how sonic feedback can affect our movements. The analysis indicated that digital technologies can enhance the sonic materiality that this, in response, may strongly affect the user's performance and enactive knowledge. Thus, sound can play an important role in providing continuous feedback to movement, and enactive learning may be enabled by varying sounds that affect the user's actions, guiding them to explore and to be expressive.

The ways in which these goals were achieved in selected projects reflect the identified qualities of enactive sound and ways of working with them:

- Firstly, these projects demonstrated that the use of everyday objects can activate existing knowledge of the user and be used to learn new interactions (e.g. *AudioShaker*).
- Secondly, natural embodied experience can be enabled only when timing of the feedback is synchronous with the user's acting on and within a system (e.g. Sound of Touch).
- Thirdly, continuous coupling between the user's movements and sonic feedback can guide user performance (e.g. *Ballancer*).
- Fourthly, multimodal stimuli can engender perceptual effects and illusions which, in response, can affect action (e.g. *PebbleBox*).
- Finally, modulating sonic and vibrotactile feedback can affect the user's movements and impulse for exploration (e.g. *EcoTiles*).

This interactivity of sound emerges into the world only if our bodies are active. Our perceptions come into existence through our actions, and the other way round. Thus, action and perception must be researched and designed as one, because they are lived as one.

Chapter 3

Existing Design Approaches

When and why have designers shaped the sound in products? What are its functional, aesthetic and social roles in digitally-augmented things? What can be learned from the existing ways of designing interaction with sound? What remains to be explored in order to set the basis for an Enactive Sound Design practice? This chapter provides an overview of the approaches to designing sound embedded in everyday products, interfaces and instruments.The need for an enactive approach is argued through an identification of functional and social benefits of sound as a medium that can modulate physical action of the user. Consequently, I propose that careful design of self-produced sound may raise the awareness of user's sonic acting in the world. By mapping the benefits and disadvantages of those approaches and the roles designers have given to sonic medium, I identify critical issues that need to be practically addressed in order to foster an alternative approach to sound focused on engaging physical action.

3.1 Introduction

Design disciplines have repeatedly neglected the enactive sound experience, although it is an integral part of the performative and aesthetic experience with any product made to be manipulated by the user. The areas of product design and architecture have been dominated by the reduction of noises (e.g. acoustic design, isolation materials) and by the functional use of sound (e.g. alarm systems, human-machine interaction). Consequently, the user's auditory experience with digital products has been limited to discrete actions, such as turning an alarm off or responding to a phone call. Performative actions have been confined to the field of musical instrument design.

Although past approaches to interactive sound have carried certain disadvantages for enactive engagement of the users, they also demonstrate ways of harnessing the benefits of sound. Thus, an analysis of these strategies can help not only trace the history of roles given to sound in products and suggest potential future applications, but also identify methods and practices useful for Enactive Sound Design. Moreover, they can show why a focus on enaction can foster interactive sound design and why sound is an appropriate medium to engage action.

Thus, this chapter elucidates why enactive sound is a relevant issue for contemporary design. The specificity of sound as a medium is discussed, providing arguments favouring the use of sound as a dynamic response to the movement of the body. I argue that an enactive approach is needed in order to foster increased engagement and awareness for the user in sound production. I conclude the analysis of design approaches with a discussion of the purpose of the Enactive Sound Design from a functional and social perspective.

The main contributions of this chapter are:

- a review of existing approaches to sound design
- proposal of potential functional and social benefits of designing sound for action
- an analysis of their benefits and disadvantages for an enactive approach
- an identification of practical issues to be addressed in order to foster sound that engages action

3.2 Disciplinary Strategies

3.2.1 Product Design

Since its origins, product sound design has been focused on the elimination of undesirable noises that are produced during physical interaction. Many companies have evaluated their products through measurements of physical qualities of sound produced during the use of a product. In 1955, Olivetti, a producer of typewriters, opened its first anechoic chamber at Centro Studi ed Esperienze in Ivrea in order to enable precise measurement of the sound pressure levels that were produced during typewriting (Franinović 2003). Such tests allowed engineers to modify the mechanical design of the product and thus reduce sonic annoyance for the user and others in the immediate surroundings. The quality of the typewriter began to be valued not solely because of its efficiency, but because of auditory effects perceived and created through its use (see Figure 3.1). However, rather than redesigning the sounds of product usage, the solution chosen was to reduce them to a minimum.

Figure 3.1: Olivetti typewriter poster (1910) by Ernesto Pirovano

Today, physical measurements of sound are still combined with the psychological evaluation, which is well suited to characterise the acoustic annoyance or preference of the user. Such methods have been applied to the design of products such as vacuum cleaners, light switches, coffee machines and air conditioners (Susini et al. 2004). However, it can be argued that they failed to account for the functional and aesthetic aspects of product sound. For this reason, researchers Blauert and Jekosch introduced the notion of *product sound quality*, defined as 'a descriptor of the adequacy of the sound attached to a product.' ((Blauert and Jekosch 1997), p. 748). Such quality is evaluated in experiments in which users judge the sound in reference to the desired features of a product. Although these evaluation frameworks go beyond classical preference tests (Vastfjall and Kleiner 2002), they have not been developed with or for designers, who often lack knowledge in experimental psychology. Such scientific evaluation is applied only after the product is designed, and is therefore hard to integrate within an iterative design process, thus leaving the gap between design and evaluation unbridged.

Within design, an alternative approach to noise reduction has been firstly provided by the sonic branding practice, which works to provide strong product identities through sound (Jackson 2003). Here, sound adds value to a product as a part of an advertisement campaign. Most often, musical motives are composed to convey the identity of the brand, such as in advertisement jingles or when the sound is played during the start of a computer operating system. Focused on communication of the identity of the brand as an abstract entity, this approach has neglected the potential of self-produced sound. In some cases, however, sonic branding has been applied to the design of an actual product, as for example in luxury cars where the sound of usage may be associated with a specific brand, opening up the potential for enactive sound.

These less representative strategies focus on affecting users' auditory perception during the use of an actual product. The mechanical properties of the object are shaped so to make the experience more enjoyable and desirable. The roaring engine of a car or a motorbike can be designed to give the owner a stronger sense of power and engage him or her in the driving experience (Sottek et al. 2005). Thus, the perceived experience may affect the user's satisfaction with a product. For example, a fridge may be perceived as more robust because the sound of the door closing is louder.

In fact, the psychologists Zampini and Spence showed that sound played during physical interactions with products could actually *alter the perception of the user*. They argued that

> 'auditory cues elicited by our contact or interaction with different surfaces (such as abrasive sandpapers or even our own skin) and products (including electric toothbrushes, aerosol sprays, food mixers, and cars) can dramatically change the way in which they are perceived, despite the fact that we are often unaware of the influence of such auditory cues on our perception." (Spence and Zampini 2006)

In one experiment, the authors showed that sounds heard when biting a potato chip can change the perception of the staleness and crispiness of potato chips (Zampini and Spence 2004).

These psychological experiments demonstrate that there is a great potential in shaping user experience through sonic interaction with a product. However, I believe that there is also a great danger in using such strategies. The user may not be aware of the ways in which his or her perception is being modulated through this type of crossmodal interactions. Could this lead the user to the point at which he or she cannot trust his or her own senses? Perhaps it is designers' responsibility to use such multisensory illusions in playful, but transparent ways.

3.2.2 Auditory Displays

Sound in digital products has been mostly employed in screen-based displays. Two main categories of sound elements found in current digital products are *earcons* - abstract musical sounds that accompany different digital events such as booting up a computer (Blattner et al. 1989) and *auditory icons* - sounds that evoke everyday events associated with the graphic icons on the computer desktop. The auditory icons were originally created for the *Sonic Finder* project, an extension of Apple's Finder developed by psychologists and designer William Gaver (Gaver 1989). His ecological approach to auditory displays used everyday sounds as interactive metaphors. For example, the sound of pouring would communicate the process of copying files from one folder into another and the emptying the trash bin on the computer desktop would result in the sound of crunching paper (see Figure 3.1). Because such sounds were easily associated with the physical events that caused them, their meaning was easily interpreted by the user.

Events	Auditory icons
Icons	
• Selection	• Hitting sound
type (file, application,	source material (wood,
folder, disk, trash)	metal, etc.)
size	source size (frequency)
• Opening	• Whooshing sound
size	size (frequency)
• Dragging	• Scraping sound
size	size (frequency)
where (windows or desk)	texture (bandwidth)
possible drop in	selection sound of container
• Drop-in	• Noise of object landing
destination size	size (frequency)
• Copying	• Pouring sound
amount copied	frequency
Windows	
• Selection	• Clink
• Dragging	• Scrapping
• Growing	• Clink on release
size	size (frequency)
• Scrolling	• Tick sound
revealed area	size (frequency)
Trashcan	
• Drop-in	• Crash
• Empty	• Crunch

Table 3.1: Actions with icons and sound events associated with them in *Sonic Finder* by William Gaver. Reproduced from (Gaver, 1989)

In *Sonic Finder*, certain qualities of sound were 'cartoonified' in order to improve the user's perception of the sound event. Such designerly strategy was in contrast to the dominant approaches in sound synthesis, where the aim was to make exact reproductions of natural sound events (Cook 2002). As Gaver argued:

> Whereas the other algorithms produce sounds that clearly indicate details of their virtual sources such as the material and size of the objects involved, the sounds produced by this algorithm only hint at some of the high-level properties of their supposed sources. ...Insofar as detailed information is left out, they may be thought of as "cartoon sounds," sounds that caricature some aspects of the events while omitting others. (Gaver 1993a, p. 14)

Coming from a psychology background, Gaver took on the challenge of designing sound based on the perception of the user rather than on simulation of the real world. His synthesis tools reflected this focus on the perceived quality of digital sound and his metaphors exploited the user's existing knowledge, demonstrating the potential of everyday sounds for interaction.

Auditory displays are often associated with the term sonification which is defined as the conveyance of information though sound (Kramer 1999). The user can gain an understanding of the data represented in sound by listening. An example is that of transferring a set of complex EEG data about an epileptic attack into sound. Information about the arrival of an epileptic attack was better perceived when it was sonified rather than when it was visualised (Baier et al. 2007). In physiotherapy, the electrical activity produced by muscle activity has been sonified by Hunt and Pauletto, in order to facilitate the monitoring of muscle movement activity from the side of the therapist, thus offloading their visual attention to the auditory channel. They have used three different sonification methods. First, the EMG (electromyography) sensor data was directly converted into sound - so called audification. Because of the slow sensor data rate and noise caused by multiple sensing streams, MIDI notes where then used to sonify values from two sensors. Finally, the amplitude modulation was used, where each sensor stream was mapped to the amplitude of sine wave oscillators. Their frequencies were harmonically related in order to make the sound more pleasant (Pauletto and Hunt 2009). The listening experiments showed that non-trained subjects could differentiate between different age groups performing movement.

In summary, auditory displays have presented digital information in the form of sound, in order to extract meaning from complex data sets and to accompany actions performed with graphical icons on the screen. In addition to defining a number of functional roles for computer sound, the auditory display community has contributed to the development of sound tools and sonic metaphors (Kramer 1994; Pauletto and Hunt 2004). Most recently, Ahmad and his colleagues combined these findings in order to propose a framework which would address all the relevant auditory display questions (Ahmad et al. 2009). The framework is composed of four design phases that cover performative, temporal and spatial design aspects. However, the sound choice is limited to speech, auditory icons and earcons. Thus, this framework neglects continuous feedback, action-sound coupling and interaction beyond the mouse and the keyboard, reflecting the dominant attitude towards auditory display in HCI community (Robare and Forlizzi 2009). Thus, although important design questions are discussed, this framework makes dubious its applicability beyond the discrete and representational use of sound. It bears witness to the need for identification of the most relevant enactive issues that could push the boundaries of auditory displays in new directions. In recent years, however, through interdisciplinary research between movement sciences and sonification and the sonic interaction design research, the enactive experience has started to play an important role in auditory displays community.

3.2.3 Tangible Interfaces

Since digital technology has been moving out of the box and into the environment and objects (Weiser 1991), various alternatives to traditional computer interfaces have been explored. One of the earliest tangible sound interfaces with no screen, the *musicBottles* (200), was created at MIT's Tangible Media Group by Hiroshi Ishii and colleagues. The user could play a song by removing the cork from the bottle, providing her or him with the sensation of freeing music from an object (see Figure 3.2). The concept of the bottle as a container for digital data was described in Ishii's AmbientROOM project in the following manner:

> Small physical bottles are employed as a graspable 'containers' for digital content, such that opening a bottle 'releases' information into the ROOM. One bottle contains information about the load on our computer network, and when opened, that data is represented in the ROOM as the sound of vehicular traffic. (Ishii and Ullmer (1997), p. 6)

The familiar bottle object acts as a powerful metaphor engaging the user action. However, the interactive feedback reduces the bottle to an on-off switch: the bottle can be either opened to play the music tracks or closed to stop them. But, the opening and the closing of the bottle constitute rich gestural actions: the continuous motion of the hand, its tensions, speed and the variations of pressure can communicate a great deal about the situation and the user. In *musicBottles*, the computer interprets these complex actions only as discrete triggers based on a set of conditional 'if-then' principles, and by doing so, does not harness the interactive potential that could be afforded through a physical artefact.

Figure 3.2: musicBottles by Tangible Media Lab (2000)

So what makes a tangible interface enactive? Based on the theoretical framework by the musician Newton Armstrong, researchers Bennet and O'Modhrain formulated a framework (shown in Figure 3.3) that takes into account two important properties of enaction: the engagement of the user and the timing of the response (Bennett and O'Modhrain 2007). The engagement is defined as the situation in which the agent is present and actively manipulating an interactive system, while timely activity is the one that is constrained by real-time events (Armstrong 2006). Within this framework, the *Pebblebox* device described in Chapter 2 can be defined as both tangible and enactive experience, while the *musicBottles* project was positioned as not very engaging and partially timely because it responded directly, but discretely. Thus, it is a good example of a tangible interface, but not of an enactive one.

These examples show that the shape, structure and materials of an interface define the ways in which the user may handle it. In addition to these physical properties of the object, the richness of bodily experience varies according to the ways in which the feedback is coupled to the user's action. The discrete feedback used in *musicBottles* is similar to that of the *Sonic Finder* project, even though it does not incorporate a screen. Neither interface sonifies action itself, but both rather provide sonic response at the end of an action. The feedback acts as a signal that the task is accomplished and the sound does not depend on the way the action is performed. For example, the music from the bottle will not play

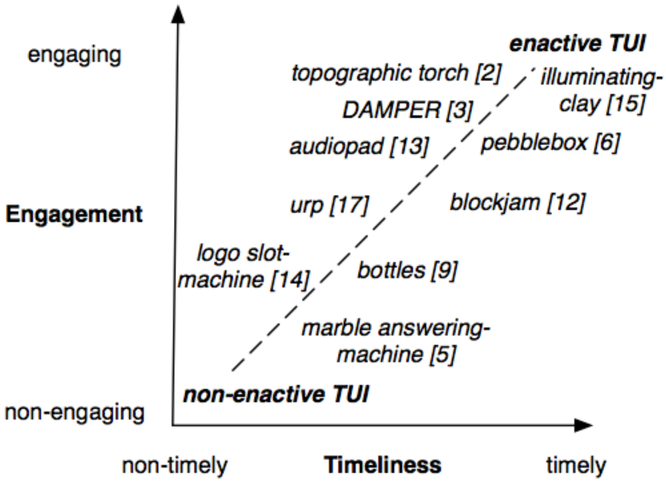


Figure 3.3: Diagram describing enactive and non-enactive TUIs. Reproduced from (Bennet and O'Modhrain, 2007)

more quietly, if one pushes the cork only half way in or moves it slowly. Thus, providing more tangibility and using objects as embodied metaphors does not necessarily result in a more engaging bodily experience. Rather, the timing of the responses and the continuous coupling between action and sound must be considered in order to engage with the user's *process of acting*.

3.2.4 Augmented Musical Instruments

These issues have been addressed within a growing New Instruments for Musical Expression (NIME) community (Poupyrev et al. 2001) focusing on the design of new sensor-augmented devices that seek to elicit more nuanced and expressive forms of human-computer interaction than traditional interfaces such as keyboards or screens.

Such sensor-augmented controllers can be seen as a new kind of instrument (see Waisvisz's work in the previous chapter). The physical manifestation of such instruments varies depending on the context and include everything from cell phones to giant metal stretched strings that connect two remote locations, as in the Global String project by Atau Tanaka and Kasper Toeplitz (Tanaka and Bongers 2001). Similar to the Crackle Family project by Waisvisz described in Chapter 2, the affordances of the large string and the simplicity of physical interaction enable musical non-experts to play with the instruments (see Figure 3.4) .

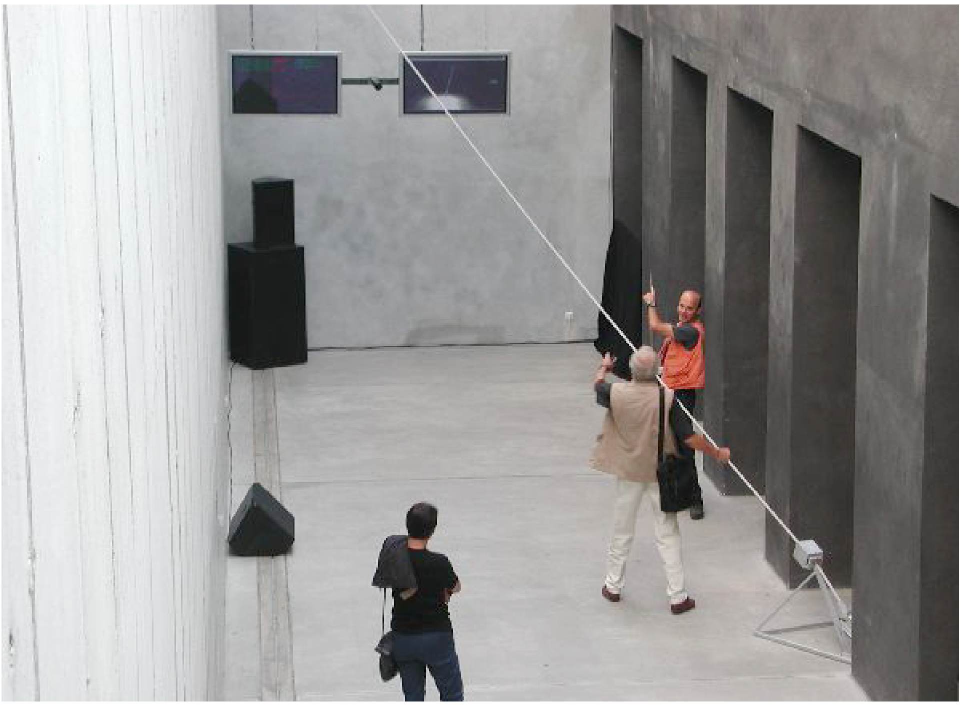


Figure 3.4: Global String (Tanaka and Toeplitz 1998-) Reproduced from http://www.ataut.net/site/Global-String

The sonic interaction is based on a model of musical expression that involves many components: real-time sensor input for the real-time control of musical parameters and related techniques for the conditioning, analysis and feature extraction of sensor signals, and mapping strategies for creating relationships between input and output parameters and the sound synthesis algorithms (Cadoz and Wanderley 2000; Miranda and Wanderley 2006; Bernardini et al. 2007). These components suggest that a model for sonic expression might consists of the following formula:

input (sensing) > mapping > output (sound synthesis) = musical expression

This model is based specifically on the design of a sensor-augmented musical device by way of gestural input both tethered (to an object) and untethered (empty-handed). The tethered or *instrumental gesture* is described as the manipulation of an instrument that is necessary to mechanically produce sounds (Cadoz 1988)). Playing a classical instrument includes a closed coupling between the body of the musician and the instrument. Instrumental gesture is complementary not only to traditional computer interaction, but also to the empty-handed gesture, one that seems to dominate HCI research in virtual environments and video conferencing (Miranda and Wanderley 2006). As music researcher Claude Cadoz stated: 'There is an energy transfer between the hand and the object. The hand acts on an object.' ((Cadoz 1988), p. 9)

Thus, such instrumental gesture is also found in the use of any physical object, from everyday things to musical instruments. The design of sonic response to instrumental gesture brings together HCI, sound and music technology research communities. Researchers Georg Essl and Sile O'Modhrain proposed transferring the common gestures performed with everyday objects to new musical interactions (Essl and O'Modhrain 2006). The familiar form and continuous sonic feedback of their instruments allowed the user to be easily immersed in a musical experience. Indeed, musical and everyday instrumental gesture share numerous engineering, perceptual and creative problems, including the design of continuous feedback in order to engage and motivate the user.[1] Moreover, everyday gesture poses social and cultural questions that differ from those related to music performance. However, the opposite direction, namely engaging unfamiliar gestures within everyday contexts, has been far less explored.

While appropriate within the context of shifting attention away from traditional input devices to potentially more body-centred controllers, it can be argued that the NIME model is not a sustainable one for Enactive Sound Design because of its almost formulaic understanding of interaction as a series of input-output processes. A gesture triggers a mapped series of responses, which may be adjusted based on the range of expression of the input. Such an approach assumes a fixed set of relations between the user, the sound making object and the environment in which the interaction takes place. This definition of interaction is far too *abstract*, because it does not take into consideration the shifts in the environment that can potentially alter the interaction over time, nor the ways in which the experience of interaction, the *production of expression*, may change in relation to the object which is being interacted with. Abstract here signifies what Francisco Varela called the input-output model of cognition-perception: 'the information processing problem of recovering pre-given properties of the world' ((Varela 1999), p.12).

In contrast, an enactive understanding of interaction suggests that the *starting*

[1] I organised a three-day expert workshop on Musical Gesture and Sonic Interaction in which we tried to bridge the theoretical gap between music and design. For more information, see http://blogs.iad.zhdk.ch/gestureworkshop/

point for perception is the perceiver's actions, and not an already pre-given, pre-designed world. Consequently, such sensorimotor action with and within the environment also continually modulates the local situation. Thus, while an electronic sensor cannot necessarily understand the context in which it senses, the sensorimotor apparatus of the human body searches specifically for the intuitive handles that enable it to explore, discover and shape, that is, interact with the environment it finds itself within.

3.3 Emerging Roles for Interactive Sound

Sonic interaction design (SID) is a new research areas brings together the existing fields of product sound, auditory displays, tangible computing and new musical instruments, but with a strong design approach. Sound is considered as 'one of the principal channels for conveying information, meaning and aesthetic/emotional qualities in interactive contexts.' ((Rocchesso et al. 2006), p. 2). In order to use sound in such ways, various questions need to be addressed: the perceptual, cognitive, and emotional study of sonic interactions, the role of sound in the performance of physical actions, sound synthesis technologies and creative and evaluation methods addressing the aspects of interactive sound experience.

Clearly, the SID community's tackling of these issues has to be highly interdisciplinary, and should involve researchers from arts and music, communication and cultural studies, psychology and cognitive sciences, engineering, computer science, architecture and design. However, different disciplines with their specific disciplinary jargons, methods and professional goals have made it hard to collaborate, with most researchers coming from engineering, computer science and psychology. I witnessed these problems within the SID research network, but also in the process of editing the book on sonic interaction design.[2] Some of these difficulties are aggravated by the importance of disciplinary publications within the economy of academia, and the difficulty of publishing transdisciplinary research. Researchers are struggling with disciplinary and fragmented approaches that neglect the overall needs of the end users as well as make difficult the development of practical design guidelines.

The overall goal of sonic interaction design is to create opportunities for new

[2] As the editor of the main chapters of the SID book, I have encountered difficulties not only in terminology but also in various approaches to sound, most of which were not design-centred.

sonic experiences for everyday settings. Thus, I suggested that determining the roles that sound may play in the interaction loop between users and artefacts, services, or environments appears to be a crucial problem (Franinović et al. 2007). In order to address this issue, I surveyed interfaces that use sound in tangible artefacts and identified the following roles for interactive sound:

- *Adding new functionalities to an existing product:*

  Here, sound adds informational and interactive potential to an existing device. For example, an everyday object may be linked to a computational process that is presented to the user in terms of changing sonic atmosphere. This is a case in the *Nike+* product, where a jogging shoe was extended into an interactive device tracking a running performance of the user. Based on this data, the music is played back to encourage the runner to improve his or her performance. Because the information about the runner's performance is communicated auditorily rather than visually, he or she can be immersed in physical activity without the added visual information load that would traditionally be presented through a screen. However, *Nike+* uses sound in a discrete rather than continuous way, as it simply changes the song rather than the quality of sound.

Figure 3.5: In *Shoogle* (2007) by John Williamson, Roderick Murray-Smith and Stephen Hughes, the user can access information while the phone moves naturally in his pocket

  In contrast the Shoogle (Williamson et al. 2007) project deploys sounds in an ecological and continuous interaction. It engages existing sensorimotor knowledge learned in early childhood, that of shaking the contents in a box, in order to present mobile phone information. Digital information is accessed through habitual physical movement. When the phone is shaken, it generates the sound of balls bouncing in a box filled with a viscous material. The number of balls corresponds to the number of sms messages. The user hears different ball sizes that reveal the importance of the messages, and their materials which communicate the identity of the sender. The viscous material within which the virtual balls are bouncing represents the battery level. Thus, the user simultaneously and quickly perceives all of these details by listening to the sonic responses to his or her actions.

- *Shaping the multisensorial experience with an artefact:*

  Sound is used to simulate the mechanical workings that are expected to be found in such products. For example, the actions of scrolling the ball of the *Mighty Mouse* by Apple or turning the wheel of the *iPod* generate the sounds of a ratchet, even though such a mechanism is absent from the actual object. Such use of sound may induce a haptic sensation that a real mechanism would generate. This phenomenon of inducing the haptic sensations through other senses has been labeled 'pseudo-haptics' (Lecuyer et al. 2004). Pseudo-haptics illusions have been shown to work for auditory displays (Fernstrom et al. 2005), but even earlier designers have created them in products like the iPod without being aware of the exact workings of their perceptual effects. This is an example of tacit design knowledge being successful without previous scientific proofs.

- *Affecting the user's physical performance with an artefact:*

  Sound appears to aid the focus and flow experienced by the user during an interactive experience. In the *Nintendo Wii* game controller, discrete sonic feedback is coupled to movement to engage users' actions. For example, in the Nintendo Tennis game (see Figure 3.6), the impact of the ball coincides with the sonic and vibrational feedback emanating from the hand-held controller, creating a sensation of hitting a real ball. When the ball hits the opposite side of the virtual tennis field, the sound of the impact between the ball and the ground emanates from the speakers attached to the screen. Even such minimal feedback makes a big difference in the user's engagement in the game. However, the visual response on the screen requires the directional attention of the player, constraining his or her movements. Sound, on the other hand, affects the 360-degrees presentation of the environment, enhancing the gamer's sense of immersion. Once such devices become untethered from screens and embedded into everyday artefacts, enactive sound can be exploited to its full potential.

Figure 3.6: Publicity for Nintendo game controllers: Although the users are looking at the screen and spatial arrangement of players is not correct, the marketing intends to communicate their freedom in physical engagement

These roles address the question pivotal for Enactive Sound Design: How can tethered gesture be coupled with embodied sonic feedback in order to shape, aid and affect the user's experience? In the above examples, existing bodily habits are exploited and no enactive learning takes place. The user associates the sounds heard with specific information (e.g., Shoogle) and is not required to learn through physical exploration of movement guided by sound (e.g., Ballancer). Although enactive learning is powerful, it is still rarely present in interaction with digital technologies and its potential remains unexploited.

3.3.1 Movement Sonification

Recently, more interactive uses of sonification have emerged, as researchers within auditory display community have realised the benefits of using human gesture to explore sonic data (Hunt and Hermann 2004). In interactive sonification, users can selectively control data sets through movement and sound (Hermann and Hunt 2005). The auditory signals provide information about either the data under analysis or the interaction process itself. The latter sonification example holds the promise of more enactive auditory displays

(Milczynski et al. 2006). Particularly important for enactive sound design is the sonification of tethered user gestures, i.e. those gestures that are performed with a physical object in the hand of the user. Researchers Hermann, Milczynski, Ritter and Tuennermann have explored sonifiction of complex data sets, such as EEG, by the means of a sensing object and through multitouch technologies (Milczynski et al. 2006; Tünnermann and Hermann 2009). Also valuable for enactive design are recent systems for movement tracking and interactive sound. For free and full body gestures, a sonification frameworks based on motion capture systems are most suitable for capturing movement, such as MotionLab (Effenberg et al. 2005), while interactive systems such as AcouMotion system use sensor devices to capture movement, such as Acoumotion (Hermann et al. 2005). The later system uses three types of auditory display: continuous sounds that change certain acustic parameters, discrete sound events and ambient sound.

Since this doctoral research started in 2005, interactive sonification has been proving to be a useful approach to monitor activities related to sport and to improve athlete performance. Effenberg mapped the vertical force in the countermovement jumps, captured by a sensor plate, to the amplitude and frequency of a sampled vocal 'a'. He showed that the accuracy of the reproduction of jumps was best when the athletes were provided with a combined audio-visual feedback, compared to the visual and auditory condition (Effenberg 2005). Movement of swimming breast strokes was also sonified using MotionLab system, but not used in any empirical study (Höner et al. 2011). An exploration for full body movement in connection to an object, a German wheel was conducted by Hummel, Hermann, Frauenberger and Stockman. They showed that a sonification of a German wheel movement could improve athlete's performance and that different types of sonification could have various advantages and disadvantages for performance. They argued that psychophysical experiments and long-term studies are needed in order to statistically prove that sound can support learning and assist a trainer. Movement scientists Schaffert, Mattes and Effenberg researched a sonification of the movement of the boat in rowing. They showed that by directly coupling the propulsive boat acceleration and velocity to a variable frequency tone, the elite rowers improved their interpersonal coordination, and resulted in an increase in the boat velocity (Schaffert and Mattes 2010; Schaffert et al. 2010).

Finally, sports in which an object is held in the hand of the athlete have also been sonified. Bovermann, Groten, de Campo and Eckel coupled different parameters in juggling of the clubs, namely left-right triggers, rotation, distance to head, rotation trigger and crossing of horizontal planes, to sonic feedback based on the decaying envelopes and continuous sonic feedback. The sound was spatialized in a twenty-four speaker setup (Bovermann et al. 2007). Kleiman-Weiner and Berger designed sonic feedback for a golf swing. The velocity of the golf club head and the relative rotation of shoulders with respect to the hips were mapped to resonant filters generating vowel sound (Kleiman-Weiner and Berger 2006). Acoumotion framework was used to create Blindminton game, which is similar to the racket game badminton and intended for a visually impaired persons (Höner et al. 2011; Hermann et al. 2005). While these examples provided interesting sonification approaches, they did not provide the evaluation of the performance with the sports objects. However, the Acoumotion system was also used in the evaluation of the sonificiation of a goalball with a visually impaired paraolympic athlete, Conny Dietz. The sound of the rolling of the ball was spatialized using five speakers arranged in a semi-circular fashion. The results showed that the subject was most precise when the velocity of the rolling ball was closest to the actual real ball condition, i.e. the one to which the subject was most used to. The authors argue for the need for the research on audio-motor control and learning.

In movement rehabilitation, PhysioSonic system was used to encourage shoulder and arm exercises in patients with limited mobility. The movement of the upper arm was tracked via motion capture system and was mapped to metaphorical sounds (Vogt et al. 2010). Different heights of the raised arm and unintended arm movements activated different sounds, while music and speech aimed to encourage the patient to exercise. The authors argue that the sonic feedback enhanced the awareness of the body movements, and are preparing a pilot study in the hospital context.

3.4 Why Design Sound for Action?

A discussion of the roles of sound in interaction brings us to consider the reasons for using auditory feedback to engage action. In our everyday life, the dominance of the visual culture and the increase of noise levels have contributed to the idea that sound, unless organised in the accepted musical structures, is unnecessary and undesired. Such claims have been disputed by proving that the quality of life is not improved by removing sound, but rather by shaping its aspects (Brown et al. 2009; Blauert and Jekosch 1997). Put simply, a lively square with children playing and barking dogs may be a more desirable auditory experience than an empty silent street. Acoustic annoyances and disturbances are still an issue in everyday contexts, but well-designed auditory interfaces can be an unobtrusive and meaningful part of our experiences (Brown et al. 2009). The shift from *no sound* to *quality sound* has been emerging in different disciplines as well as in projects that involve user in sound production and/or listening; one example in the arts would be soundwalks (Westerkamp 1974).

In this thesis, I argue that by designing sound for action, a more aware and explorative engagement of the user with and within his or her surroundings can be achieved. But what is the purpose of enabling this type of active relationship between the user and the soundscape? And what are the benefits of sound as a medium for engaging action?

3.4.1 Functional Benefits

The overall advantages of using sound in interaction design have been shown through experiments (Gaver 1997; Kramer 1994; Brewster 2002) and case studies such as in interfaces that lack visual displays and in complex time-based data sonification (Baier et al. 2007; Pauletto and Hunt 2009). The specific arguments for using sound as feedback to physical movement are particularly strong. First, sound is omnidirectional, and therefore it does not require the user's directed attention in the way that visual media does. This quality can make interaction particularly immersive and natural; a user can move around freely and interact with the physical world while receiving information through sound. Second, sound is a temporal medium and is suitable for accompanying and responding to continuous time-based experiences. Thus, it can be well-synchronised with bodily movement. Third, users can perceive information about physical events through audition, which, in return, can directly affect their actions. For example, if (without looking at the glass) a user is pouring water and hears that the glass is almost full, she or he can immediately stop pouring the water on the basis of auditory information. Fourth, the emotional power of sound can be used to engage or disengage users in performing an action. For example, fast rhythmic feedback can stimulate a user during a sports activity. Finally, sound can present complex information by using peripheral awareness that can be valuable for supporting sensorimotor learning. For example, when the correct movement is learned during physical rehabilitation, its sonic feedback can be reduced in strength but can still peripherally communicate to the user.

These perceptual and physical properties of sound allow designers to create a more engaging and immersive sense of interaction. In the past, some of these properties were hard to exploit due to technical limitations; however, today computing capabilities have increased and both the hardware size and memory requirements have been minimised so that interactive sound can be easily and cheaply embedded in everyday products. Gaming applications, sensorimotor rehabilitation, and sport and body training are promising application domains for Enactive Sound Design.

3.4.2 Acting within a Soundscape

In addition to the functional benefits of sound, Enactive Sound Design may be able to make other, broader contributions to the human experience. Murray Schafer, the father of soundscape research, argued that the awareness of our sonic actions may be the key to reshaping the quality of our everyday lives (Schafer 1994 (1977)). This type of awareness could be enhanced through a clear relationship between a person creating sound and the sonic effects produced. However, this relationship is disturbed by certain perceptual phenomena as well as by technological and design strategies.

On the perceptual side, the awareness of our sonic agency is decreased because we are less conscious of sounds we make than we are of those others create.[3] For example, the car driver perceives his or her car noise differently than does a passerby. Thus, we can design products so to increase the awareness of sounds we make, allowing us to take the responsibility for our contributions to the overall soundscape.

Another obstacle to taking ownership of self-produced sounds is the fact that, when using digitally augmented devices, our agency is often displaced from its effects. Schafer coined the term *schizophonia* to describe the phenomenon of separating sound from its source through technological means, such as recording devices or telephony (Schafer 1994 (1977)). Similarly, we can think of splitting human action from the effects it causes as a kind of *schizoagency*. An example of

[3] I discuss this in more detail in Section 2.3 of this chapter (Chion 1998; Ballas 2007).

sonic *schizoagency* would be that of hitting a nail with a hammer, but hearing its effects in a different location and in different time.

Technology makes such schizoagency experiences possible. For example, the sound of a mobile phone ringing during a lecture is embarrassing because it signals that the owner forgot to turn the phone off (agency 1). However, the ring also represents the action of the caller (agency 2), who cannot perceive the effect of his action in the context in which the call is received. Moreover, a third agent, the university (agent 3), had the potential to block the mobile network in the lecture hall. In this scenario, agency is distributed across people, technological devices, and infrastructure. However, the only person who could take the consequences of this disturbance during the lecture is the receiver of the call, who in fact did not directly cause the ringing of the phone.

When the sound is separated from its source, our interpretation of the cause of the sound event is challenged, affecting our perception of the agency and potentially decreasing our responsibility for the sound we produce. While others embrace *schizophonia* as a principle of contemporary living and a basis for sound design (Hug 2008), I argue that designers must consider the negative effects of *schizophonia* and *schizoagency* on users' actions. In our cacophonous world, taking responsibility for self-produced sound is an ethical issue. The currently dominant automatic sounds in digital products could be substituted or complemented by sounds directly linked to the user's action. Thus, the broader goal of designing self-produced sound is to bring agency back into the hands of the user. Designers can play an important role in creating transparency between our actions and the sonic effects of these actions, raising awareness of our sonic agency in the world.

3.5 Conclusion

This chapter has shown that different design strategies support and shape specific roles that sound can play in interaction with objects. Although a range of such roles has been explored, from the critical functionality of an alarm clock to the artistic significance of music creation, the most promising opportunity for novel application of interactive sound appears to be its capability to engage users in bodily interaction (Franinović et al. 2007; Franinović 2008*a*). Moreover, existing applications and products show that societal and technological conditions are ripe for a physically more engaging interaction with computing technology.

However, only a few tangible interfaces that have been developed are truly enactive and related research has been dominated by engineering and scientific approaches. Artistic and design projects that may contribute on a transdisciplinary level lack a structured practice and are often separated from these technology- and science-motivated environments. Therefore, there is a need for a more specific methodology that can enable designers not only to navigate many different disciplines, but also to collaborate with scientists on emerging enactive sound issues, such as multisensoriality and continuous feedback to action.

As discussed, some aspects of the existing auditory practices are beneficial for Enactive Sound Design, while others block the potential for *doing with sound*. These can be summarised as follows (see Table 3.2):

- In product sound design, attention is slowly moving from reducing auditory annoyance to shaping sound quality. Multisensory interplay is being studied by psychologists, who have been showing that sound can influence other senses and alter the user's perception of an object or experience.

- New design strategies can be developed by working with human perception, as has been showed by Gaver's cartoonification approach.

- Auditory displays and sonification research teach us that everyday sounds can be useful metaphors for interaction.

- Tangible media approach exemplifies how existing enactive knowledge can be engaged through the use of objects as metaphors for interaction. By contrasting the discrete interaction through representative metaphors typical for tangible interfaces to continuous feedback and performative engagement of enactive systems, we can better identify the new roles for sound in digital products.

- NIME's conceptual frameworks for enactive instruments and mapping strategies address the qualities of an enactive experience: namely expressive sensorimotor knowledge, multisensoriality and continuity of

Approach	Role of Sound	Design Strategy	Goal
Product Sound	none silencing the action	through mechanical design	noise reduction
	representative emotional	use emotional power of sound during interaction	strong product identity
	modulates multisensoriality	alter user's perception	change perceived product quality
+ multisensoriality, tangibility, emotion		- sound removal, representational use	
Auditory Displays	functional	earcons abstract sounds	alert about the computer processes
	immersive	auditory icons everyday sonic metaphors	create a more immersive experience
	informative	sonification	explore complex data
+ metaphors, sonification, cartoonification		- symbolic and iconic use, reduced tangibility	
Tangible Interfaces	material content	tangible metaphor	ease of interaction
	immersive	co-locating action and sonic response	natural sense of cause-effect loop
+ metaphors, tangibility, embodiment		- symbolic and iconic use	
Augmented Musical Instruments	expressive	coupling analog gesture to digital sound	express artistic intention
	creative	inventive mapping of input data to sound	create unknown musical spaces
+ conceptual frameworks, gesture, continuity		- weak design approach	
SID	new functionality	add to the existing product	expand the existing use
	pseudo-sensory feedback	use one modality to affect another	alter user's perception and action during product use
	control/guide movement	use continuous coupling of sound and action	guide and change physical movement
+ multisensoriality, tangibility, continuity		- too many disciplines	

Table 3.2: Comparison of the approaches to designing interactive sound.

auditory feedback to action. Related findings in musical contexts could be adapted and transferred to habitual everyday gestures.

- The SID community works with these issues through interactive sonification and physical sound modelling coupled to human movement. Researchers begin to integrate a design questions into scientific and technological fields.

On the downside, these approaches neglect the potential of sound in relation to physical action. These disadvantages can be grouped in three problem areas:

- EVALUATION

  Firstly, research efforts are taking place on a disciplinary level, as witnessed by the existing product assessment procedures. The evaluation methods are developed by psychologists, but without the involvement of designers who have tacit knowledge about the subject. This leads to evaluation that is an added element at the end of the creative process, rather than integrated within an iterative loop of improving a product idea and prototype. Moreover, these tests follow traditional guidelines for a psychological evaluation of auditory perception, whereas Enactive Sound Design necessitates a more complex evaluation of how shape, movement and sound may affect user's perception and action. The gap between design practice and scientific evaluation was one of the main issues for which the CLOSED research - a central project of this thesis - was initiated. The problem of enactive sound evaluation is addressed in Chapter 5.

- DESIGN

  Secondly, digital products are still dominated by auditory displays working with symbolic and iconic knowledge. Even in research, auditory display frameworks do not consider the core problems of enactive design such as sensorimotor interplay. Meanwhile, tangible computing projects often limit themselves to objects as metaphors, neglecting the qualities of physical action. Although dealing with directly and continuously providing feedback to movement, new musical instruments research is tech-centric and does not need to work with everyday gesture and broad user groups.

Solutions of how to integrate, understand and shape sonic gesture in a designerly way are proposed and evaluated in Chapter 4.

- TRANSDICSPLINARITY

  Thirdly, this chapter showed that shaping auditory perception can be, and has been, exploited by the market for profit. This raises questions about the role of sound within our society and everyday life. Thus, a reflection on social and cultural issues is needed in order to raise awareness of the effects of interactive sound. This is particularly the case for researchers whose topics are rather narrow and thus tend to lose the picture of the larger outcome of their work. Including the critical view in working with enactive sound could increase researcher's awareness and responsibility for shaping future. Strategies for achieving this goal within a transdisciplinary context of Enactive Sound Design are presented in Chapter 6.

In summary, through a review and analysis of existing practices, I identified key problem areas that need to be addressed to enable Enactive Sound Design. I proposed that the sonic agency is the key element to raise awareness and responsibility for our contributions to everyday soundscapes and thus for improving the quality of life. If we want to achieve this goal, the three problem areas described here must be tackled practically, in order to bridge the gap between science and design in a concrete manner.

Chapter 4

Action-Sound: Basic Design Methods

Designers understand the world through a tacit knowledge of materials and the experiences these engender. How can enactive sound be designed in such a direct embodied manner and yet create new knowledge and practices that can be shared? The relative lack of designerly research that currently exists for those working with sound makes it difficult to answer this question. In this chapter, I propose new creative methods based on a level of structured exploration that has been instrumental in formalising design processes for nearly a century, that of basic design. I formulate the notion of basic interaction design by extending the current research on interaction gestalt and, through practice-based explorations, exemplify a basic design methodology for enactive sound. The latter consists of two main parts: the subjective examination of everyday activities in which sound is generated and the creative experimentation resulting in a number of abstract sonic artefacts.

Parts of this chapter were previously published in an article 'Toward Basic Interaction Design' in special issue on design research in Elisava Temes de Disseny Journal (Franinović 2008b) and my chapter 'Basic Interaction Design for Sonic Artefacts in Everyday Contexts' in the book 'Focused - Current design research' (Franinović 2008a).

4.1 Introduction

The interaction designer and educator Gillian Crampton-Smith often began her lectures with the following statement: ‘Designing the right thing. Designing the thing right‘ (see also the interview in (Caenepeel 2003). To design the right thing means to find culturally, socially and functionally suitable solutions, while designing the thing right reflects the aesthetic choices made when handling materials. However, in interaction design, a predominantly technologically driven and socially concerned discipline, these choices are often neglected. They are often assumed to be an obscure part of the creative process that cannot be explained or, at the other extreme, aesthetics is taken over by the functionality and efficiency of an interface. Considering creation as an intrinsically individual, quasi artistic process makes it hard to formulate and to share knowledge about interaction materials and processes. The aesthetic guidelines remain borrowed from the ‘older’ design disciplines such as graphic, sound and product design, but the aesthetics of interaction itself, particularly its temporal aspects, remain underexplored. This issue is even more nuanced in an enactive approach dealing with the performative processes fostered through physical objects.

Indeed, the actual object around and through which experience evolves is often absent in the quick-prototyping and ethnographically-inspired methods (Maze and Redström 2005). This may have led to overlooking the aesthetics aspects of interaction that are embedded in the artefact itself. One promising path for working with the aesthetics of interaction appears to be the research on interaction gestalt that combines the spatial and temporal aspects of interactivity (Svanæs 1999; Lim et al. 2007). It is grounded in Basic Design - a structured, yet creative approach to exploring materials that draws its roots from early design history. This approach enables the pursuit of research through design, because it combines the theoretical and methodological foundations of design disciplines (Findeli et al. 2008). Such foundations are particularly important when a new field emerges, as is the case in interaction design, and more specifically Enactive Sound Design, today.

In this chapter, I propose a structured exploration of interactivity through a study of dynamic action-sound relationships, inspired by basic design principles. The main goal is to understand how to identify, analyse and recombine the object’s sonic, physical and interactive properties that engender an enactive experience. The proposed approach combines tacit methods, or learning by doing, with research in real context and classic usability methods.

I have chosen to follow a basic design prospective for a number of reasons. Firstly, because its methods relate the material qualities of an object to the senses and actions activated by that object. Secondly, its techniques such as reduction, abstraction and translation can help identify unfamiliar gestalt qualities, for example those that create an enactive sonic experience. Thirdly, basic strategies for experimentation with elements of shape, form, colour, texture and light are useful for considering multisensory complexity and user engagement. Because the core of basic design is a tacit, explorative and enactive knowledge that the designer acquires from working with physical materials, I believe that such methods should be the basis of enactive design.

The main contributions presented in this chapter are:

1. extension of the discourse on interaction gestalt through a definition of basic interaction design and proposed methodology

2. development and evaluation of the analytic methods for identification of basic action-sound relationships from everyday activities

3. development and evaluation of the synthetic methods for exploration of the relation between action, sound and form through abstract objects

4.2 Basic Interaction Design

Since its foundation, basic design has been both a creative strategy as well as an educational practice. It is predominantly a visual approach to design research and education grounded in the analysis of perceptual experience in terms of simple, abstract properties, such as forms, patterns, or colours. Its origins can be traced back to the kindergarten movement of the early 20th century, but it was firstly taught as design practice at the Bauhaus School of Art and Architecture and at the Vhutemas School in Moscow.

4.2.1 Distilling from the Real World

In these schools, students often worked with predefined abstract elements and thus it is almost forgotten that these elements were actually abstractions of real-world objects. This can be seen in the drawings of Ramsauer (see Figure

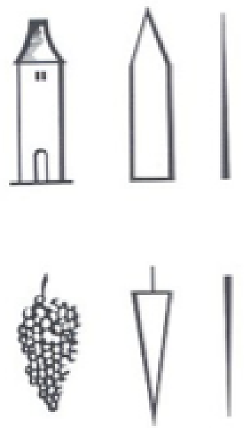
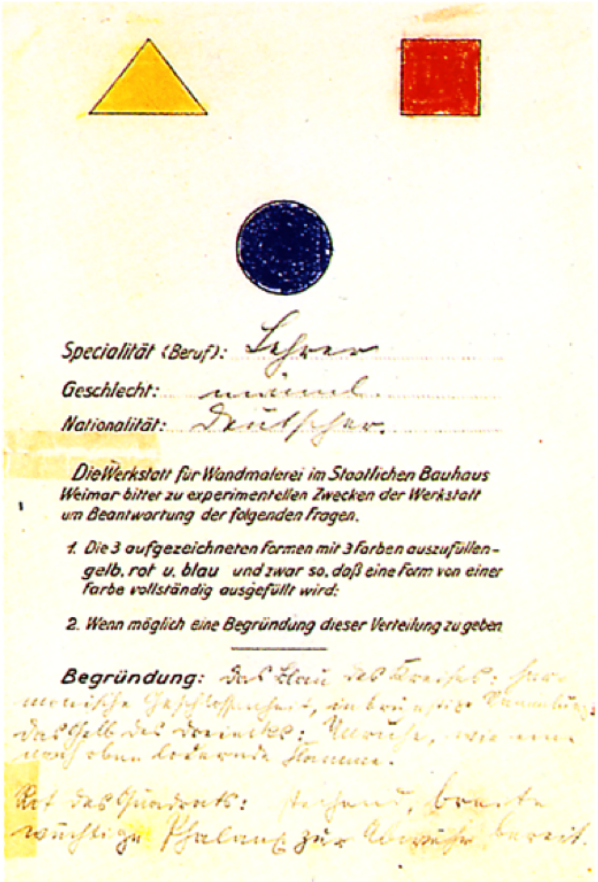


Figure 4.1: Drawing plates show the process of abstraction of a graphical element from an everyday object. Reproduced from (Lupton and Miller pp. 6)

4.1), one of the predecessors of basic design, that show how reduction and abstraction from real-world objects can help define abstract elements (Lupton and Miller 2000). Although the basic design approach is considered to be highly abstract, Ramsauer's work shows that its origins are bound to the contextual observation of our surroundings. Thus, the principles of basic design have actually been distilled from the everyday world and the ways in which we perceive it.

For this reason, many artists and designers worked to scientifically understand human perception. They searched for perceptual rules that could not be affected by a social and cultural context - the modernist ideal that was expressed in abstraction. One of the main goals was to uncover a universal visual language which would be independent of the limitations of alphabetical writing and could facilitate communication across different cultures. Various members of the Bauhaus School used experimental methods to study intuitive responses and the most frequently occurring perceptual relations between abstract properties such as graphics, colour and texture. For example, the artist Wassily Kandinsky performed a test in which he asked participants to fill in elementary shapes with basic colours, in order to identify a perceptual link between the two (Figure 4.2). His test was strongly biased because it was performed by students and colleagues who were already well informed about Kandinsky's theories (Kandinsky 1994). However, it exemplifies the affinity of basic design with an experimental, scientific approach to perception, particularly with gestalt psychology.



Specialität (Beruf):

Geschlecht:

Nationalität:

Die Werkstatt für Wandmalerei im Staatlichen Bauhaus Weimar bittet zu experimentellen Zwecken der Werkstatt um Beantwortung der folgenden Fragen.

1. Die 3 aufgezeichneten Formen mit 3 Farben auszufüllen – gelb, rot u. blau und zwar so, daß eine Form von einer Farbe vollständig ausgefüllt wird:

2. Wenn möglich eine Begründung dieser Verteilung zu geben

Begründung:

Figure 4.2: Wassily Kandinsky's test from Berlin Bauhaus-ArchivMuseum fur Gestaltung. Reproduced from (Droste, 1998)

4.2.2 Gestalt Qualities

A precursor of gestalt psychology, the philosopher Christian von Ehrenfels, formulated the notion of gestalt qualities in his paper 'On Gestalt Qualities' published in 1890. He argued that the perception of form or melody is not caused by the individual elements, but rather, by their combination. For example, a melody can be played with different notes and still be recognisable. Ehrenfels defined spatial shapes, melodies, chords and complex tastes as gestalt qualities which, themselves multisensory phenomena, could be combined in more complex gestalt qualities. They were not seen as a sum of elements, but as 'something new in relation to these, which exists together with [their] combination, but is distinguishable from it' (Ehrenfels 1988, p. 93). Similarly, the psychologist Max Wertheimer argued that it is a dynamic interaction between these elements that causes a perception of the whole, giving the example of the effect of apparent movement. In his paper titled 'Experimental Studies of the Perception of Movement' from 1912, Wertheimer showed that when two stationary objects are presented in succession at different places they appear to move. Ehrenfels' gestalt qualities resonate with enactive sound qualities and the approach of shaping the user experience through the interaction of different stimuli.

4.2.3 From Perception to Action

Bauhaus members worked to explore such perceptual interactions in a tacit and practical way. The temporal properties of the creative process attracted more interest, for example, in the explorations of graphical elements. As Kandinsky wrote: 'a line is a track made by the moving point: that is, its product. It is created by movement' (Kandinsky 1979, p. 71). Working with the manipulation of form and the creative process extended the practice of basic design from studying perception to exploring through action. Although the initial focus was on the perception of visual and formal aspects of objects, it also included the three-dimensional form that could be physically handled.

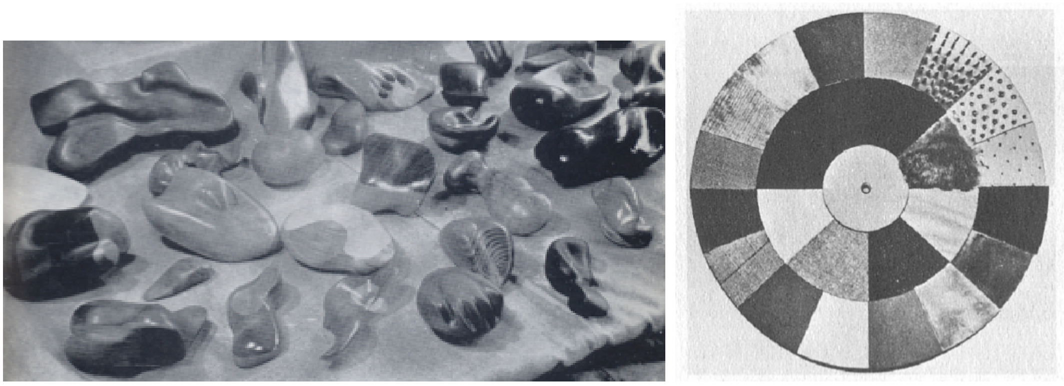


Figure 4.3: Students' works for Laszlo Moholy-Nagy's *Designing for the Hand* exercise and the revolving tactile chart by student Walter Kaminsky (1927)

The best example is the work of the artist and educator Lazlo Moholy-Nagy, who regarded phenomenological experience as a result of the interplay between various senses and actions in time. He included touch and movement as qualities to be explored in basic design, as a result of his courses at the Bauhaus school demonstrate. For example, the tactile charts and haptic structures in Figure 4.3 were created to engage touch and provided various sensations of pressure, temperature and vibration. Such objects afforded sensorimotor exploration and discovery through manipulation and use, thus turning the user into an active player who creates his or her own aesthetic experience, and thus meaning, by interacting with the world. Therefore, Moholy-Nagy developed a new dimension of basic design, expanding its methods towards the exploration of active perception and the affordances of an object.

4.2.4 Interactivity and its Gestalt Qualities

> Compared with traditional design disciplines, there is a relative lack of established traditions in the design of computational objects based on the materials we use. Deep knowledge of the materials at hand provides a basic understanding of what can be done and how - many areas of design practice are defined in relation to the materials employed rather than the usage area. Working with new and complex technologies has meant that deep knowledge of these materials have been topics for engineering and scientists. However, in considering computation as a basic material we work with in the design of new things, we need to develop an understanding of computational technology as used in design. (Maze and Redstrom 2005, p. 8)

As interaction designers Ramia Maze and Johan Redstrom argued, materials have rarely been explored in the field of interaction design, especially that of tangible media. The existing methods for forecasting use do not address 'basic design questions and the need for methods for designers to develop a deep understanding of the appearance in use, expressions, and aesthetics of the computational object itself.' (Maze and Redström 2005). Although interaction designers are still in search of the way to define appropriate ways that can enable them to tacitly engage with interactivity, most agree that interactivity enhances the temporal aspects of an object.

Maze and Redstrom, for example, reconsidered the notion of physical form as spatial and temporal phenomenon (Maze and Redström 2005). They defined the temporal form as the one related to the use of the artefact and to its interactive behaviour, while the spatial form has been associated with the object as a collection of its physical properties such as size, shape, colour and material. Their argument was that an interactive experience can be created and improved by exploring the interplay between the temporal and spatial form of an object. To enable such a process, they proposed a two step design methodology and demonstrated it through their projects. First, they explored different combinations of materials that can create possibilities for new expressions, and then they investigated these combinations in the context of use. The goal of the second step was to explore how an artefact's properties would evolve over time in response to users' actions.

Figure 4.4: Sonic City interface in an everyday context. (Gaye, Maze, Jacobs and Holmquist, 2003)

In the *Sonic City* project, for example, a device generated sounds according to different environmental and personal conditions such as light, temperature and heartbeat (Gaye et al. 2003). In order to create different sonic patterns and musical variations, users had to move and change their own physical state and the conditions of their surroundings. Because the users required freedom of movement in everyday contexts, the designers reconsidered the spatial form and transformed a technological device into a jacket with different sensors (see Figure 4.4). Thus, the exploration of the temporal form (artefact in use) stimulated new spatial forms (artefact as object). However, it was not clear how the spatial and temporal aspects shaped their design decisions, making their reflection on the spatial and temporal form appear as an afterthought. Although their research revealed the importance of the elements that created an interactive experience: the physical manifestation of the object (spatial form) and related experience of its use (temporal form), their research lacked a clear process that could be reused by other designers.

4.2.4.1 Interaction Gestalt

The temporal form of an artefact and the opportunity to shape its use through computing technologies differentiates augmented objects from non-augmented ones. In order to explore this issue, the idea of interactive gestalt emerged as the means for basic design explorations of interactivity. Originally, the notion was introduced by the interaction designer Dag Svanaes in order to explain the way in which users perceive interactive behaviour (Svanæs 1999).

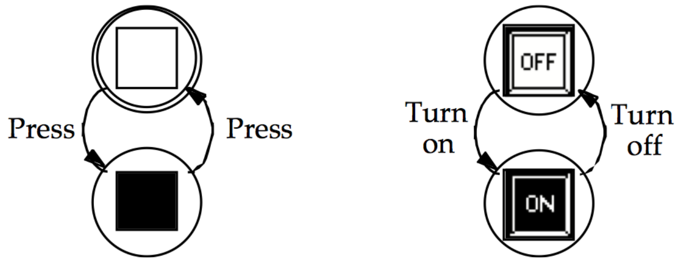


Figure 4.5: Through interaction, colour change emerges as a switch metaphor. Reproduced from (Svanaes, 1999)

He constructed the experiments using simple screen-mouse interactions with abstract graphical elements. These showed that users' attention was focused on the behaviour of the objects instead of on their formal characteristics. For example, a square on the screen was interpreted as a light switch due to the changes in the colour caused by clicking on it. Svanaes concluded that:

> ...the interactive experience has gestalt properties, i.e. that its first-class objects are interaction gestalts... you perceive the interactive behaviour not as a collection of action/reaction pairs, but as a meaningful interactive whole.' (Svanaes 1999, p. 218)

These words recall the work of Ehrenfels, providing a concrete example for his theory of gestalt qualities. Thus, interaction gestalt can be seen as a perceptual relationship that is shaped by the temporal evolution of design materials, rather than solely their composition.

4.2.4.2 Interaction Attributes

Recently, this research was extended by interaction designers Youn-Kyung Lim, Erik Stolterman, Heekyoung Jung and Justin Donaldson in their paper

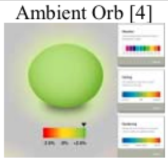
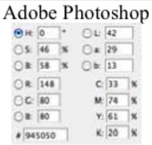
Attributes	Definition	Examples	
Connectivity (independent-to-networked)	The level of connectivity among various information elements accessible through interactive artifacts or those artifacts themselves.	AskOxford.com [5]  (independent)	Visual Thesaurus [44]  (networked)
Continuity (discrete-to-continuous)	The level of continuity of users' manipulation toward interface elements.	SanDisk Sansa [36]  (discrete)	Apple iPod [3]  (continuous)
Directness (indirect-to-direct)	The level of directness of what is shown through an interactive artifact or its information elements.	Ambient Orb [4]  (indirect)	Weather.com [28]  (direct)
Movement (static-to-dynamic)	The level of movement dynamics for both users' manipulating interface elements and artifacts' showing information elements.	AIGA Des. Archive [1]  (static)	BBDO [6]  (dynamic)
Orderliness (random-to-orderly)	The level of orderliness of either artifacts' showing information, or users' searching or manipulating information through an interactive artifact.	Scattr [40]  (random)	Flickr Slideshow [46]  (orderly)
Proximity (precise-to-proximate)	The level of proximity of controlling information.	Adobe Photoshop  (precise)	Adobe Photoshop  (proximate)

Table 4.1: Interactive attributes (part 1). Reproduced from (Lim, Stolterman, Jung and Donaldson, 2007)

'Interaction Gestalt and the Design of Aesthetic Interactions' (Lim et al. 2007). Beginning with the three key elements of interaction, namely time, space and information, the authors defined the attributes of an interaction gestalt that can be compared to visual elements such as margins, shapes and typefaces. Several existing interfaces were compared across eleven interaction attributes, including pace (from fast to slow), resolution (scarce to dense), speed (delaying to rapid), state (fixed to changing) and time-depth (concurrent to sequential), among others (see Figure 4.1). The authors suggested that these attributes 'are to be considered in order to create a certain gestalt that in turn will result in desired

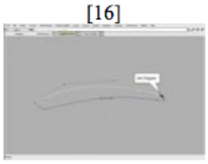
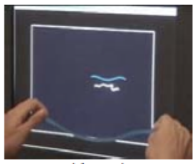
Attributes	Definition	Examples	
Pace[3] (slow-to-fast)	The rate of moving or the relative speed of change. Tempo. A combination of different rates of paces may create some kinds of rhythms.	RPA (*using keyboard for browsing*) [38]  (slow)	RPA (*using the timeline for browsing)* [38]  (fast)
Resolution (scarce-to-dense)	The level of resolution of either users' manipulating information or artifacts' representing information.	Autodesk AliasStudio [16]  (scarce)	3D curving tool [17]  (dense)
Speed (delaying-to-rapid)	The speed of either users' behaviors or artifacts' responses.	typical loading pages [38]  (delaying)	typical speedy games [31]  (rapid)
State (fixed vs. changing)	The case of state, it has only two variables: fixed vs. changing. When elements stayed in a same state, it is in a fixed state. When elements change to different states, it is in a changing state.	Philips USA [21]  (fixed)	Samsung Australia [39]  (changing)
Time-depth (concurrent-to-sequential)	The time-based depth of events occurring during interactions—simultaneous and concurrent events, or multiple elements with a few steps of depth, or every individual element shown through a larger number of steps of depth.	Mac OS X Exposé  (concurrent)	Mac OS X Switcher  (sequential)

Table 4.2: Interactive attributes (part 2). Reproduced from (Lim, Solterman, Jung and Donaldson, 2007)

user experiences.' (Lim et al. 2007, p. 240) Thus, interaction attributes were seen as a list of material properties that can shape the aesthetics of interaction.

Lim and colleagues positioned interaction gestalt inbetween the subjective user experience (temporal form) and the interactive artefact (spatial form). The former was defined through qualities such as fun, ease of use and pleasantness, while the latter was characterised by its properties including size, structure, texture and arrangement (see Figure 4.6). Similarly to Maze and Redstrom, they argued that there is a gap between the qualities of use and the properties of the artefact. Their goal was to bridge this gap by articulating the notion of an interaction gestalt and its attributes. However, beyond the list of candidates for the interaction attributes, the authors did not offer methods for identifying or

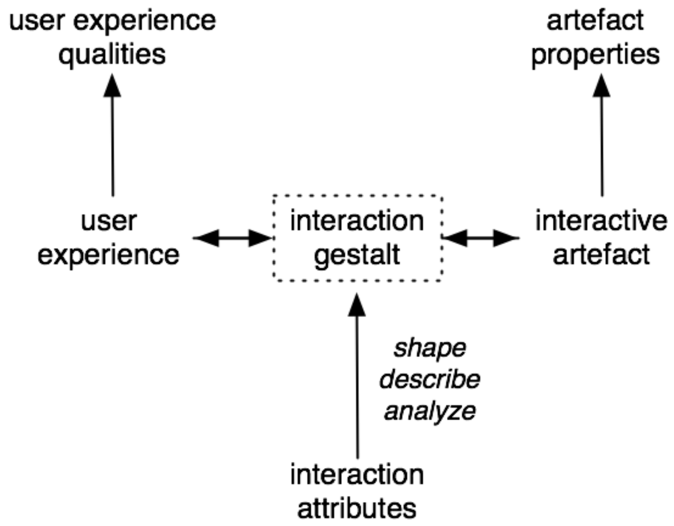


Figure 4.6: Interaction gestalt can connect the object-centered approaches to those centered on use (Lim et al. 2007).

working with them.

4.2.4.3 Exercise-Grounded Material Discovery

Instead of working with a pre-defined lists of attributes, basic interaction elements can be explored through process-oriented exercises, in the tradition of early basic design methods. The interaction designers Hallnas and Redstrom proposed exercises that aimed to raise awareness of designers' aesthetic choices (Hallnas and Redstrom 2002). The process was based on exploring the relations between the functional products and the so-called abstract information appliances with removed functionality. The physical properties and the way in which an object is manipulated were described as its *expression*. For example, in the *Shaker* abstract appliance (Figure 4.7), the *expression* was described as 'A black box the size of a small book that makes a sound as it is shaken'. The potential function of the object was described as follows

> ...something we use to write information by shaking it in certain patterns? Besides being a device for writing, we can also imagine other basic information handling "functions" in the expressions of this device. For instance, we might start it up by shaking it lightly, similar to how we shake a person we want to wake up in the

> morning. Similarly, we can think of putting it into "sleep" as carefully placing it somewhere without any abrupt motions that will make it make a sound. (Hallnas and Redstorm 2002, p. 111).

Among these functions, the authors chose a final concept for the appliance and elaborated on its technical issues and learning processes. In the Shaker case, a new kind of keyboard was equipped with accelerometers and microphones.

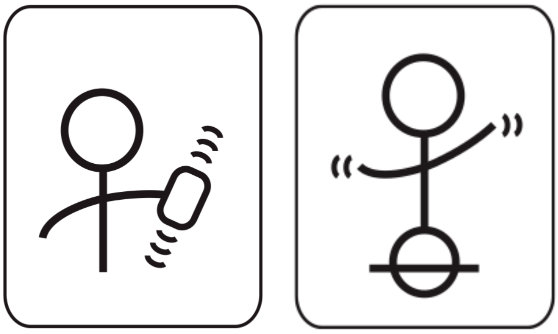


Figure 4.7: *Shaker* and *Balance Board*, abstract information appliances (Hallnas and Redstrom, 2002)

The design process moving in the opposite direction started from a functional product in order to create an abstract appliance. In the example of the *Balance Board* (Figure 4.7), an ordinary PC with embedded trackball was transformed into a new concept. The authors proposed that the trackball could be used to write patterns of information through full body movement. The new object was similar to boards used in balance training, but was augmented with accelerometers allowing it to write digital data through body motion.

These examples present a method for conceptualising new design ideas using abstract objects. The benefit of such an exercise-based approach is that it allows designers think about the interaction materials. Although such exercises do not necessarily result in the definition of specific properties of interaction gestalt, they provide useful methods for exploring them. However, these conceptual exercises do not work on an embodied level and thus do not allow designers to acquire tacit knowledge.

4.2.4.4 Towards Basic Interaction Design

> *The artist must not forget ... that each one of his materials conceals within itself the way in which it should be used, and it is this application*

> *that the artist must discover. (Kandinsky 1994, p. 154)*

Various authors agree that there is a need for more attention to analysis of an interactive artefact and related materials. As Lim and colleagues stated:

> *...designers should have knowledge of how to shape aesthetic interactions in a more visible, explicit, and designerly way. This is a kind of knowledge we are currently missing in HCI. (Lim et al. 2007, p. 240)*

Similarly, Maze and Redstrom have described the scarcity of material exploration in interaction design.

My argument is that in order to develop such practices, the abstraction methods and the analysis techniques must be combined. Lim and colleagues defined a list of specific interaction gestalt attributes by analysing existing products and argued that the interaction attributes 'must be translated to and manifested in the interactive artefacts properties in order to be communicated, perceived, and experienced by users.' (Lim et al. 2007, p. 246) But how shall this process of 'analysing, describing and shaping' of interaction gestalt proceed? How can basic exercises on abstract appliances be extended?

I propose *Basic Interaction Design* as an in-depth tacit exploration of relationships between the sonic, visual, haptic and behavioural properties of an artefact. Rather than relying upon an understanding of these properties separately, I argue that interaction designers must study the relational interplay that stimulates and emerges in an experience by engaging in both the analysis and the creative synthesis of object properties. Through this process they may become more familiar with and aware of their creative material and the aesthetic choices they make. Therefore, a set of procedures and methods for performing such activities needs to be created building on the existing efforts within the field.

4.3 Abstract Sonic Artefacts: A Case Study

The study presented here furthers the initial attempts to bring the issues of enactive sound into the field of interaction design and showcases a novel basic design methodology. Its subject was the creation of abstract artefacts that can engage enactive learning (see Figure 4.9). These objects were designed to afford simple manual interactions, such as squeezing, pushing or twisting, accompanied by continuous sonic feedback. Their purpose was double: on one hand they were probes into basic design methodology that should engage the designer with enactive sound experience, while on the other hand, they were used as a part of an experimental apparatus investigating the enactive learning (see following chapter).

4.3.1 Classifications of Self-Produced Sound

In Enactive Sound Design, choices must be made about the sound and the form that will afford a range of movement for the user. In order to identify and subsequently combine action and sound, existing classifications of everyday sounds, forms and body movement can be seen as a material to work with. But can such classification be fruitfully reused in design? The everyday sound already embeds, and is sometimes defined by, its relationship to the action and the object that caused it. Thus, instead of exploring the taxonomies of embodied actions (Robertson 1997), I focused on everyday sounds by human action.

4.3.1.1 Sound Classifications

Relevant classifications of everyday sounds originating outside of the music community have been identified by Schafer and Gaver. Schafer divided everyday sounds into five categories: natural sounds, indicators, human sounds, mechanical sounds and quiet sounds. Sounds were not described in relation to the action that caused them, but rather as the artefacts producing sounds (Schafer 1994). Thus, bells, horns, telephones, machines and mechanical tools were listed, but not the actions of using them.

Gaver, in contrast, explored everyday sounds in relation to the basic physical events that caused them (see Figure 4.8). The first three groups of his taxonomy were defined through materials: liquid, solid and aerodynamic sounds. These groups were subdivided into basic sound events caused by simple interactions such as impacts, dripping or explosions. He suggested that, for each sound event, properties relevant for sound production could be defined. For example, impact sounds could be affected by a vibrating solid's materials, sizes and configurations, the surface hardness of the impacting materials, or the force of the impact (Gaver 1993). Gaver himself suggested that this classification was just an initial and probably incomplete proposal. The benefit of his approach

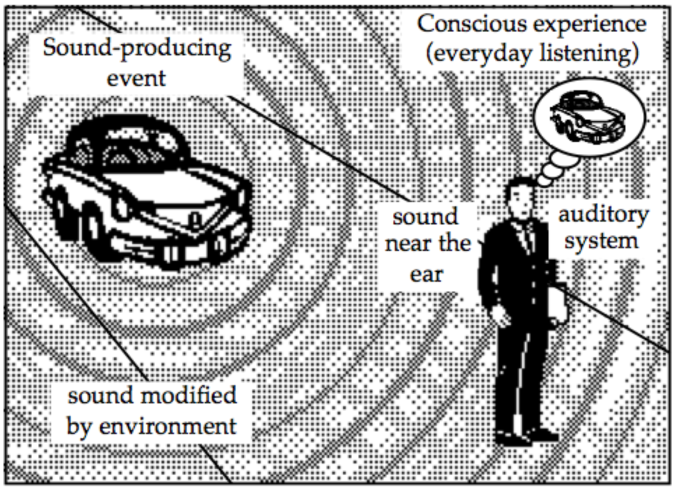


Figure 4.8: Explanation of everyday hearing process (Gaver, 1993)

was that it brought into focus the temporal aspects of sound events that were neglected by other taxonomies. However, similarly to other classifications, it did not provide tools for studying the experience of self-produced sound in which acting and listening coexisted and affected each other.

4.3.1.2 Action-Sound Couplings

Music research provided relevant findings about this issue, although it focused primary on expressive gestures performed with an instruments or under the influence of music (Cadoz 1988; Cadoz and Wanderley 2000; Godoy 2006; Jensenius 2007). The music researcher Rolf Inge Godoy used temporal aspects to define the action-sound relationships in musical instruments, including impulsive (e.g., percussion and piano), iterative (e.g., guitar) and sustained (e.g., bowed instruments) action-sound types (Godoy 2006). His student Alexander Jensenius pointed to the importance of natural relationships between actions as goal-oriented movement and sound. He described the action-sound coupling as a special kind of a natural action-sound relationships 'where there is a mechanical and acoustical coupling between the action and the sound' (Jensenius 2007, p. 21). Naturalness of sound has also been used as a descriptor in psychological experiments. For example, psychologists Susini, Misdariis, Lemaitre and Houix described natural sound as the sound that was a natural consequence of a performed action (Susini et al. 2012). Jensenius suggested that the amount of naturalness of an artificial action-sound relationship shaped by the digital means may strongly interfere with the interaction and the embodied experience. He argues that this naturalness, based on our existing knowledge, would affect our expectations of what kind of sound an action will produce. Thus, an understanding of the existing action-sound couplings found in natural events may help designers to play and to deviate from the natural action-sound couplings in an explorative manner.

4.3.2 Abstracting from Everyday Experience

In absence of suitable guidelines for studying and designing everyday action-sound materials, a direct study of self-produced sound may prove to be the most useful for a designer. Similar to the tacit knowledge that foley artists possess (see section 2.2.1.4 Foley: Objects in Sound Design), a product designer learns about his materials by physically engaging with them, but also reflecting and structuring such embodied knowledge. I thus developed an observational and analytic process to define such materials by abstracting it from real experiences and by tacitly understanding everyday action-sound couplings.

The aims of this investigation were the following:

- to concretise the relationship between sound and action, using objects and processes in the kitchen. The central aim was to investigate general concepts about action and sound in a concrete, everyday scenario of use, applying theories related to action and sound analysis and description.

- to directly explore the importance of everyday sound for action. The focus was on 'learning by experiencing and observing' in a structured and methodological way. Therefore, the investigation focused on the designer's, that is my own, ordinary activities. By analysing their video recordings, I had a means to reflect upon everyday sonic phenomena.

- to understand the relation between function, task and action. The goal was to investigate, how the device's function, the intended task and the resulting action correlated. Also it was important to find out, what kind of basic actions could be identified in a specific scenario, in this case the kitchen. But, most importantly, I wanted to find out how sounds related to the functions, tasks and actions.

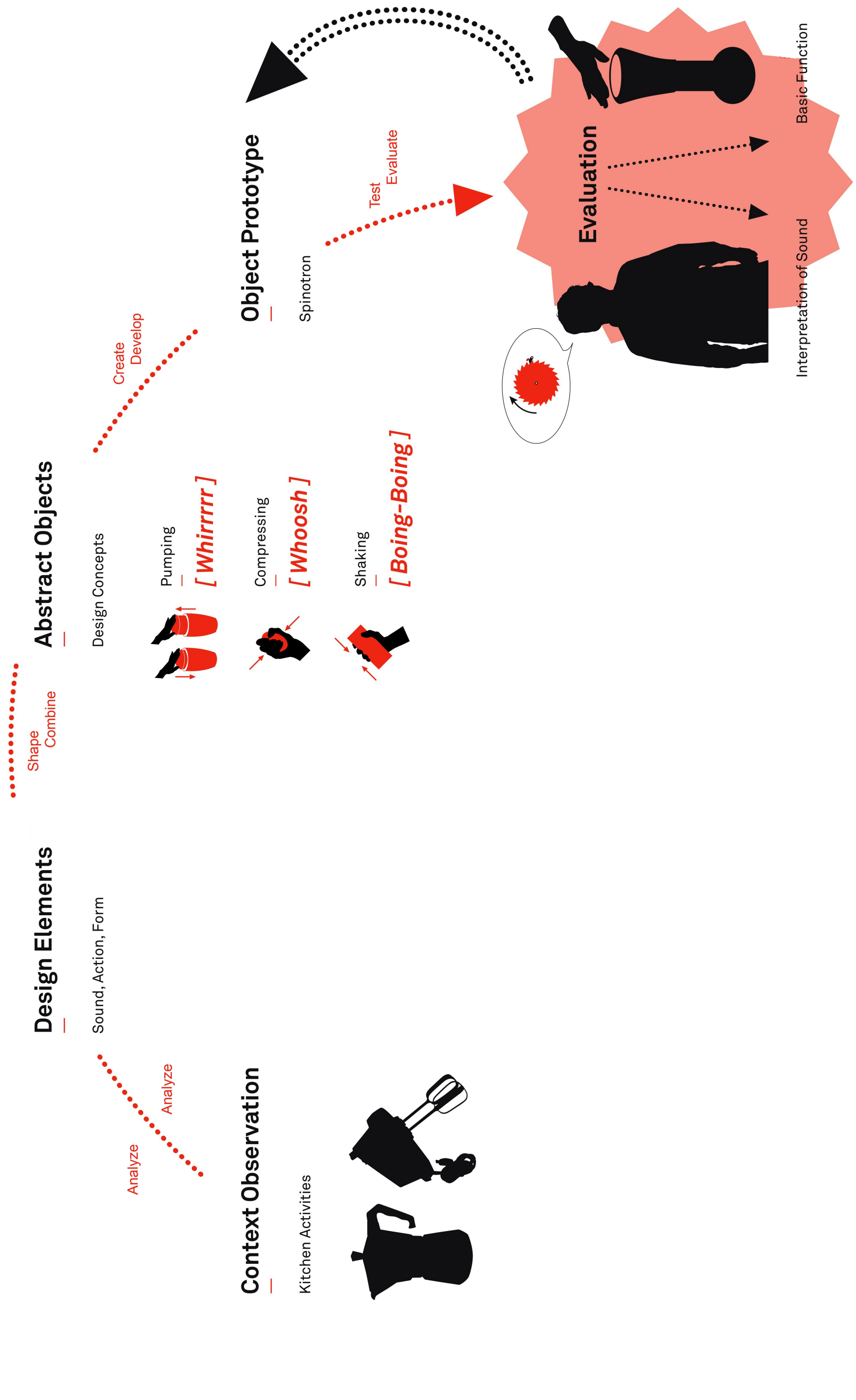


Figure 4.9: Creation process using basic design and situated interaction design methods and linked to evaluation described in the following chapter. Although represented here as a logical sequence, many design research activities are happening concurrently (Franinović, 2009)

4.3.2.1 Kitchen Context

The domestic kitchen was identified as a rich context for exploration of self-produced sound, because it is filled with artefacts that allow for physical manipulation. The actions studied included three types of interaction: the use of simple manual tools, such as knives or spoons, the manipulation of mechanical tools with moving parts, such as garlic squeezers, and electromechanical kitchen appliances, such as toasters, coffee grinders and blenders. The focus of the field research was objects in which the action and its sonic effect were directly linked (see Figure 4.10). The chemical and electromechanical processes were not studied, as they did not involve performative user engagement. Therefore, the study did not cover electronic tools such as the stove, or the freezer, which produce heat or cold, and evoke a series of processes involving movement of physical matter, thus generating sound. It is interesting to mention that Jack Foley also played with various kitchen tools in order to discover possible sounds for use in the cinema (Ament 2009).

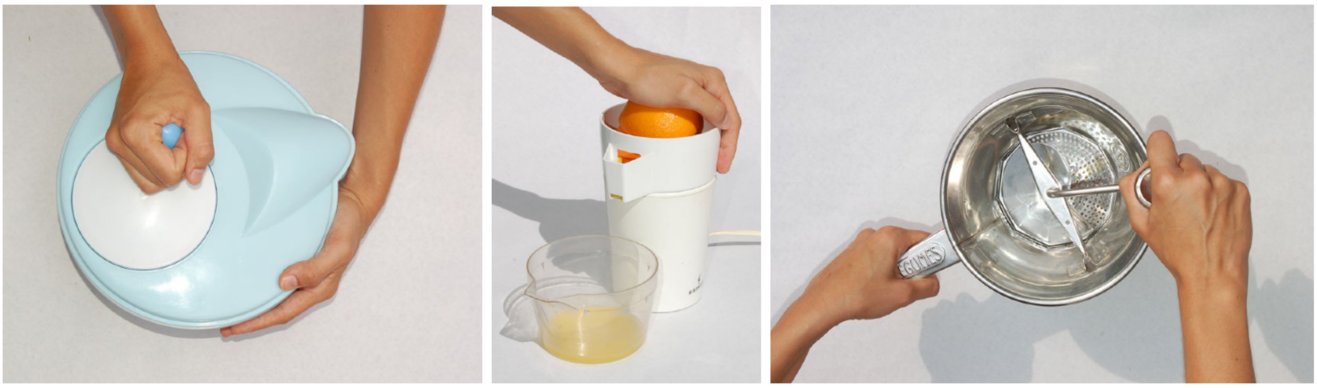


Figure 4.10: Handling different kitchen tools (Franinović, 2007)

4.3.2.2 Data Collection

The fieldwork began with the audiovisual documentation of common kitchen activities, including peeling and grating carrots, cooking oatmeal, making coffee and tea and using the dishwasher, the water-boiler and the toaster. The goal was to produce a critical mass of documentary material on sonic actions that could be used for further research and reference. The recordings were acquired with a single video camera and microphone placed near the interaction locus, to capture sonic details. Forty-eight individual audiovisual sequences of kitchen processes were acquired, with recordings ranging in length from approximately twenty seconds to a few minutes. The full videos can be found on the attached DVD in the section named 1 Videos of Kitchen Activities.

4.3.3 Designerly Action-Sound Analysis

Once the audio-visual documentation was completed, the recorded experiences were described and analysed. The analysis began with the decomposition of existing kitchen tasks into actions that accomplish the task. This approach is similar to the traditional task analysis that tends to consider user experience as composed of steps in a process, and that is performed from the viewpoint of an idealised detached observer (Diaper 2003). However, this study strived to allow the designer herself to experience the self-produced sound phenomena. In this way, she could gain a deeper understanding of the experience she was studying. Also, this approach avoided the usual difficulties of ascribing significance to phenomena purely through observation, such as multiple and disembodied interpretation (Mulder and Caro 1985).

Thus, I preformed a detailed analysis of six of selected kitchen activities.[1] The actions were analysed by asking why and how the movement was performed, and a number of descriptors were defined (see Table 1 Section Action Descriptors). The force and the speed required to execute the action was subjectively evaluated, representing the general effort linked to a specific action and sound (AE - action energy). The temporal aspects were considered relevant for sound production and thus the duration of action was described as short, repeated or steady (AD - action duration), reflecting a similarity to Godoy's musical action-sound relationships (Godoy 2006). The type of manipulation descriptor explored how an object was handled in relation to its mechanics and the body of the user. For example, the user could be holding the object with one or two hands or touching it using his or her lips and hand.

The sound effects of using kitchen appliances were subsequently analysed. The existing descriptions from psychoacoustics, music and ecological categorisation were developed (see Table 1 Section Sound Descriptor Types). The control modus has been described as manipulation sound (MS) or automatic sound (AS). The form and configuration of an object including its weight, size, texture and other properties that appeared to be relevant for the performance were

[1] For comparison purposes, one activity of 'preparing a latte macchiato' was analysed by my coworker Daniel Hug.

Action - General Parameters	
AD	Duration of action in seconds
AE	Energy exerted during manipulation
Action Descriptors (Examples)	
Elementary	Push, hit, slide, squeeze, grasp, elevate, put down, remove, tilt, turn, spin
Composite	Pulling, moving in circular motion, smoothing, uncoiling, turning, picking up, pouring ...
Sound - General Labels	
MS	Manipulative sound
AS	Automatic sound
NSf	Incidental or weak sonic feedback
RSf	Relevance of sonic feedback
Sound - Dynamics	
pp, mp, mf, f, ff ...	
Sound Descriptor Types (selection)	
Psychoacoustic	Loudness, brightness ...
Physical source	Aerodynamic, liquid, solid, combustion ...
Material	Elasticity, density ...
Configuration	Shape, size, structure (resonant cavities, etc.), support, weight
Surface contact	Smooth, rough, regular/grated, jagged ...
Spatial qualities	Delay, reverb, echo, damping, perspective, distance, resonance ...
Soundscape	Location/context, interpretation, semantic interactions ...
Gestalt / pattern	Rhythm of vibration, iteration of sound event (e.g., bouncing) ...

Table 4.3: Summary of notation and annotations used for action-sound analysis (Franinovic, 2007)

incorporated in this analysis. As for linking aspects of force and energy of action and sound, the use of musical notation was also investigated (e.g., piano (p) or forte (f), diminuendo (>) or crescendo (<)).

The new descriptor named Relevance of Sonic Feedback (RSf) was introduced to reflect the significance of specific sounds for performance in the relevant situation. The following question was asked: What would happen if we remove auditory feedback? The description included the influence of sound on the action being performed, but also intrinsic ways in which sound affected the task and emotions. Sound was considered relevant to the action, if it was associated with executing the action, either by being tightly linked to it or as a sonic sign that would affect a certain action. If the relevance of the sound was unclear from the video analysis, I would repeat the activity while putting my attention on the sound. Earplugs were used in order to asses whether the sound had an influence on the action or the overall experience.

4.3.3.1 Case of Pouring

An example reported here is the task of pouring, one part of the analyses of the activity coffee making with a stovetop expresso machine (the full analysis can be found on a dedicated website (http://actionanalysis.wikispaces.com/scenarios):

1. *Action: Grasping and squeezing the handle of the pitcher.* The squeezing continues in all steps of pouring.

    (a) *Sound: The sounds of squeezing the handle of the pitcher.* Plastic and skin interaction. This sound continues throughout the whole process becoming more or less audible due to other sounds produced. MS.

    - Relevance of sonic feedback (RSf): The sound communicates the firmness of the grip. Slipping or movement of the fingers on the handle can be heard. Can be rather silent.

2. *Action: Elevating the pitcher from the counter.* AE: depends on the size and material of the pitcher and quantity of liquid in it.

    (a) *Sound: The short impact and friction sounds.* Caused by the contact between the counter and pitcher. MS.

    - RSf: N/A However, it provides information about the material of the pitcher and the surface on which it has been positioned.

3. *Action: Displacing the pitcher towards the stovetop expresso machine.* AE: depends on the size and material of the pitcher and the quantity of liquid in it. AD: 2s

   (a) *Sound: Moving liquid in the pitcher.* The liquid hits the walls of the pitcher. MS.

      - RSf: It communicates the quantity of water in the pitcher. Can lead to the action of refilling the pitcher.

4. *Action: Tilting the pitcher, while aiming at stovetop expresso machine.* AE: Larger than in the previous action, but still depends on the size and material of the pitcher and the quantity of water in it. AD: 2-3s

   (a) *Sound: Water impacting the bottom of the metal stovetop expresso machine followed by the sound of splashing: water hitting the water surface.* The sound changes continuously as the volume of the stovetop expresso machine is being filled. The sound is louder than that of other actions. If there is not sufficient liquid in the pitcher, the sound of filling will end with the sound of dripping. MS.

      - RSf: The sound provides information about how filled the vessel is. The stovetop expresso machine has a valve at the bottom part that is filled with water. This valve is the limit to which one can pour the water.

5. *Action: Tilting the pitcher back to the vertical position.* AE: Smaller than in the previous action, because less liquid is contained in the pitcher. AD: 2s

   (a) *Sound: Moving liquid in the pitcher.* The liquid hits the walls of the pitcher. MS.

      - RSf: It communicates how much water is left in the pitcher.

In this analysis of pouring, the following actions were identified: grasping, squeezing, elevating, displacing and tilting. Several of these, and related sounds, happened concurrently. For example, one had to maintain pressure on the pitcher's handle in order to perform any of the subsequent actions. While squeezing produced little to no sound, tilting the pitcher to fill in the stovetop expresso machine generated a dominant sonic contribution, that of pouring liquid. The sound of the water impacting the vessel that was being filled, and the resonant excitation of the metallic volume of the stovetop expresso machine informed the user about the level of the liquid that was poured. Removing the sonic feedback resulted in heightened visual attention and slowed down the coffee making process, proving that, during the performance of certain actions, sound does play a critical role.

4.3.3.2 Findings and Discussion

From these analyses, basic action elements were identified as those that appeared repeatedly in the studied examples and to which no specific meaning could be assigned when they were isolated from each other and from the context. Together these comprised approximately thirty actions, grouped into two categories. The first category includes actions that cannot be decomposed into smaller actions, but that would still be perceived by the performer as actions. These were referred to as *basic actions* and included three groups: directional movement (push, pull, hit and slide), embracing (squeeze, grasp and release) and rotation (tilt, turn and spin). The second category is that of *composed actions*. In these, two or more basic actions occur together simultaneously but still do not generate a complex semantic meaning. For example, pouring is composed of aiming, tilting and holding while adapting to the changing weight, and picking something up contains the actions of embracing and maintaining constant pressure, so that the object does not fall, while generating a displacement.

The key points about the relevance of sonic feedback for action included cases in which sound can affect performance, can help focus the attention to the action, can affect intentionality. Additionally, its loudness is in relation to action energy (AE) and action duration (AD). The type of relationship between action and sound analyses can be described as direct (e.g. when grating a carrot, the sound is directly linked to the movement of the hand) or indirect (e.g., when the action triggers another movement that produces sound, like closing a cupboard). The type of feedback to action - continuous versus discrete sound - showed that it provided different type of cues and experience (e.g., pouring water versus putting a glass on a table). The occurrence of the sound seemed to have influenced the way the action was exerted on the level of feedback, either continuous or discrete.

These identified actions elements can be coupled to different sounds and generate different mental metaphors. The natural action-sound coupling may vary due to the material and the gesture. For example, an equally executed action of pouring will sound differently if it is water, not rice that is being poured. The development of the full taxonomy of action-sound couplings, even constrained to the domestic kitchen contexts considered in this work, would exceed the scope of this research. However, the goal of this research was not to develop a taxonomy of actions, but rather to propose and apply processes that can engage designers in exploration of action-sound materials.

4.3.4 Conceptualising Abstract Artefacts

Inspired by the kitchen field study, a series of concepts was created, consisting of abstract shapes that can afford simple actions and continuously respond to these with sonic feedback (see Figure 5.9). They were designed to enable further basic studies of the simple relationships between sound and action that are experienced in the handling of objects.

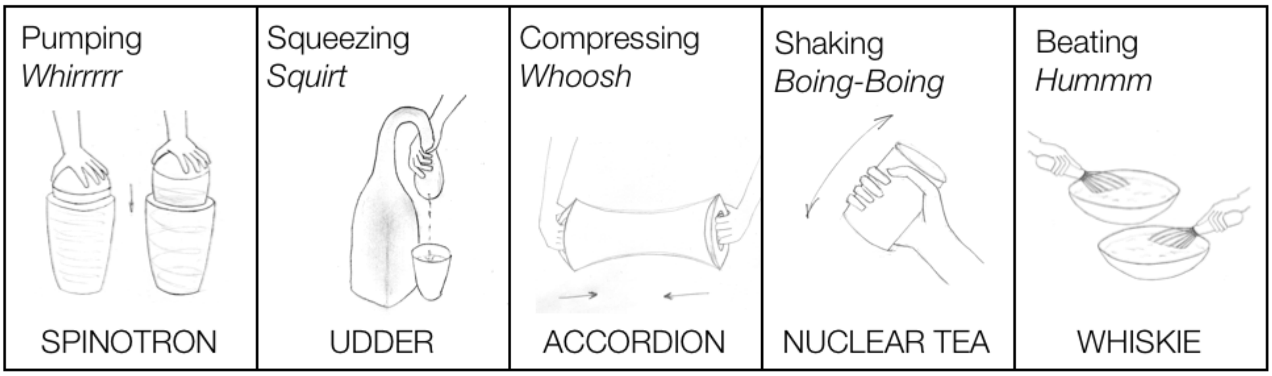


Figure 4.11: Concepts for *Abstract Sonic Artefacts* (Franinović, 2007)

4.3.4.1 Conceptualising Methods: Martix and Soundstorm

For the concept phase, I used two design methods, namely Design Matrix and Sonic Bodystroming using kitchen tools. The design matrix method allows the designer to decompose an otherwise seemingly non-reducible complex design problem, by reorganising the related multi-dimensional qualities (for example sonic, formal, interactive) along several axes (Paulos et al. 2005; Otto and Wood 2000; Zwicky and Wilson 1967). The resulting space is then sampled at individual points, and the resulting set of properties is used to generate a design case. Soundstorm is based on foley techniques and is described in more detail in Chapter 6. It was here applied to kitchen tools from which the abstract sonic artefacts originate (see Figure 4.10) and videos on the DVD section '1 Videos of Kitchen Activities'.

The generation of concepts began with process-oriented exercises on the re-mixing of sonic and action features extracted from the context. I developed a two-dimensional matrix to create a space for new concepts defined by one axis corresponding to actions identified in the field study and another axis corresponding to everyday sounds. The latter were also related to the sound synthesis tool that was used in the prototyping phase, namely the Sound Design Toolkit (SDT) (for more information visit http://www.soundobject.org/SDT/). This software, developed by collaborators on CLOSED project from University of Verona, simulates everyday sounds with the goal of allowing the designer to interactively explore different parameters, such as material or hardness of the sound source (Rocchesso and Fontana 2003).

In this process, the problem of the redundant labelling of sound and action became evident, as sound can often be described in terms of action: the sound of walking, of cutting, typing, and so forth. However, since I had conducted the field analysis, it was easier to associate everyday sound labels with actual experiences. In contrast, when the same matrix was used in workshops, as described in Chapter 6, designers who did not have experience with action-sound analysis had difficulties dissociating between sound and action descriptors. Thus, it can be argued that analytical activities of enactive experience can be beneficial for subsequent creation stages.

In the initial concept phase, thirty-two abstract artefact concepts were generated. Seventeen of these were further proposed for psychological tests, as their design suited experimental specifications. A number of constraints related to the experimental measurement and interpretation of human action with the prototypes had to be taken into account. The objects had to allow for simple performance tasks that could be measured. For example, in targeting a certain area, time to reach the goal could be measured in relation to the size of the target (Fitts 1954). The proposed task had to be used for evaluation of the relationship between action and sound and, more specifically, to investigate the ways in which this action-sound coupling affects functionality and preference. The complete set of seventeen ideas for abstract objects and related experiments is available at a dedicated website (http://sound-scene-storm.wikispaces.com/).

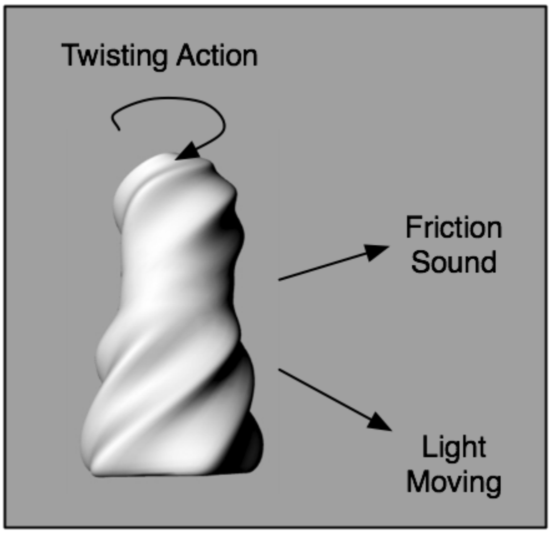


Figure 4.12: The *Twister* prototype and interaction (Franinović, 2007).

4.3.4.2 Sharing Artefact Concepts

In order to share the artefact concepts with the rest of the CLOSED team, I prepared sketches and the description of the object including its form and affordance, the action or the way to handle the object, the action primitives and the sounds involved, the way action and sound may affect each other, technical details, experimental task and potential real-world scenario. This can be best illustrated through the following example of the concept for the *Twister* artefact (see Figure 4.12).

- *What is it?*

  It is a vessel with two halves that screw shut into one another, forming a seal (as on a stovetop expresso machine).

- *How do you do it?*

  You hold the upper and lower part together and start screwing until the desired tightness is reached, as reflected in the sonic feedback.

- *What are relevant action primitives?*

  Screwing, twisting, tightening. Fitting matched parts together.

- *What is the sound? How does it relate to action?*

  The vessel furnishes assistive sound when being assembled. When the unit is appropriately closed (correct tightness), the sound stops.

The increase in tightness is expressed through the sound of resonant squeaking and friction sounds. Its pitch increases and the density of the squeak-events decreases as the tightness increases.

In order to assist tightening without over-tightening, an additional tightness-linked feedback informs about this level of tightness, becoming urgent as the tightness limit is approached, and fading or attaining a different character if that point is overshot.

- *Technical details?*

  The physical tightening of the top should be measured through a mechanism within the artefact. A force sensor with a layer of rubber could be used to measure the tightness. The initial tightening could be measured using a pair of rate gyroscopes, one on each half, or perhaps using an optical encoder matched between the two parts.

- *Experimental task?* To turn the Twister to a perfect tightness that is communicated through sonic feedback.

  Subjects are presented with a set of vessels to be assembled. They must be twisted to identical amounts of tightness by approximating a predetermined level of tightness.

- *Real-world scenario?* Resembles a sonic assistant that could help you find the right level of tightness for your stovetop expresso machine. The augmented stovetop expresso machine would make a lot of (helpful) noises when being put together. This is critical, because if it is too tight, you will not be able to open it anymore after boiling and if it is too loose pressure is lost and your coffee will turn out bad. Therefore a short but continuous feedback is supplied to inform you about the ‘level of tightness‘.

  It recalls a DJ finding the kick drum on a record by moving the record back and forth.

As can be seen in Figure 4.13, the shape was developed to afford a continuous twisting motion from the side of the user. While the *Twister* object has not been chosen for the perceptual experiments, a mock-up was developed using 3d printing (see the images on the attached DVD in the section 2 Abstract Sonic Artefacts - 01 Twister).

The concept that became a subject of the psychological experiments was the Spinotron. While the Twister used a sound-action coupling existing in stove-top expresso maker, the Spinotron utilised more random couples of action and sound like that of pumping action and rolling or spinning sound. Although these elements are arbitrary selected, they can be ecologically coupled as in the case of

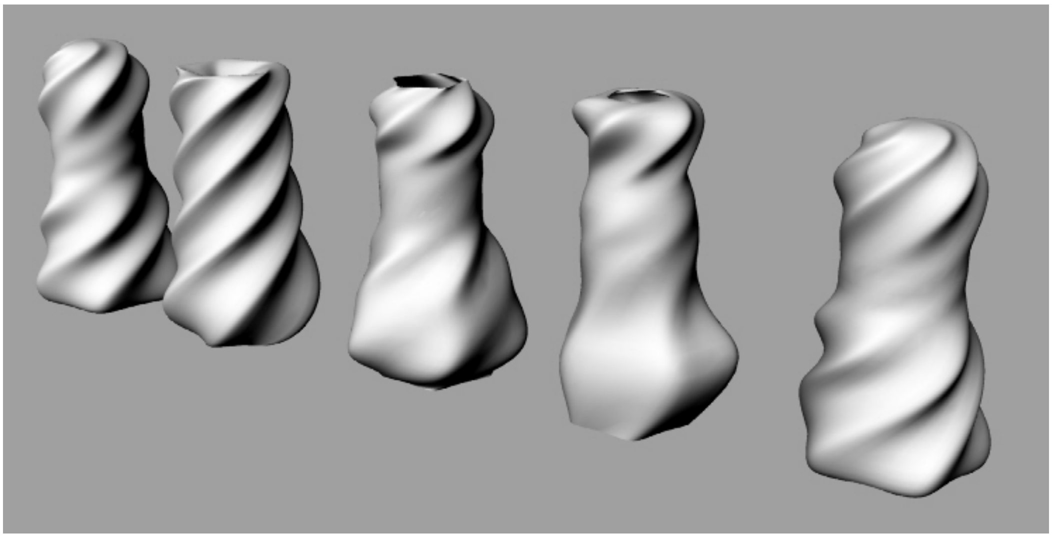


Figure 4.13: The *Twister* form evolution (Franinović, 2007)

Spinotron. Related design process and the interface are presented in the following chapter.

The conceptual objects enabled certain kinds of actions, data collection and evaluations and therefore shaped the way in which experiments would be conducted. After the discussion of these issues together with my colleagues from psychology, six concepts were chosen for the prototyping stage based on the following criteria:

- the physical interaction with the artefact had to be simple, so that users would not have difficulty using it or understanding how to do so correctly

- the mode of gestural control over the sounds had to be continuous, so that both discrete and continuous feedback could be studied in the experiments

- the mode of gestural control over the sounds had to be *effective*, in the sense of supplying (virtual) energy to excite the sound, as described by Cadoz (Cadoz 1999), rather than merely modulating an ongoing sound process.

- interaction had to avoid an especially strong association with a particular sound class, in order to avoid excessive bias in users' interpretation of the synthesised sounds during the experiments.

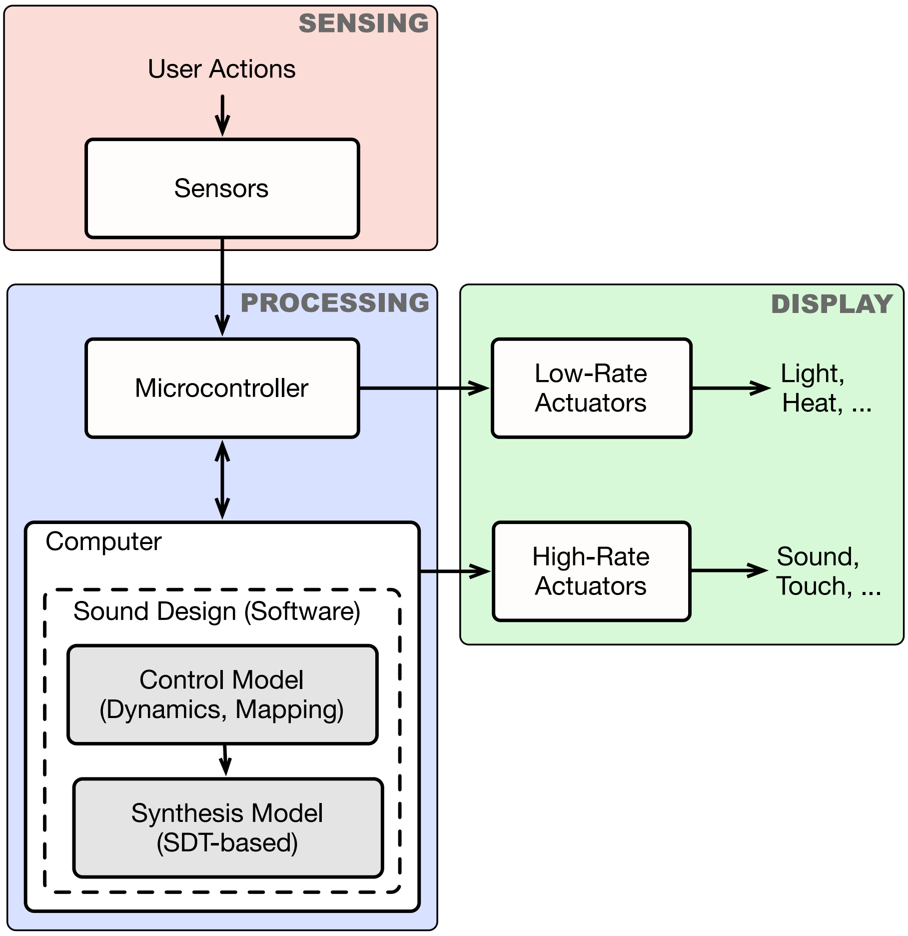


Figure 4.14: Technical organisation of the prototypes.

4.3.5 Prototyping

The first working prototypes combined elements of sound, form, action, object behaviour and, in several cases, light. I designed the physical shapes to provide a desired affordance - a suggestion for a type of action that could be readily performed. The variations of the form were explored using the 3D modelling software Rhinoceros (see Figure 4.13) and produced through ABS 3D printing. The sonic and light feedback enabled through the manipulation of the form were designed within a real time data processing environment (Cycling 74 Max/MSP). The artefacts interacted by means of sounds generated through models of everyday physical sound events such as the pouring of liquid and the rolling of a ball.

4.3.5.1 Sonic Moka

The idea for real-world scenario for the Twister object included a scenario with an italian stovetop expresso machine where the interaction of suitably closing the object was sonified. The scenario was implemented in a doctoral workshop entitled La Moka Sensibile at the Istituto Universitario di Architettura di Venezia. Davide Rocchesso and Pietro Polotti, my colleagues on the CLOSED project from the University of Verona asked doctoral students to sonify a stove top espresso maker in which a force sensor was placed between the filter and the gasket. They asked the students to use continuous, non-symbolic, pre-attentional sonic feedback, but divisible into three clear stages of screwing the connection between the two parts of the coffee maker (Rocchesso and Polotti 2008). The sound was designed using the physical model of friction: the timbre ranged from the sound of a glass harmonica for the loose stage, to assuming a rubber quality for the tight stage. When the parts were too tight, the sound of a squeaking hinge was produced. The video named 01TwisterCaffettiera.mov and related patches are available on the attached DVD in the section 2 Abstract Sonic Artefacts - 01 Twister - 01patches.

4.3.5.2 Crushhh

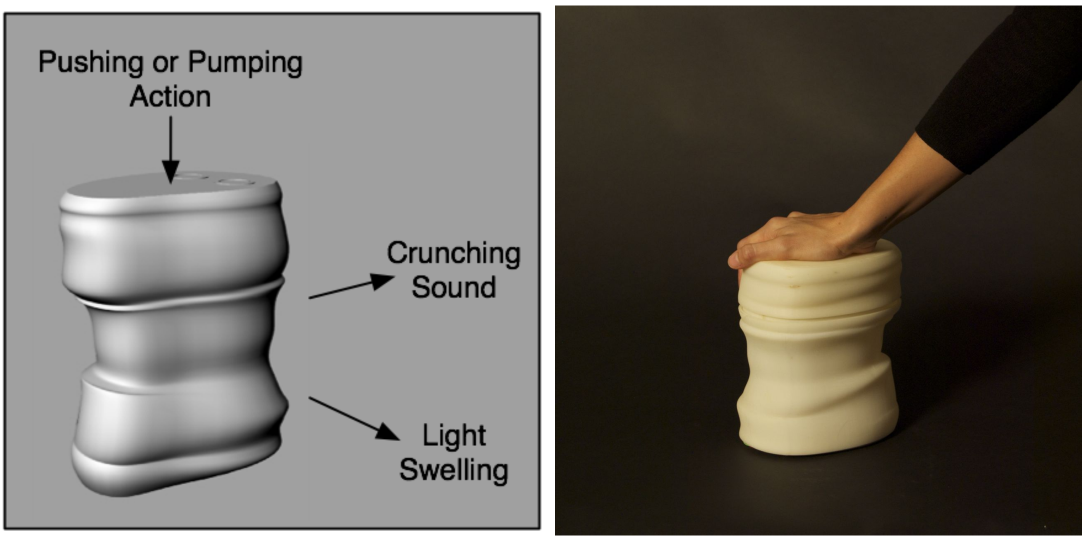


Figure 4.15: The *Crushhh* model and interaction (Franinović, 2007)

Among others, the *Crushhh* (See Figure 4.16) was developed as an empty vessel to be crushed, i.e. compressed to a (predetermined) smaller vertical height (see images and patches on the attached DVD in the section 2 Abstract Sonic

Artefacts - 02 Crushhh - 01patches). It was based on the action and sound elements that were abstracted from the experience of crushing a plastic water bottle. If *Crushhh* was regularly compressed, via a force applied to its top surface while the object rested against a solid (table or similar), the accompanying sound was generated by a SDT impact and crumpling model (Fontana and Bresin 2003). This model was extended in order to allow interactive control over the crushing activity (Visell et al. 2007). The sound was coupled to the pressure captured by a force sensing resistor located in between the two parts being compressed. The level of crushing was also reflected in the light illuminating the interior of the artefact using a high-intensity RGB LED module. The proposed task for the subjects in the experiment was to compress the object vertically without breaking it, in a sound/light sense. Light was intended to provide reference and comparison feedback in relation to sound. In other words, sound was guiding the user's control of light.

Figure 4.16: The *Crushhh* prototype with force-sensitive resistor and LED module (Franinović and Visell, 2007)

4.3.5.3 Adaptive Bottle

Another concept developed into a functional prototype was the *Adaptive Bottle*, a receptacle that augmented the act of pouring. It was inspired by the everyday action of pouring liquids (See Figure 4.17). When filled with a dry granular material (rice or pebbles), the quantity of this material that has entered the vessel is sonified. A physical sound synthesis model of liquid sounds was excited by the arrival of material in the vessel captured through FSRs (force-sensitive resistors), and modulated according to the level of material that has entered it (see the video named AdaptiveBottleVideo.mov in the attached DVD in the section 2 Abstract Sonic Artefacts - 03 Adaptive Bottle). Rather than affording interaction directly through the manipulation of primitives linked to pouring (i.e. grasping, elevating, displacing, tilting), the artefact employed the intermediate concept of a transportable medium to facilitate control, similarly to the *Pebble Box* interface described in Chapter 2 . In addition to pouring water or granular materials such as sand, this prototype could also be used to augment interaction with other media, such as controlling the intensity of light or volume control, or in watering plants.

Figure 4.17: The *Adaptive Bottle*: the receptacle and the bottom part hosting speaker and sensing system.(Franinović and Visell, 2007)

The construction of the artefacts created in this study raised a number of issues about industrial design considerations and processes, electronic sensing (sensor selection, integration, signal conditioning and acquisition), actuation (mechanical design, actuator selection, signal transmission), and real-time software integration (control and sound synthesis models, task implementation, hardware interfacing). These issues are reported in Appendix IV. The solutions for an object that can best engage enactive learning aimed at satisfying the requirements for the experiments, but also intuitively emerged from iterative prototyping process.

4.3.5.4 Sound Prototyping using an Optimisation Tool

The *Adaptive Bottle* was further used in a collaboration with the Neuroinformatics group from the Technical University of Berlin. In this research process, my role was the conceptualisation, the design, the electronics and the prototyping of the *Adaptive Bottle* object. Also, as a designer searching for the right interactive sounds for the specific product, I was the intended user of the tool that was to be the outcome of the project. My colleague Yon Visell from the Zurich University of the Arts worked on adapting the physical sound model for liquid sounds, created in the University of Verona by Carlo Drioli, to the *Adaptive Bottle* interactive object. The adaptive artificial intelligence tool was developed by our colleagues at the Technical University of Berlin, Kamil Adiloglu and Robert Annies, under the guidance of Prof. Klaus Obermayer. They also performed the experiments with human subjects. The *Adaptive Bottle* was demonstrated at Neural Information Processing Systems (Adilogu et al. 2007) and also published at International Computer Music Conference (Adilogu et al. 2008). The reflection on this collaboration is further discussed in Conclusion chapter, section 7.4 Models of Interdisciplinary Collaboration.

We started from the problem that when using physical sound models to design interactive sound, the designer has to vary a large number of parameters in the model in order to explore different possibilities. This can be done through sliders provided in the software patches, or more ideally, by using sensor data that capture the gesture of the user with an interface for which the sound is being designed. In both cases, however, the tuning of the many parameters is a long process, depending on designer's aesthetic taste, but also his or her sonic memory because he or she must play with a large number of sounds that the physical model is capable of generating.

The goal of the collaboration with the Neuroinformatics group was to reduce the amount of time spent for searching for right parameters within the physical sound models, while including the interaction of the artefact in the design process. We wanted to demonstrate a sound design tool using adaptive artificial intelligence algorithms that could facilitate a sonic interaction design process. This tool would allow the search of a control parameter space for adapting the parameters of a physical sound model based on the preference of a designer and user. Thus, the input parameters of a physically based sound model were to be defined by using human evaluation in an interactive and iterative way. In order to achieve our goal we had to design an interactive sound object, to develop the tool allowing the user to navigate a space of parameters found in physical sound models and to perform experiments with human subjects.

Figure 4.18: The *Adaptive Bottle* first prototype (left) and final prototype (right) with embedded bluetooth sensors (Franinović and Visell, 2007)

We started from the idea that enactive sound design for objects is the design of an interplay of different parameters, namely sound, human gesture and shape of an object. We wanted to create a design process which involve these three aspects of a sonic artefacts, and to ground the aesthetic decision-making about interactive sound in the judgments of designers or users. These judgments were meant to measure sound quality, or the suitability of a sound attached to the product, as discussed in Chapter 3. Thus, the choices about the synthetic generation of sound were to be based on the users' feedback. While the sonic feedback was the attribute of the sound object to be varied and designed, the coupling between sound and action, as well as the shape of the object were to be kept fixed.

Thus, the first step in the process was to design an interactive object and to conceptualise the sonic feedback and action-gesture coupling, but not to create specific auditory feedback for it. We took one of the concepts already tested, the *Adaptive Bottle*, but rather than using an actual medium as in the first prototype where rice and pebbles were poured from one vessel to another, we decided to use the user gesture with the pouring object as an input. Thus, the hardware and software setup had to be changed: we had to capture the action of the user with the object, rather than the effects of his or her actions. A three-axis accelerometer was chosen for the inertial sensing and had to be embedded in the bottle. Thus, a new shape of the object had to be designed to accommodate the new hardware, but also in order to create a smaller and lighter object, closer to a real fluid container. The first prototype of the shape was developed using an existing plastic container in order to test sensor data (see the first prototype on the Figure 4.18). A second prototype was designed in a 3-d modelling software, Rhinoceros, with the aim to provide a suitable ergonomic grasping that could improve sensor data received. Also, the shape had to suggest an unusual bottle that could be imagined as a novel object, with a novel function. For example, the bottle that could communicate how much water needed to be poured when watering a specific plant. Thus, the final design was the one that allowed to control the bottle when held in a certain way, afforded by the shape of the object. It was produced by fused deposition 3D printing (see the final prototype on the Figure 4.18).

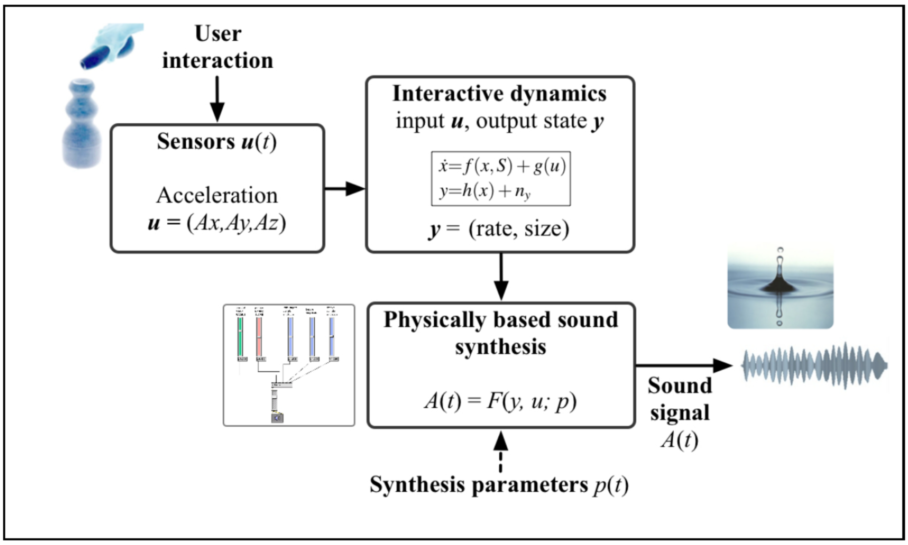


Figure 4.19: Technical diagram of the *Adaptive Bottle* final prototype.

The data acquired by the accelerometer was wirelessly transmitted to a computer running a MaxMSP software in which sounds were synthesised using the liquid drop model from the Sound Design Toolkit. The bottle was assumed to be full of liquid at the beginning of interaction when kept vertically. From the tilting of the bottle, the volume of liquid remaining in the bottle was calculated. Out of various parameters which could be used to generate various sounds within the liquid model, two were selected for optimisation, namely the bubbles size and formation rate, while the others were kept constant. The current bubbles size and the current formation rate were varied according to the quantity of the virtual liquid inside of the bottle, and generated pouring sounds. As the liquid was poured out of the bottle, the size of the bubbles decreased, thus affecting the pitch: the sound of larger bubbles in pitch was lower than that of smaller bubbles (see the technical diagram of the final prototype on the Figure 4.19).

The tool for selecting parameters was developed using the least squares optimisation algorithms. The tool was used in a following way: a user performed a pouring action repeatedly and chose a preferred sound among the four offered samples. Thus, he or she iteratively supplied perceptual evaluation of the quality of the sounds offered by the system. These evaluations were then used to calculate the direction and amount of movement of the sound control parameters in the parameter space. After each step, four new parameter values were generated, and the user repeated the sound selection process. For more information about the algorithms see (Adilogu et al. 2008).

Three preference learning experiments have been performed in order to test the tool, each starting with different initial parameter settings. The task was to design sound for an artefact which simulates the event of pouring liquid out of a bottle. The users could tune a physically based sound model by navigating the parameter space, as described above. The quantitative evaluation showed that the subjective quality was increased step by step and a principal direction in parameter space could have been identified (Adilogu et al. 2008). This supported the idea that the psychoacoustic evaluation could be supported by a machine learning system with the user in a central point and that statistical methods could facilitate sound parameter search. However, the qualitative results showed process of designing in such a step-by-step way was too long and cumbersome to work in real design context, as discussed in the Conclusion of this thesis in the section 7.4.1 Design-Science Collaborations within CLOSED project.

4.3.5.5 Sound Prototyping using Soundstorm

Based on the abstract pouring objects, I developed an artistic installation called the *Flo)(ps*, composed of a series of interactive sounding glasses. The design process applied to these functional objects included a more traditional sound design methods, such as foley techniques or Soundstorm method (see Chapter 6). For example, the design of action-sound couplings took place by exploring sonic gestures using different objects and materials (see Figure 4.20 and Figure 4.21) or by using voice while performing gestures. I continued testing my decisions tacitly throughout the design process. In addition to individual use of the object, I also explored the interaction between two people such as throwing the sound toward someone. This helped me decide which habitual and non-habitual gestures should be identified from sensor data and how these should be mapped to different sounds.

Figure 4.20: Sonic Bodystorming: probing sound concepts by the use of analog physical objects and voice.

In total eight different gestures were extracted from sensor data. The habitual gestures included filling the glass with liquid, raising the glass, stirring the liquid, drinking and toasting, and the unusual gestures comprised twirling, moving the glass very slowly and shaking the glass. Habitual gestures generated sound of liquids such as pouring or splashing while strange movements opened

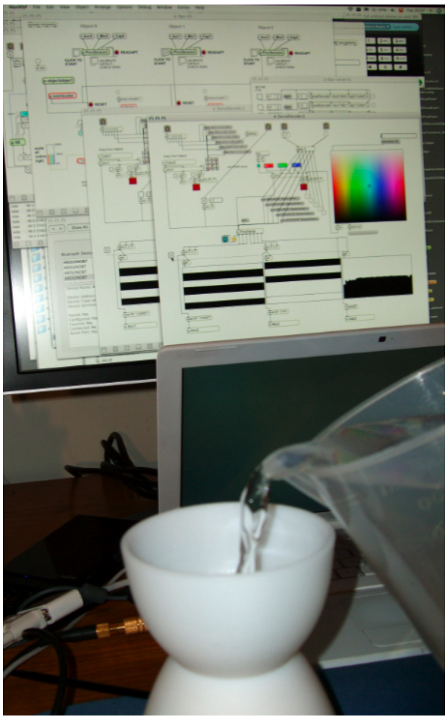


Figure 4.21: Developing sound concepts by the use of combined digital and analog means.

up unexpected sonic spaces such as the sound of the wind or the rain. The movement of the glass continuously changed the qualities of the sound in order to give the user the feeling of an 'ecologic experience', in the sense of cause and effect behavior found in physical phenomena. For example, tilting the glass would make some virtual water come out and than stop until the user inclined the glass more in order to pour out the remaining water.

The final goal of the *Flo)(ps* project was to foster social interaction by means of habitual and explorative sonic gestures within everyday contexts. The results demonstrated that social interaction and personal use require different ways of transitioning from habitual to explorative gestures, and point toward possible solutions to be further explored (Franinović 2011) (see Appendix I). Together with the *Spinotron* described in the following chapter, the *Flo)(ps* reached the most elaborated stage of the prototyping development. The *Flo)(ps* were also used in the experiments on emotional response to enactive sound (Lemaitre et al. 2009) (see Appendix II).

In conclusion, the process of designing sound for the *Flo)(ps* was much less structured than that of the *Adaptive Bottle* sound design. However it showed

Figure 4.22: The *Flo)(ps* installation at the Amplified Intimacies group exhibition at Oboro gallery (Franinović, 2008)

that using everyday objects and voice provides great freedom and speed for designer, and thus related methods should be seen as beneficial for the experimentation and creativity, expecially in the early stages of the process, while those based in the optimization via machine learning tools can be useful in the latter stages of design.

4.3.6 Abstract Artefacts Methodology

Although the goal of my study was to create a-functional abstract artefacts, I have chosen to initiate the design process in an everyday setting in order to tacitly engage with existing enactive experiences. Simple ways of exploring the interaction based on adapted situated task analysis allowed the designer to engage with her own tacit and analytic understanding of the ephemeral relationships between sound and action. Moreover, the action and sound examples that were gathered proved to be useful as source material and served to generate abstract artefact ideas in the next creation stage.

The methodology for the creation of abstract sonic artefacts can be summarised as follows (see Figure 4.23):

1. Perform background research on relevant materials

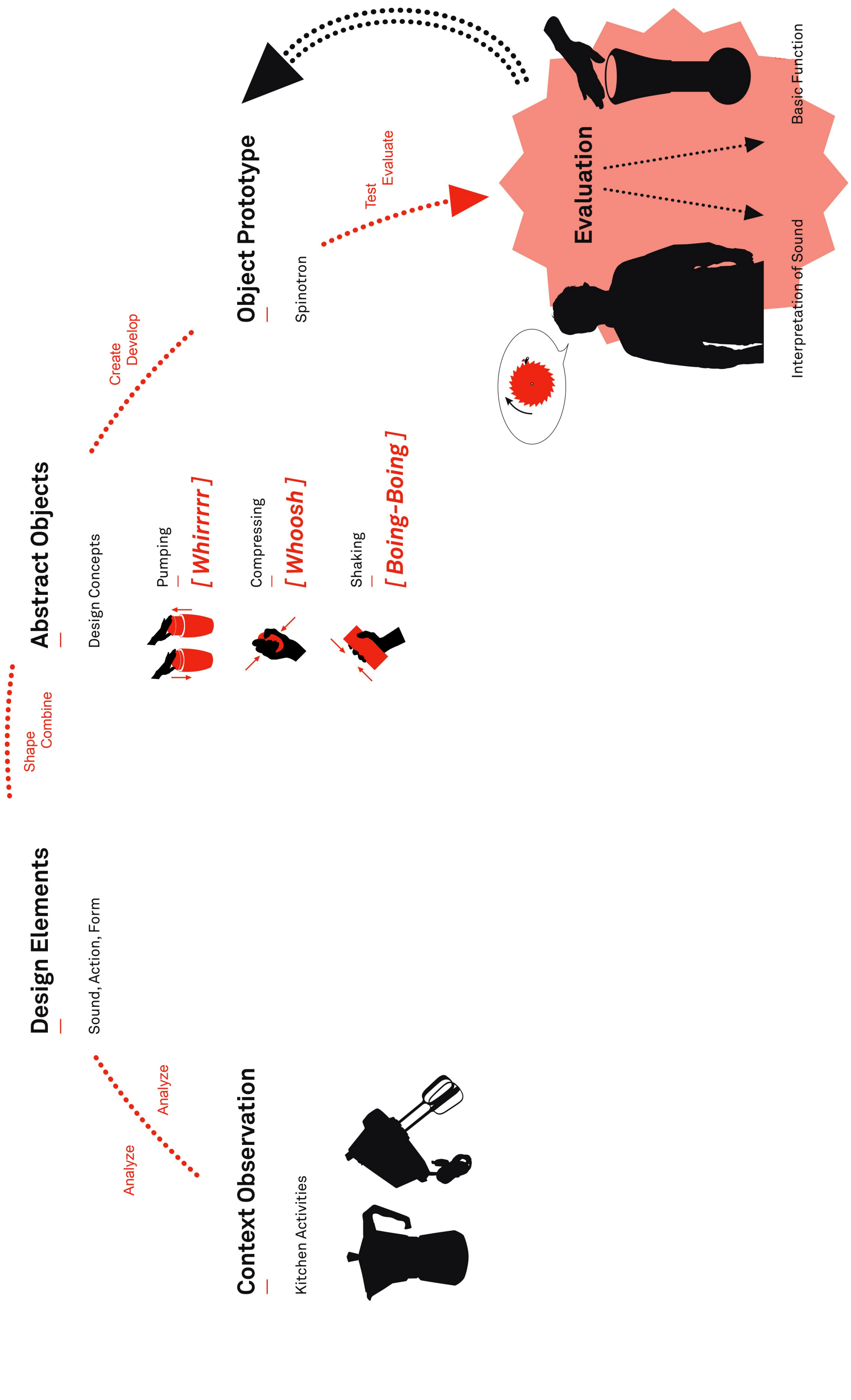


Figure 4.23: Design process for abstract artefacts (Franinović, 2009)

2. Document interactions in an existing setting (kitchen)
3. Analyse and abstract from everyday experiences (with manual tools)
4. Shape and combine found materials (sound and action)
5. Create abstract interactive artefacts (for experiments)
6. Define and perform experiments (see following chapter)

This process reflects the combination of learning in an embodied as well as analytic way. The contextual evaluation may not be new to designers, but the innovation of the loop proposed here lays in the connection of the analysis of materials with the aesthetics of interaction, which bridges the gap between the soft and hard, between analytic and synthetic methods.

4.4 Conclusion

In summary, the methodology presented here brought together tacit knowledge with the explicit, working with the exploration of relationships between the sonic, haptic and behavioural properties of an enactive artefact. Experiencing sound activities in the kitchen was combined with a structured task analysis. The creative process of developing concepts was combined with the functional requirements for experiments. And finally, the prototypes were iteratively tested, combining technical solutions with experiential probing by myself and my colleagues.

The abstract artefacts study contributes methodologically to the current research on interaction gestalt and basic interaction design. Insipired by work such as that of Svanaes, it proposes a compositional approach to the aesthetics of interaction. The latter is seen as emergent through a process of acting, rather than as a summ of different variables that compose an interactive object. Thus, a direct engagement with a designed object is closer to a process of dancing, rather that of adding colours to a paining pallete.

The case study serves as a case for a basic methodology and for creation of experimental apparatuses that can further the research on enactive sound. In it, I have demonstrated strategies that can help designers to engage with enactive sound materials, rather than relying on the list of predefined attributes. The proposed creative process worked from the contextual interconnections through basic design approaches.

The elements that Lim et al. identified in their diagram can be connected with the methods presented in this chapter (see Figure 4.24). These methods extend their framework, and propose a radically different approach in which design materials are not predefined, but emerge in relation to different contexts and problems.

Because the design of abstract sound artefacts was guided by their experimental purpose, this research could proceed without considering the complexity of real-world settings. In this sense, the methods presented here are aesthetic explorations directed towards basic research. For the design of real products, the methodology must be complemented with contextual ethnographically-inspired practices. For such applications, the following process, in which the objects are designed for and evaluated in the everyday context, could prove useful:

Basic design does not account for specific user needs or for the myriad of issues arising in different contexts of use. Rather, it directs creators towards formal explorations. However, it could be integrated with context-based research needed for the development of real products, because an experience is shaped both by perception of formal elements as well as by meanings emerging from users' cultural background and social interaction. For example, some centuries ago, it would not have been possible to associate Svanaes's square behaviour, discussed in the beginning of the chapter, with the notion of a switch, as electricity did not exist. Such interpretations of perceived basic elements provide motivation for further research that can ground basic design methods in real-world contexts.

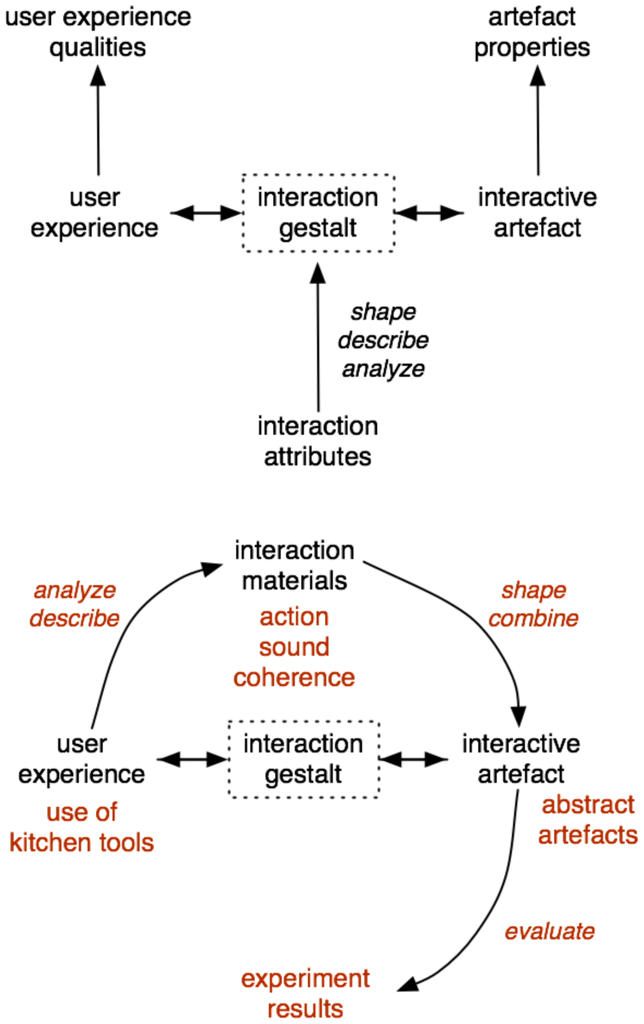


Figure 4.24: Comparison of the framework adapted from Lim et al. (top) and my extension through basic design methods (bottom, additions in red)

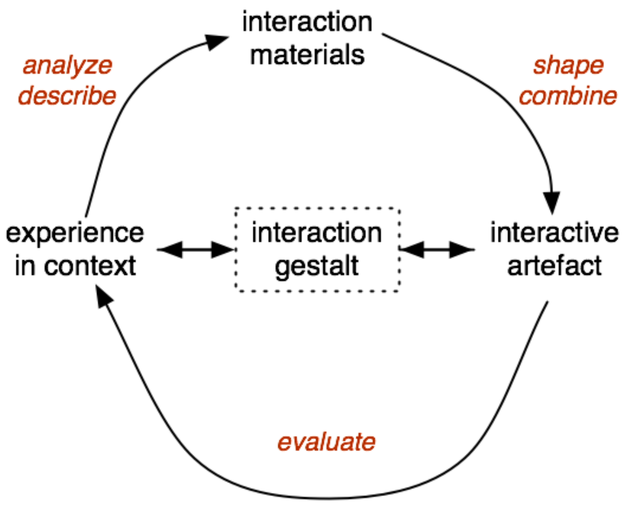


Figure 4.25: Proposal for the design process for functional artefacts (Franinović, 2009)

Chapter 5

Towards Evaluation of Enactive Sound

Most quantitative methods evaluate auditory experience by focusing only on listening and do not suit the evaluation of enactive sound interfaces. The aim of this chapter is to develop a new approach that can address the sensorimotor performance with tangible sound artefacts. A case study presents the development of quantitative experimental methods that can enable the evaluation of enactive learning in sound objects. In addition to the methodological contribution, the hypothesis that sonic feedback can guide human performance and support enactive learning is practically researched.

5.1 Introduction

Researching the influence of sonic feedback on user's performance with a tangible interface can not only help understand the perceptual mechanisms involved, but can also allow us to examine the relevance of enactive sound for real-world applications. Traditionally, auditory psychology has focused on listening, but enactive sound brings new challenges as the subjects need to manipulate physical objects while listening, rather than focusing solely on what they hear.

This chapter proposes a set of experiments that attempt to evaluate how an interactive object can be enactively controlled through sound. This research has a double purpose. On one hand, it seeks to develop the methodology for the quantitative evaluation of enactive sound interfaces. On the other hand, it aims to validate the argument that interactive sonic feedback can support enactive learning. My claim is that in order to achieve this goal, the psychophysical methods need to be expanded to include performative aspects of *doing with sound*, and that this can be achieved through collaboration of science and design.

A new methodology was developed based on two premises:

- Firstly, that interactive objects play an essential role in experiments whose goal is to explore enactive learning:

  Because enactive knowledge emerges from bodily interaction with our surroundings, enactive learning is strongly influenced by the physical aspects of an artefact that enables movement. Therefore, I propose that an interactive object/apparatus significantly affects the experiment itself and that it needs to become a key component of the successful evaluation. The objects not only affect the design of experiments, but also the other way round: their design is an embodiment of an experimental task. Because of this entanglement, the designer and the psychologist must closely collaborate in order to pursue such an evaluation.

- Secondly, that sonic feedback can affect the manipulation of an enactive object and in turn the manipulation can affect users' auditory perception. Therefore, my research aims to answer two related questions:

  - How does the physical manipulation of the sounding object modulate users' perception of the cause of the sounds?

– Can sonic feedback guide users in learning how to control an interface?

The Spinotron study exemplifies ways in which transdisciplinary teams of designers and scientists can contribute to each other's practice. My goals as a designer in the group were:

- to initiate sensorimotor experiments on performance with sound
- to shift the experimental methodology from sound source identification to the evaluation of enactive learning
- to develop the requirements for experimental interface that define the experimental task
- to design and construct the interface and to adapt it during the testing process
- to facilitate the know-how transfer within the group

The chapter opens with a short introduction to the psychophysics of sound and a discussion on the existing ways of evaluating sound. I then introduce the Spinotron design, the trial tests and analyse the reasons for which the initial sound design has been abandoned. I address design choices that were made during the creation of abstract sound objects and discuss the evaluation procedures developed with my colleagues from auditory psychology. Finally, the second and final sound design and related evaluation procedures are presented, and the results of the experiments discussed. I explain how the objects affected the design of the experiments and conversely - how the design of the artifacts embodied experimental tasks. The conclusion summarises the evaluation methodology and experimental results, discusses the role of physical objects in the experiments and outlines the role of designer in interdisciplinary teams.

5.1.1 Collaboration Context

The research presented in this chapter was funded by the European Commission 6th framework project entitled CLOSED: Closing the Loop of Sound Evaluation and Design and developed together with the partner colleagues from Sound

Design and Perception group at the Institut de Recherche et Coordination Acoustique/Musique (IRCAM) in Paris.

The experiments presented were conducted by the team composed of psychologists Guillaume Lemaitre and Olivier Houix, computer scientist and engineer Yon Visell and myself, an interaction designer. The apparatus was designed by myself and Yon Visell who focused on the adaptation of the physical sound models developed by the colleagues at the University of Verona. I developed the concept for the apparatus and improved it according to the comments of my colleagues. My role was the development of the prototype, involving product design, 3d modelling and digital fabrication and electronics. Sound design was strongly shaped by the models developed by Yon Visell. The presets for the models were proposed by all colleagues and then selectively chosen for the greatest difference among them and the closest similarity to a desired sound metaphor.

Through a set of visits to IRCAM, where the experiments were performed I was closely involved in the development of the experimental procedures and iterative design of the sounds. These research was funded through a grant awared by the MINET: European 'Measuring the Impossible' Network, which subsidised my research missions in Paris (See Appendix VIII). The experiments and the statistical analysis was performed by the psychologists using ANOVA, a set of statistical models used to determine if the perception and performance of all subjects in a study are affected by the same factors, and to what degree. While quantitative analysis was performed statistically, I interpreted the soft data gathered through the interviews, questionnaires and videos. The results of this research were published by the team in the journal paper 'Toward the Design and Evaluation Continuous Sound in Tangible Interfaces: The Spinotron' at the International Journal of Human Computer Studies 2009 (See Appendix VII).

In this interdisciplinary context, my aim was to explore how the addition of designers on scientific teams could work to extend research past current scientific methodologies. More specifically, in relation to the premise of this thesis, the goal was to shift the current focus in auditory cognition from listening to *doing with sound* and provide scientific foundation for Enactive Sound Design.

5.2 Auditory Psychophysical Methodology

Psychophysical methodology is based on 'the analysis of perceptual processes by studying the effect on a subject's experience or behaviour of systematically varying the properties of a stimulus along one or more physical dimensions' (Gescheider 1997). Similar to gestalt psychology, the discipline has often been accused of being nonscientific, due to the importance of subjective experience (Kantor 1962). This may be the reason why its methodology has evolved to be rigid and has focused on single perceptual stimuli. Due to the complexity of actual human experience, the experiments are usually associated with a specific sensory domain, such as the auditory one. However, more recently researchers are venturing into exploring multisensory or sensorimotor experiences that require new methodological and scientific approaches. Such studies of sensorimotor experience require long and multiple experiments.

5.2.1 Evaluating Sound Design

The methodologies for quantitative evaluation of sound design are related to experimental methods grounded in psychophysics. The traditional auditory experiments are conducted in the following way: the subject listens to the sounds and subsequently describes or compares them by using scales, classification tasks, descriptions, forced-choices and other methods. These different experimental protocols involve listening in a passive situation: participants listen to sound, within a context of use or not. This approach is well-suited to non-interactive sound within basic scientific research as well as in some applications. Different psychophysical studies, such as those on the design of car horns (Lemaitre et al. 2007), interior sounds of cars (Langlois et al. 2005) and perception of soundscapes in train stations in order to propose sound signalling (Tardieu et al. 2008), have guided specifications for sound design in various contexts (for e.g. alarms, auditory icons, sound signaling). However, in these studies, sounds were not coupled with any user's action and were focused on identifying the stimulus (i.e. the sound source). Thus, they are not suitable for studying the dynamic sensorimotor interplay that occurs during enactive experience.

5.2.2 Evaluating Performance with Interactive Sound

The methodologies for evaluating performance within HCI generally fit within the framework of information-processing theory that is based on the idea that human cognition can be reduced to a computer model and that logical information flow diagrams can be used to understand human performance. In such a reductionist approach, the human is seen as a complex system of other subsystems whose relations can be evaluated and their performance improved (Proctor and Vu 2007). Classical assessments of physical interaction with input devices (dominantly the computer mouse) have been based on Fitts' law (Fitts 1954). The latter predicts the time required to reach a target as a function of the distance to the target and its width. These studies focus on time efficiency, and do not take into account other factors that can influence sensorimotor performance that 'may not be best indexed merely by chronometrical methods' (Welsh et al. 2007), p. 29). Thus, the complexity of embodied interaction cannot be fully considered through the information-processing approach and new methodologies for evaluation of enactive learning are needed.

One of the rare examples evaluating the impact of continuous sound on sensorimotor performance, are the Ballancer experiments conducted to test the hypothesis that 'the (modelled) sound of the rolling object can convey information about the velocity of the virtual rolling ball in a more direct way and with higher perceptual resolution than the visual display.' (Rath and Rocchesso 2005). The most obvious approach to verify such an assumption would have been to ask subjects directly about their perception using rating or scaling tasks. However, because psychoacoustic experiments rely on the conscious reactions, and enactive experience includes both conscious and automatic action, Rath and Rocchesso created a new methodology that aimed to asses the perceptual mechanism of which the subjects were not aware. The experiments was based on the task of guiding a virtual ball on the specific area of a physical stick in the shortest time possible. The procedure was divided in three parts: first the subjects were given 20 trials to learn how to control the ball with visual and sonic feedback, then they performed the task with and without sonic feedback. In the third part, they performed the task without visual feedback. The results showed that guiding the ball to the target area was more quickly achieved if the sonic feedback was added to visual response of the system (Rath and Rocchesso 2005). In addition, the effect of the sonic feedback based on a physical model that simulated the sound of the rolling ball was compared with abstract sounds that could not be perceived as being generated by a physical event. In the initial learning stages, subjects performed faster with the realistic sound, whereas the abstract sound provided better performance after training. Even though participants performed well with the abstract sonic feedback, they preferred the realistic rolling sounds.

The Ballancer explored how direct interaction with an object can be influenced through continuous sonic feedback. While the experiments were based on traditional chronological measurements of performance, the novelty of Ballancer methodology lays in the adaptation of the evaluation of performance to an interactive setting where continuity and directness of interaction play an essential role. These experiments suggest that human performance can change depending on sonic feedback. The Ballancer methodology provided useful insights related to the challenges of enactive evaluation, such as defining an appropriate performance task to address the perceptual mechanisms of which the subjects may be unaware. The Ballancer task engaged existing bodily knowledge that users possessed since birth: balancing. Therefore, the action of moving a stick coupled to the sound of the rolling ball appeared to be appropriate to the performance task. But can such experimental procedures be generalised to assess other interfaces that require less familiar actions?

5.3 The Spinotron: A Case Study

The goal of this case study is to contribute new knowledge towards a basis for the evaluation of enactive learning through sonic feedback. The Spinotron artefact is designed to be used in these experiments and generates sounds through physical interaction, via a metaphor based on a virtual physically modelled mechanism. It utilises an unexpected coupling of action and sound: pumping the device generates the sounds of rolling balls and a spinning ratcheted wheel. Thus, sounds are ecologically coupled to movement in order to recall mechanisms found in everyday objects such as a a salad spinner or a spinning top toy.

The Spinotron case study has a double aim: one directed towards developing an transdisciplinary methodology suitable for evaluation of enactive sound objects, and the other to contribute new knowledge about learning and perception in

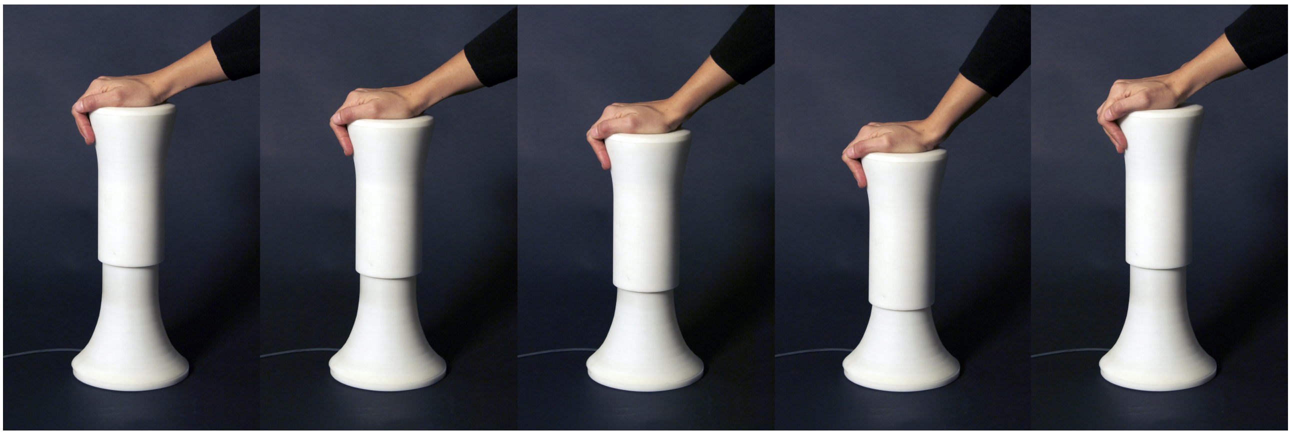


Figure 5.1: The Spinotron prototype used in the experiments (Franinović and Visell 2009)

enactive sound experience. Two specific questions were investigated:

1. How does physical manipulation of the sound source modulate the perception of the cause of the sounds?
2. Can sonic feedback guide users in learning how to control the interface?

The methodology developed in order to answer these questions combined design and evaluation activities. Due to the complexity of manipulation of an unknown object, the experimental procedures were developed incrementally, based on a number of trials that provided new findings about the user's perception and learning process. The methodology could not have been planned at the beginning of the experiments, because it was shaped as new questions emerged during the evaluation process. This required a close collaboration between the designer and psychologists on the team.

The Spinotron design and related experiments were developed over eight different steps that are described in this chapter:

1. Conceptualisation of the apparatus and experimental task (The Spinotron)
2. Design and development of the prototypes (using sound based on the virtual mechanism of a ball rolling inside a bowl)
3. Listening experiment on sound source/parameter identification (Can listeners estimate the height of the rolling ball?)

4. Sound design iteration (development of a new, clearer sound metaphor based on the virtual ratchet mechanism)

5. Recognition listening experiment (Can listeners estimate the speed of the ratchet?)

6. Sound design iteration (specification of the parameter presets that represent metal)

7. Listening experiment on sound source/parameter identification (Can users identify the ratchet?)

8. Learning experiment:
   - Step 1: Listening experiment on sound source/parameter identification in active situation (the interface is being manipulated) and passive situation (the users listen passively)
   - Step 2: Performance experiments: the investigation of the influence of sonic feedback (How can users learn to control the Spinotron through sound?)

At the end of each phase, the team discussion took place and decisions about the following step were made.

5.3.1 Apparatus and Task Conceptualisation

Experimental apparatus is a tool used to accomplish an experimental task. In classical listening experiments, it is usually composed of the device through which the stimuli are presented (the headphones or the loudspeaker) and the tool through which the subject gives his or her feedback (the computer software that automatically guides the subject through the experiment). Similarly, in the Spinotron listening experiments, the computer interface was based on PsiExp v3.4 experimentation environment including stimulus control, data recording and graphical user interface (Smith 1995). The sounds were played with Cycling'74's Max/MSP version 4.6 and were presented through the headphones during the experiments and through the loudspeakers during the explanation at the beginning of the experiment. The participants could interact with the interface through a mouse and a keyboard. All experiments took place in the double-walled sound isolation booth, a small, sonically isolated space that can host one subject, located at the Perception and Sound Design Labs of the IRCAM in Paris. Due to the lack of space, the experimenter's explanation of the procedure to the subjects took place outside of the booth or in the booth with the doors open. For the performance experiments, a novel apparatus was developed: the Spinotron, an abstract artefact that embodies an enactive task. In addition, the input device was changed from the computer mouse to an Elo Touchsystems Intuitive touch screen for easier interaction.

Figure 5.2: Pumping of the Oxo brand salad spinner

Following the methodology described in the previous chapter, kitchen tools were used both as an inspiration for the abstract sonic afterfacts and within task analysis focusing on understanding action-sound relationships in everyday context. Thus, the designer developing the Spinotron concept was equipped with both tacit and explicit knowledge about the sonic manipulation of such objects. The Spinotron interaction emerged from the pumping of the salad spinner (see Figure 5.2) which was used in the brainstorming of the concept. In this way, having in mind various constraints of experimental context, the experimental task was defined by combining a shape, an action-sound coupling, virtual sound metaphors and technical details. A set of sketches (see Figure 5.3) served as a platform for the discussions and was accompanied by the following description of the interface:

- *What is it?*

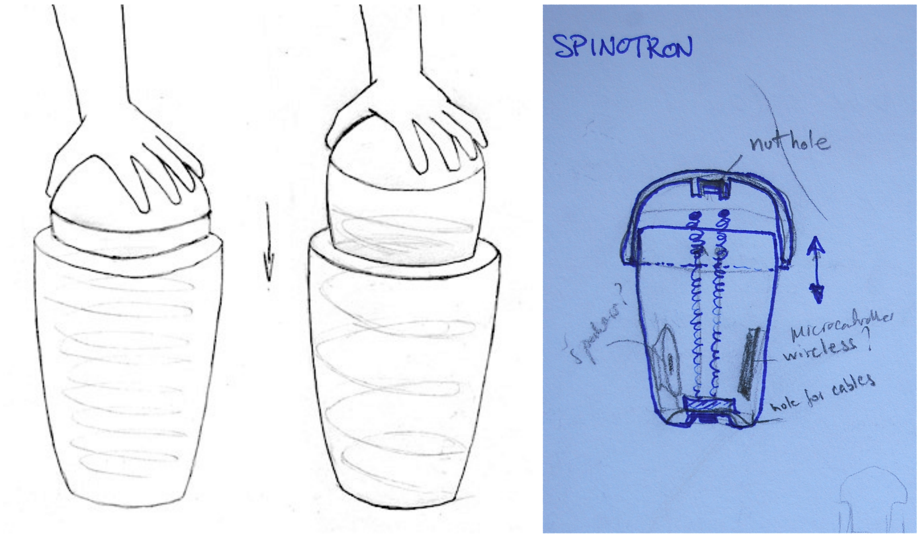


Figure 5.3: First ideas of the Spinotorn (Franinović, 2007)

- A device that the user pumps to energise or pressurise it

- *How do you do it?*
  - The user has to apply periodic force, compressing piston on top of device down

- *What are relevant action primitives?*
  - Plunging (like clearing a drain)
  - Pumping
  - Pressing

- *What is interactive metaphor or control dynamics?*
  - Virtual rotating cylinder with particles on bottom (circular) surface
  - Cylinder is driven to spin by plunging
  - Spins freely, with relatively low friction

  Alternative metaphors:

  - Vessel is pressurised. Safety valve regulates overpressurisation (gas escaping). Virtual pressure is supplied by pumping action of device.

- *What is the sound? How does it relate to the action?*
  - Sound of particles rotating in a cylinder: rolling sounds and impacts. Aerodynamic sounds associated with fast spinning.

  - Sound communicates the state of system, its "energy level" as embodied by spinning particles.
  - As an alternative, the sound of gas pressurisation would communicate if an excess of energy is injected.
- *Technical details?*
  - Mechanical action is spring-loaded
  - Sensing of position or force
- *Real-world scenario*
  - Manual centrifuge dryer (salad, clothes drying) during travel on remote hikes
  - Water sedimentation device, for purification in developing countries (the separation of large particles from impure water)
  - A coffee-grinder that tells you how fine your coffee is ground
- *Experimental task?*
  - Subjects maintain target "energy" level over time though pumping
  - Energy should be constant and non-excessive

The experimental tasks proposed by the designer conflicted with methodologies used by the psychologists on the team. The psychologists argued that the active manipulation during listening overly complicates the experimental procedures due to the involvement of senses other than auditory. They saw problems in setting up an experiment that could manage a large number of variables which would be changing during the interaction with an object, namely visual stimuli of the object moving, tactile sensations while touching the object, the kinaesthetic perception during the manipulation of the object, the sounds produced through mechanical interaction of the object and the digitally added sound. None of these could be kept fixed in the interaction with a physical object, unless an interface for masking each of these senses is developed, as for example in the experiments by Giordano, Visell, Yao, Hayward, Cooperstock and McAdams where a tactile sense was masked by a vibromechanical noise in order to isolate kinaesthetic condition in the experiment (Giordano et al. 2012). In addition, problems were expected during the experiments due to the numerous possibilities of action-sound coupling and the variety of potential virtual mechanisms. These issues raised a risk of very long experiments which, in fact, was the case in the Spinotron evaluation. However, considering that the overall goal of this research was to explore interactive sound related to bodily gesture, the questions related to sonic objects raised by the designer were accepted. The unsuitability of traditional auditory cognition approaches for an evaluation of sensorimotor performance was discussed. However, the psychologists argued that listening evaluation must be the basis for the performance experiments. As I will discuss later, the focus on the listening experiments led to the sound design of the apparatus which was based on listening only, thus contradicting some of the principles of the enactive approach (see also section 7.4 Models of Research Collaboration in the Conclusion of this dissertation).

5.3.2 Interface Design

Physical, mechanical and electronic design was iterated in order to create an interface that was sufficiently robust for repeated user testing. It had to enable compression and return to the initial full extension when the user released the top, capture data about the user's gesture and provide sonic feedback that was coherent with the virtual mechanism.

Figure 5.4: First Spinotron prototype (Franinović and Visell 2007)

Various mechanical and electronic prototypes were tested in order to accomplish these requirements (see the images on the attached DVD in the section 2

Abstract Sonic Artefacts - 04 Spinotron) . The first functional prototype was assembled using linear guide components, a 1000 count/rotation rotary encoder for sensing the position of the moving shaft and a Wiring microcontroller board (see Figure 5.4). The spring return was provided by a small length of shock (bungee) cord. Preliminary evaluations revealed this arrangement to be excessively complicated, to possess a larger stroke of movement than required and to produce excessive mechanical noises.

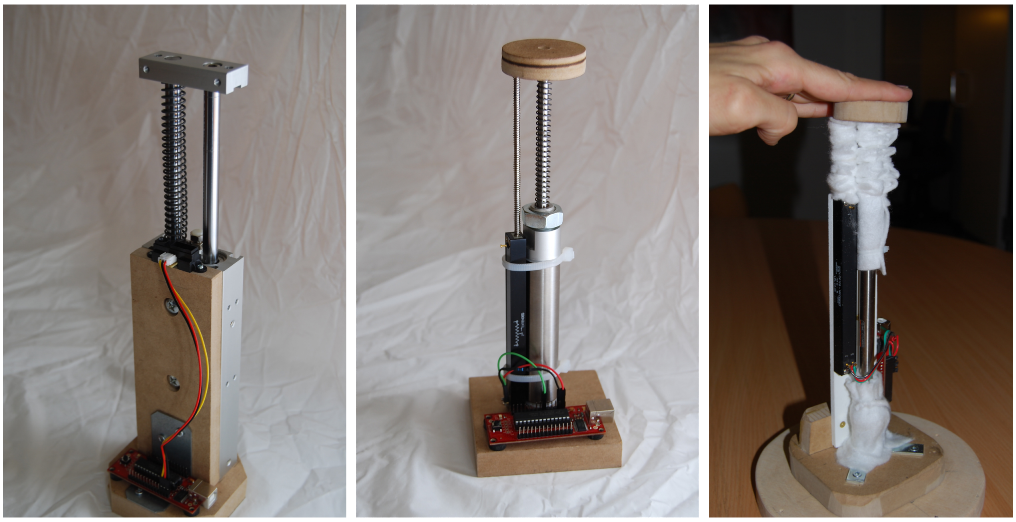


Figure 5.5: Final mechanism prototype based on off-the-shelf pistons (Franinović and Visell, 2007)

Therefore, subsequent models employed off-the-shelf pistons normally intended for industrial pneumatic systems. These mechanisms had the advantage of intrinsic damping due to the passage of air, which could be tuned by obstructing the inlet ports of the cylinders. The same method was used to mitigate the pneumatic noise produced by the device. The sensing in these prototypes was based on inexpensive infrared range sensors (as seen in Figure 5.5a) or somewhat more costly, but commensurately more precise, long-stroke linear potentiometers (as in Figures 5.5b and 5.5c). The linear potentiometer was eventually chosen as the most precise technology for sensing the user's pushing gestures. Thus, the digitised position was transmitted over a serial link to a computer running the sound synthesis.

The mechanism, electronics and core structure were hidden within a shell designed to invite the pushing of its top. Different handles were sketched and developed in balsa wood in order to define which one best suited the shape of

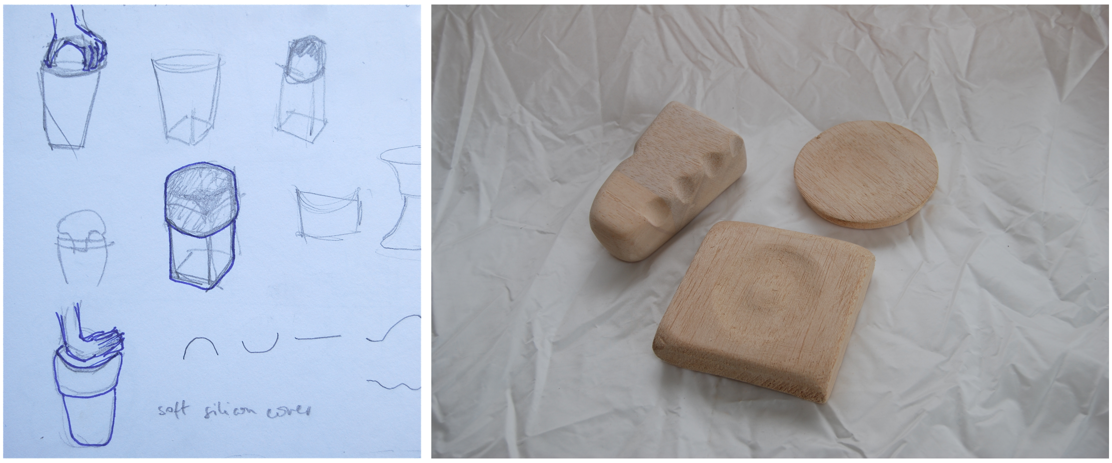


Figure 5.6: Studies for Spinotron top that should allow for easy pushing (Franinović, 2007)

the hand (see Figure 5.6). Two different shapes of convex or concave profiles were tested in order to create the affordance that best communicates pumping action (see Figure 5.7). They were modelled in 3D software and extruded in ABS plastic using a rapid prototyping printer. Both prototypes were used in exhibitions in which visitors manipulated the Spinotrons in order to perform the experimental task (see Figure 5.8), and the concave-shaped one was used in the learning experiments (see Section 5.2.8.).

Sonic Interaction

Based on the goal of guiding the actions of a user through sound, two main requirements were specified:

- The users should be able to recognise the action producing the sound at all times during manipulation of the interface. This allows the users to perceive the metaphor of the sound source, which can guide them in manipulation of the interface.

- Interactive metaphor should be based on a simple relation between the actions afforded by the Spinotron and its sonic feedback. Such coupling is essential to enable the users to perform a task with the interface.

Figure 5.7: The Spinotron in its concave and convex appearance (Franinović, 2007)

Based on these requirements, everyday sound was chosen because it maintains the perceived invariants during its manipulation.[1] Moreover, the sonic feedback had to be continuous because it has to guide users' movement at all times. Thus, the SDT software based on physical everyday sound models developed by colleagues from CLOSED project was used for sound generation.

For the coupling of sound and action, I proposed six different metaphors for the virtual mechanism that would generate sound under the user's action of pumping or pushing on the Spinotron top (See Figure 5.9):

1. the ball rolling in a bowl
2. friction between the moving part and the fixed part
3. air compression
4. water splashing
5. crushing of solid material

[1]The invariants are properties of sound that allow the user to identify the sound source (more on invariants in Section 2.3.1.1).

Figure 5.8: The Spinotron in exhibition at St. Etienne Design Biennale ((Franinović, 2008)

The selection among these different metaphors was guided by the search for a sufficiently complex coupling between sound and action, that would allow for enactive learning. The simple coupling such as that of pushing on the object to compress air would not allow us to specify a novel performance task that had to be learned. The metaphor of a ball in a bowl was chosen because it had a sufficient complexity that made it possible to specify a performance task. A user had to control the system by pumping the Spinotron in order to generate rotation of the virtual bowl. Sounds of the rolling ball were created, corresponding to five different configurations of ball size and materials and bowl shape, roughness and material (see Table 5.1). The names A-E are given to different parameter sets for the patches that can be found on the attached DVD in the section labeled '2 Abstract Sonic Artefacts - 04 Spinotron - 01patches - software - Spinotron Ballinabowl'.

The task was to keep the ball spinning at a certain height target area. In order to achieve this task, subjects had to be able to identify the height of the ball in a bowl by listening to the sound of its spinning. The initial idea was that the target area should be defined through the roughness of the bowl surface: either by using the strategy similar to that of the Ballancer experiments described

Patch	Parameter	units	A	B	C	D	E
SpinRolltoImpact	bowl curvature	1/cm	0.135	0.135	0.135	0.135	0.135
	ball radius	cm	5	5	5	5	5
	prob. of bounce		0.4	0.4	0.83	0.83	0.83
	out amp. scale		50	50	100	100	100
	elasticity	Ncm	0.004	0.004	0.004	0.004	0.012
	mod. for rolling ball		0.94	0.94	0.94	0.93	0.93
	mod. bowl shape		0.84	0.84	0.53	0.53	0.53
	sample period	ms	4	4	4	4	4
	bowl tilt angle	radians	0.7	0.7	0.7	0.7	0.7
	ball motion damping		1	1	1	1	1
Impact	hammer mass	kg	0.01	0.01	0.01	0.01	0.01
	force stiffness	N/m^α	66697380	370776448	370776448	370776448	66697380
	contact surface		1.666	2.414	2.16	2.414	1.557
	dissipation coeff.	Ns/m^(α +1)	1e - 5	1e - 5	1e - 5	1e - 5	1e - 5
	frequency factor		3	2	3	2	1.5
	decay factor		0.04	0.06	0.049	0.06	0.02
	gain factor		15	15	15	15	13.17

Table 5.1: Five sound model parameter configurations (named A, B, C, D and E) for the patches used in the Ball in a Bowl experiments

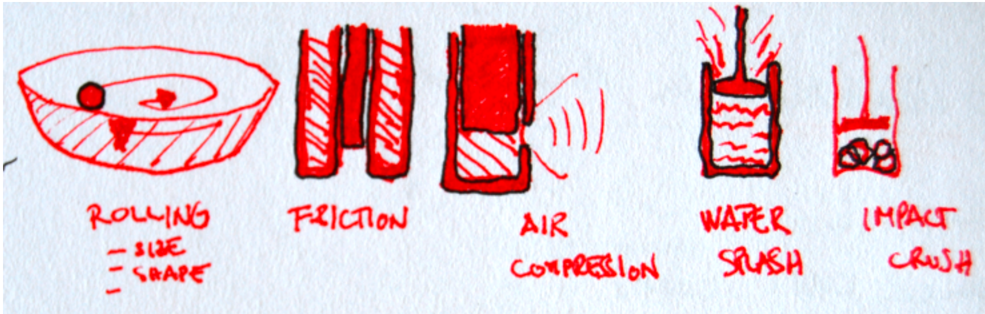


Figure 5.9: Sketches of different virtual mechanisms to be sonically activated during user interaction (Franinović, 2007)

above (i.e. by having two different textures: one for the target area and one for the remaining surface of the bowl) or through continuous variation of the bowl texture as the ball approaches the target height (see Figure 5.10). However, while testing by spinning the actual ball in the bowl, we realised that the resonance of the bowl varies with the height of the spinning ball and that sound provides sufficient information about the changing height, even on an equally textured surface of the bowl. Therefore, the hypothesis was formed that the realistic sonic representation can allow the user to perceive the different heights at which the ball is spinning.

5.3.3 Listening Experiment: Ball in a Bowl

After the sonic metaphor and the experimental task were determined, the psychophysical measurements were conducted in order to verify that the property of the sound event related to the experimental task could be easily identified. We had to prove that the subjects could identify the sound source of the ball rolling in the bowl as well as perceive the height at which the ball was rolling.

Experimental Procedure

Twenty participants listened to five different presets of sound parameters defined in the previous design phase. The first part of the experiment evaluated the perception of the sound source through:

1. a free description of the event causing the sound
2. a forced-choice experiment, where subjects had to choose among different categories of action that they thought caused the sound and those of

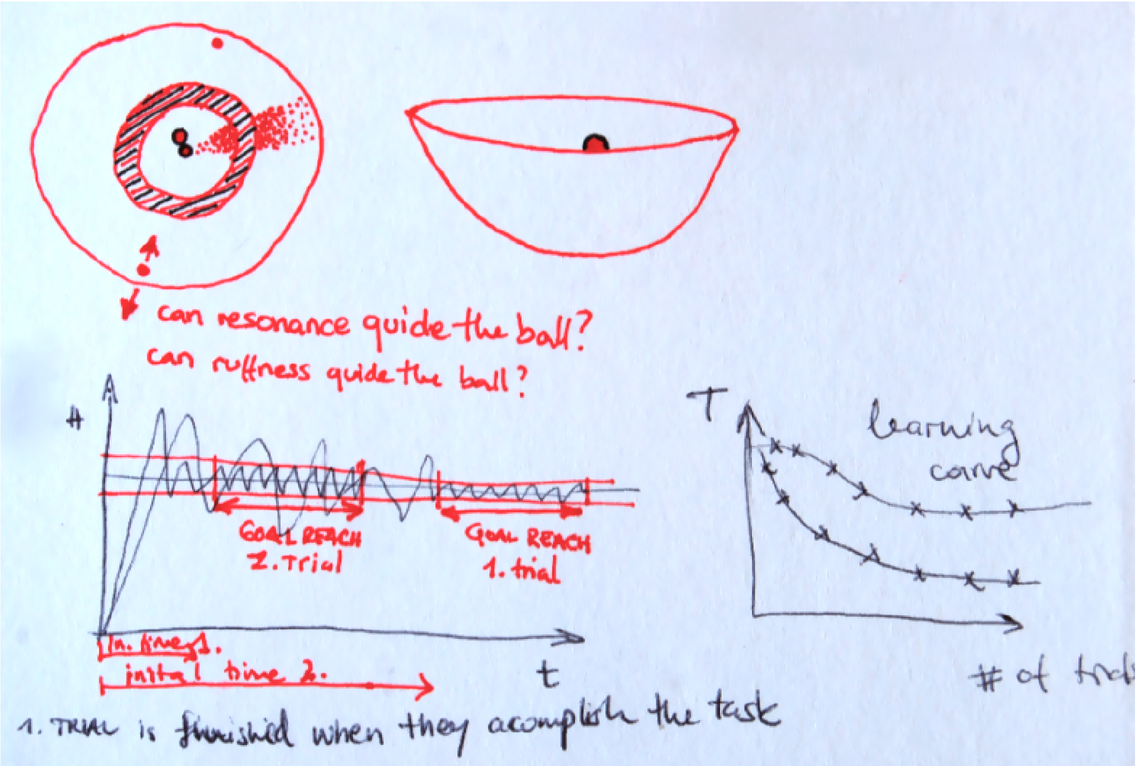


Figure 5.10: Sketches of the experimental task: keep the ball spinning in a certain target height area using granular bowl surface or bowl resonance (Franinović, 2007)

materials that they perceived. The actions included turning, shaking, rolling, rubbing, creaking, crumpling, tearing, falling, closing, breaking, hitting. The material categories were metal, glass, wood, plastic.

In the second part of the experiment, participants estimated the height of the ball during the rolling. They were told that the sounds had been produced by a ball rolling in a bowl and they were shown videos of different balls rolling in different bowls (see Figure 5.11). In five sessions corresponding to the five presets, they had to estimate the height of the rolling ball by positioning a ball on a perceived height in a custom-made graphical user interface (see Figure 5.12). Finally, participants' comments were recorded, and they were asked whether they believed that the sounds were recordings of real events or were produced synthetically.

Figure 5.11: Different kinds of balls and bowl used in the videos (Franinović, 2007)

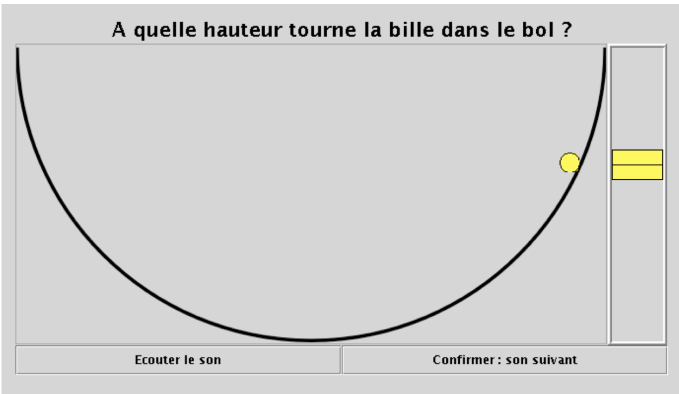


Figure 5.12: GUI for the listening experiment (Houix, 2007)

Analysis and Results

In free description of the cause of the sound, half of the participants spontaneously mentioned a ball when asked to describe the cause of the sound. The other half of the subjects described the sounds as a plate rolling on itself, objects vibrating, hitting, rubbing, bells and even water. These alternative descriptions showed that users' perception was dominated by the micro-impacts provided by the physical sound model and not by the rolling movement. Thus, when rolling was heard, the object was perceived as irregular. For example, one participant wrote: 'An irregular object rolling in a circular object in resonating wood.'[2] Another said that he heard: 'Back and forth movement of a small

[2]This is my translation of the original text: 'Roulement d'un objet irregulier dans un objet circulaire en bois raisonnant."

object in a circular object made out of glass. Maybe the object is not regular and has salient parts causing impacts, or it is not perfectly circular, and has steep slopes.'[3]

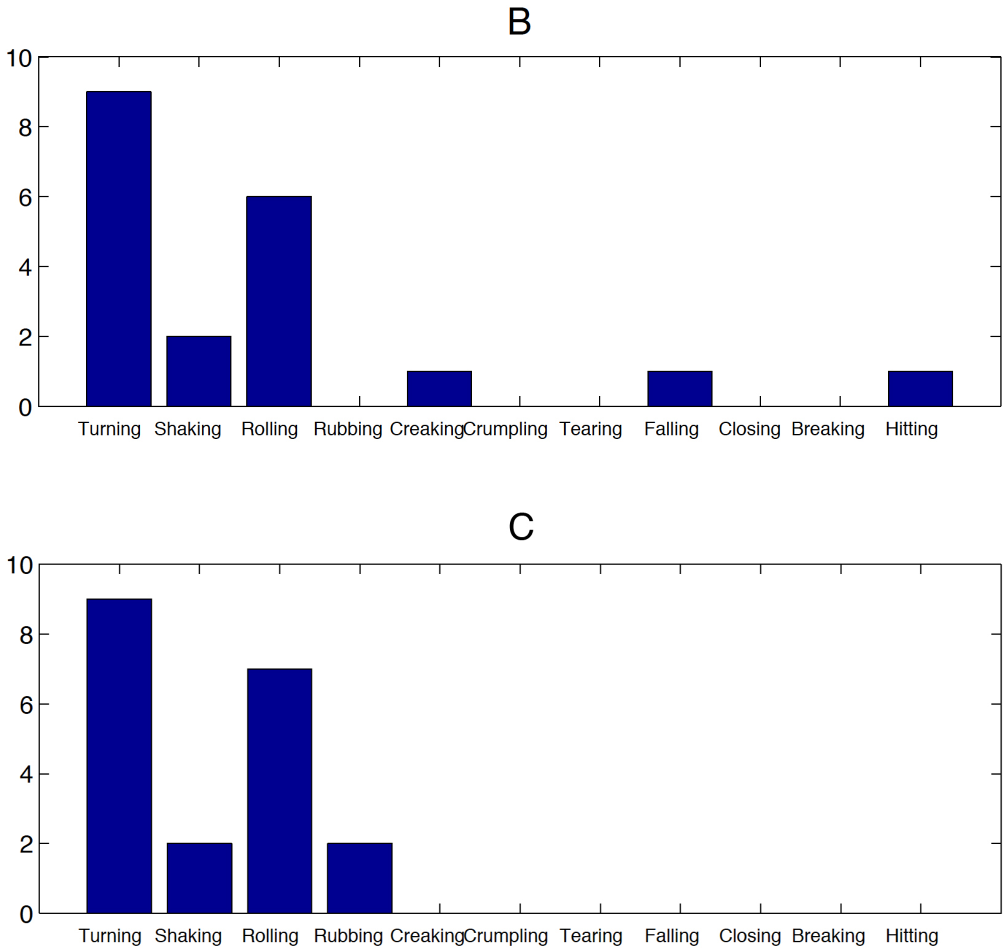


Figure 5.13: The histograms of the answers in the forced-choice experiment, for the action causing the sounds for parameter presets B and C

The results of the forced choice of action showed that the sounds were most often associated with actions of 'turning' and 'rolling', followed by 'shaking' and 'rubbing' (see Figure 5.13). The materials were identified mainly as wood in configuration A and E, and as glass or metal in the remaining ones (see Figure

[3]This is a translation of the original text: 'Aller-retour dans un objet en verre circulaire d'un petit objet avec chocs. Peut etre l'objet en plus de ne pas etre regulier contient des parties plus saillantes provoquant les chocs, peut etre l'objet n'est il pas parfaitement circulaire et contient des rebords abruptes.'

5.14 for examples of the wood and metal groups). These results indicate that the different presets were perceived as different materials, but that participants could not well identify a small object rolling. However, when the participants were afterwards told that the sounds had been made by balls rolling in bowls, none of them reported to be surprised or doubtful.

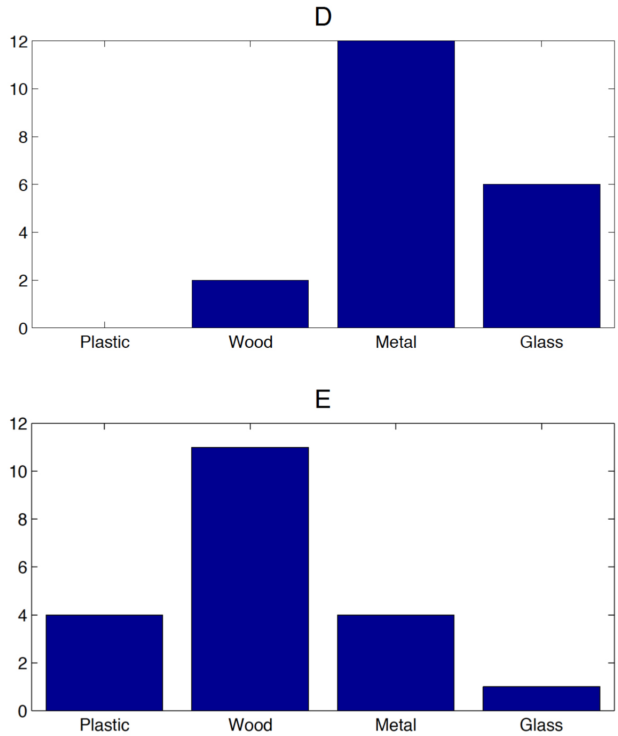


Figure 5.14: The histograms of the answers in the forced-choice experiment, for the material causing the sounds for parameter presets D and E

Regarding the height estimation of the rolling ball, the correlation between the estimations of heights of the subjects were correlated significantly ($p<0.05$). The distributions of estimations of height, as a function of the height parameter, for each of the five configurations is shown on the Figure 5.15. Except for configuration A, the estimations of height increase with the height parameter. The variances of estimations are the smaller for configuration D. Thus, it can be concluded that all five parameter configurations of physical sound model showed an increase of the estimation of height when this parameter increases. The five curves showing the perceived height in relation to the actual height in Figure 5.16 display a rather linear behaviour except for the largest values of the height parameter.

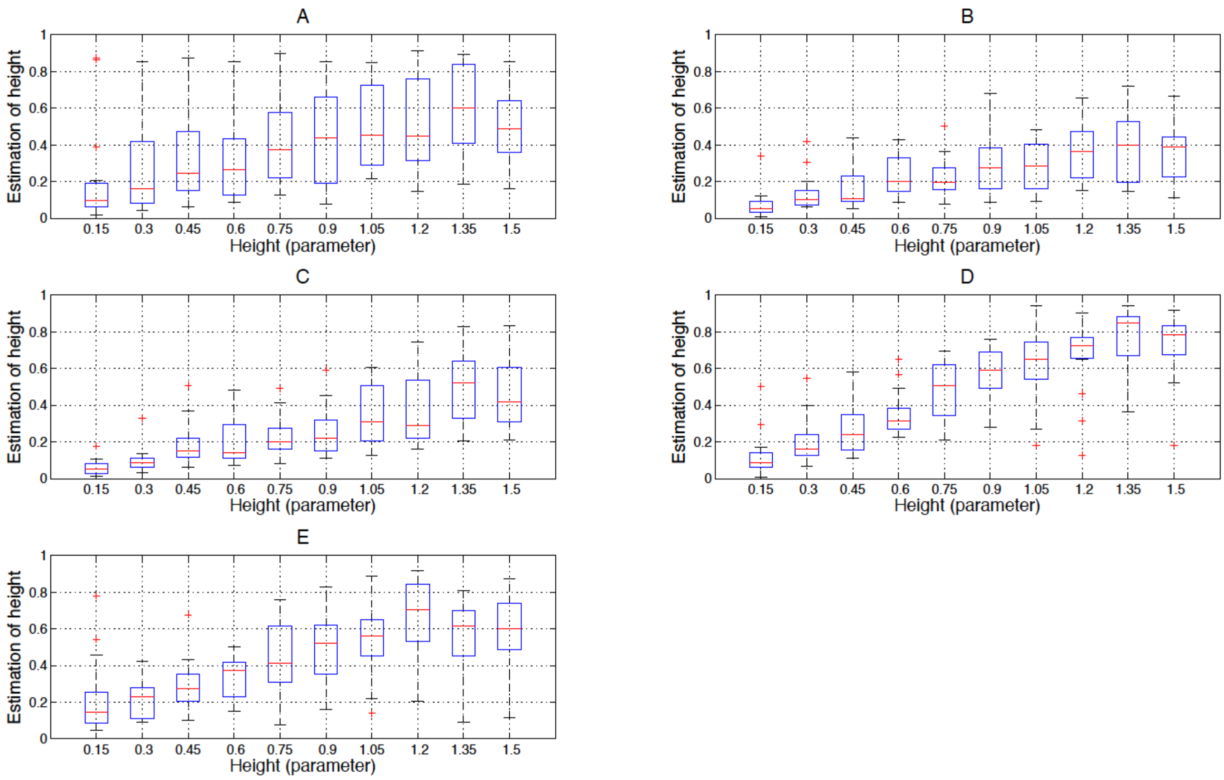


Figure 5.15: Diagram showing the distributions of estimations of height, as a function of the height parameter, for each of the five presets.

The results of a pilot study for the ball in the bowl model showed that listeners can estimate the height of the ball well. This estimation was very dependent on the model parameters. Most listeners reported that they found the sounds convincing, and several stated that the sounds originated from recordings of real sounds. This supported our hypothesis about the perceptual success of the synthesis based on the physical modelling of a real event.

However, the results indicated that the dynamical model of a ball rolling in a bowl was too complicated for users to easily control an interface. With half of participants not being able to identify the correct cause of the sound, the virtual mechanism of a ball in a bowl appeared to be too ambiguous to be used as an interactive metaphor. As a result, this sound design was discarded and a new control and sound synthesis model had to be developed.

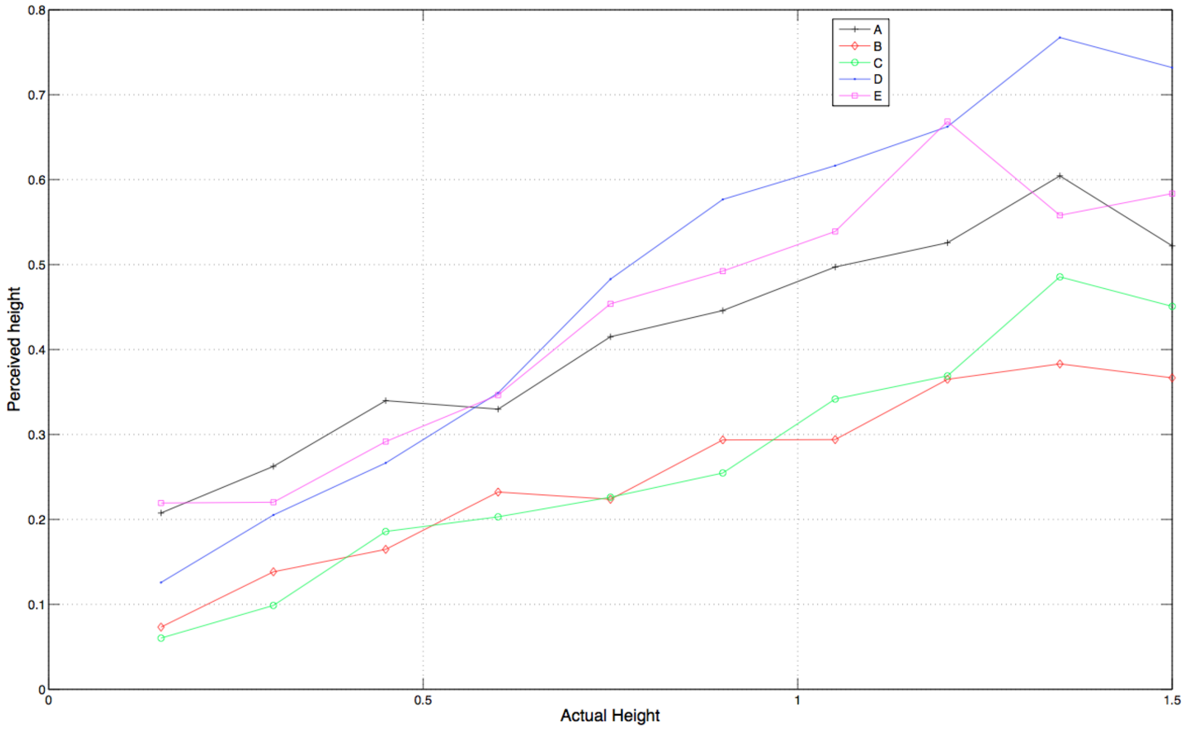


Figure 5.16: Estimations of height, averaged over the participants, as a function of height parameter. Perceived height is the position chosen by the subject through the interface seen in Fig. 5.12 and the actual height is the height of the actual rolling ball as defined by the sound model.

5.3.4 Iteration of Sound Design: Ratcheted Wheel

The goal of a new design was to provide a clearer mental model and simplified control mechanism. The metaphor chosen was based on the mechanism, which, when pumped, generated rotation of a wheel. The sound of the wheel was based on a ratchet mechanism, similar to that which is present in a socket wrench or bicycle wheel. For each angular increment of rotation, a tooth of the ratchet was encountered, leading to an impact sound between small metal parts (see Figure 5.17). Therefore, the ratchet sound was designed as a series of impacts, the rhythm of which was driven by the speed of the wheel: the faster the wheel turned, the greater the density of impacts. This was reproduced using the Sound Design Toolkit impact model in max/MSP software, where the parameters could be selected in order to convey different impressions of materials. The impact model was a nonlinear spring: when the two object collided, a spring mechanism described their interaction. The force f acted by the spring depended on both the compression x (i.e. the difference of the two objects' displacement while in contact) and the impact velocity v (or compression velocity, i.e. the difference of the two objects' velocity while in contact). More information about the SDT models can be found on the webpage http://www.soundobject.org/SDT. The parameter presets described in Table 5.2 refer to the parameters in the patch named SpinotronExperiment0.pat that can be found on the attached DVD in the section called '2 Abstract Sonic Artefacts - 04 Spinotron - 01patches - software - Spinotron ratchet'. Although the sound design was based on discrete impact events, they generated a continuity through sequencing, rate and velocity of the impact. The speed of the wheel was particularly important because it was to be used in evaluating how well a user performed the given task guided by the sound of the Spinotron.

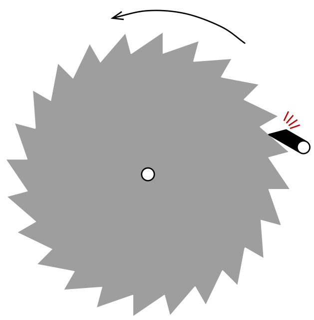


Figure 5.17: Second virtual mechanism: a ratcheted wheel, whose rotation is driven by the pumping motion of the device

Sound and Action Coupling

Two control models defining action-sound coupling were implemented: the continuous sonic response and the quantised sonic response to users' movements. The goal was to study the impact of different types of sonic feedback on enactive learning, as discussed in Section 5.3.8. Learning Experiment.

A continuous mode corresponded to the physical behaviour of the ratchet and was particularly sensitive to input gesture. A user of the Spinotron was able to control the sound synthesis model by driving the virtual ratcheted wheel into rotation through pumping action. The wheel's rotation accelerated in proportion to the velocity of pumping, but only when the interface was compressed (i.e. the energy was not given to the virtual system when the interface was released). The auditory feedback was continuous as it would have been in the manipulation of an analogue ratchet.

A quantised mode corresponded to a simplification of the continuous one. The impact rate obtained from the continuous control mode was discretely coupled to the continuous rotation of the wheel. With this control model, the user was expected to have less fine control of the speed of the ratchet because he or she could keep the ratchet at predefined constant speeds and jump from one speed to another.

The quantised case was easier to manipulate than the continuous one because of its simple behaviour. It was expected that the continuous mode would be learned more easily by the users, because it corresponded to an expected physical behaviour that may be encountered by the users in their daily experience (salad spinners, spinning toys, etc.).

5.3.5 Listening Experiment: Ratchet Speed

The listening experiment evaluated the ability of the subjects to estimate the speed of the ratcheted wheel. This feature was important for successful auditory-motor performance with the Spinotron, because the enactive learning could take place only if subjects could well perceive the speed of the ratchet. Therefore, the speed estimation had to be tested before proceeding with the learning experiments. In addition, our goal was to test the hypothesis that the perceived material could affect the perception of the virtual mechanism. Therefore, wood, rather than metal, was chosen in order to evaluate speed perception independently of the perceived material of the impacts.

Experimental Procedure

Nineteen participants volunteered as listeners and were paid for their participation. The sounds were designed to give the impression of three different kinds of wood named B, F and G (See Table 5.2). For each of the ‘wood’ settings, 13 sounds were created that correspond to 13 different ratchet speeds in the range between 2.8 and 36.7 RPM. Therefore, all sounds presented constant speed of the ratchet with a density of impacts varying from 1 to 13 impacts per second, and were between 3 and 4 seconds long.

As in the previous listening experiment, the procedure consisted of two parts:

1. the sound cause identification (free description + forced-choice experiment)
2. the estimation of the speed of the ratchet

Patch	Parameter	units	B	G	F	1	2	3
Spinotron Ratchet.pat	hammer mass	kg	1.22	1.22	1.24	1.08	0.07	1.23
	force stiffness	N/m^α	163	163	146	171	199	185
	contact surface		43	43	106	43	47	46
	frequency factor		1.7	0.55	0.47	4.9	10	1.7
	decay factor		10.82	6.44	13	12.68	0.26	0.66
	gain factor		5	3	1	12	30	1
	wheel gain		1	1	1	1	1	1
	wheel radius	cm	1.7	1.7	1.03	1.7	1.03	1.03
	rotational modulat. depth of wheel		0.2	0.2	0.27	0.2	0.27	0.27

Table 5.2: Parameter configurations for ratcheted wheel sound used in the experiments: B, G and F are the 'wood' settings and 1, 2 and 3 are the 'metal' settings.

The first part evaluated whether subjects could identify the ratcheted wheel as the sound source independently of the material intended to be communicated. Participants had to describe in writing what the physical cause common to the 13 sounds was for three settings. Then, they had to choose among categories of actions and materials that corresponded to those used in the experiment with the ball in the bowl.

In the second part, related to the estimation of the speed, the participants had to estimate the speed of different ratchets with a slider on a scale from 0 to 1. They were previously told that the sound source was the ratcheted wheel turning. The second experiment took place in three sessions corresponding to three different 'wood' models. For each session, 13 sounds representing different speeds were randomly arranged for each subject and repeated two times. Subjects could listen to all sounds in the beginning of the session in order to be able to compare the range of wheel speeds.

Analyses and Conclusion

The free descriptions of the sound cause suggested that the material affected the perception of the virtual mechanism. Most subjects described the sound as something being hit, falling or bouncing (e.g. one subject wrote: 'the physical cause is a percussion on a drum, i.e. a stretched skin.'[4] One participant described the sounds as being caused by a ratchet system: 'a wheel turning at different speeds is hit by semi-rigid sticks which are fixed on a wooden ball' [5] and another wrote that the sounds (parameter B) were caused by a 'metallic mechanism'. For all free descriptions of the ratchet model sound see the file named 'Free Descriptions of Ratchet Sounds with Evolving and Constant Speed', in the section called 3 Spinotron Performance Experiments on the attached DVD.

In the forced choice, subjects could not agree on the materials involved in the sound production. However, the resonances of hollow wooden objects were reported, and these contradict the metaphor of a ratcheted wheel. Only a few reported descriptions were coherent with the wheel metaphor. Moreover, the forced choice of actions agreed with the free description of cause, making 'hitting' and 'falling' the most dominant answers. Figure 5.18 shows the histograms with the number of answers on the vertical axis for each category describing the actions that produced the sounds. Subject have mainly reported that the sounds is generated by something 'hitting' and 'falling' for the three presets B, G and F. These results combined with the results of the free description task indicate that the participants did not hear a turning ratcheted wheel. Therefore a new sound design had to be created and perceptually tested.

As expected, the results showed that perception of the material has an influence on identification of the sound source. Moreover, the use of the constant speed of the wheel further complicated the perception of the metaphor, because the inertia of the object through temporal variation of the speed was not presented. These results strengthened our hypothesis that the perception of the virtual mechanism can be strongly affected through the choice of the material and the temporal patterns presented to the user. The results from the free description experiment were also used to inform the next experiment.

Regarding the speed evaluation, the differences between the evaluated speed in the tests and the retests is on average 0.1, which is a fair consistency. Therefore,

[4] This is my translation of the text: 'la cause physique est une percussion sur un element de batterie, c'est a dire sur une peau tendue.')

[5] This is my translation of the text: 'une roue tournant a differentes vitesses sur laquelle on a installe des baguettes semi rigides se finissant par une boule en bois venant percutter une plaque metallique'

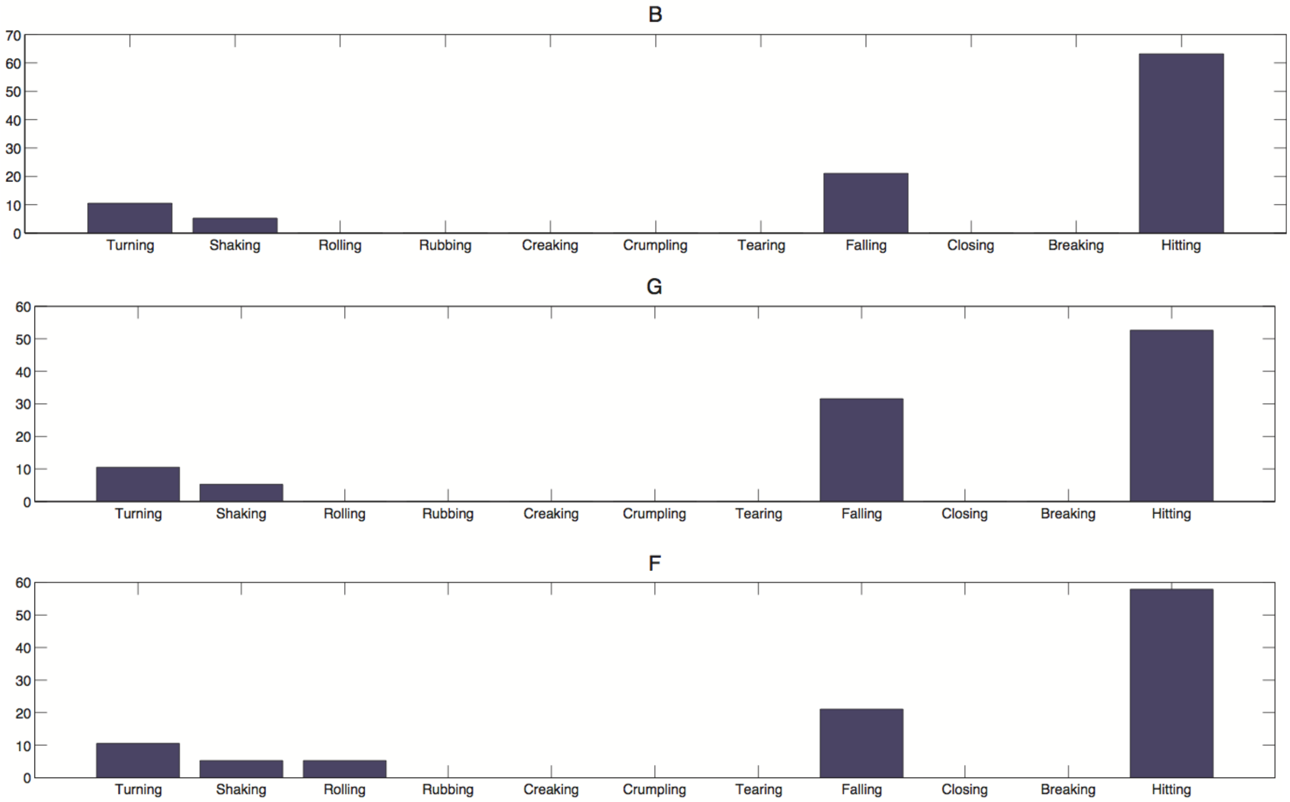


Figure 5.18: Histograms of the answers in the forced-choice experiment show that 'hitting' was the main choice for the action causing the sound. On the vertical axis are the number of subject's answers for each category of action producing sound

the test and retest scores are averaged. The estimations of speed produced by all the participants but one are correlated with a statistical significance < 0.01. The remaining participant is correlated with the other ones with a statistical significance < 0.05. The estimations of speed are therefore consistent.

Figure 5.19 represents the dispersions of the estimated speed as a function of the speed parameter, with the estimations ranging from 0 to 1. The estimated speed increases when the speed parameter increases. The dispersion is homogeneous across the 3 presets and is much smaller than in the ball in a bowl listening experiment, showing that the participants were more consistent in estimating the speed of the ratchet than the height of the ball in a bowl.

Figure 5.20 shows the estimated speed (vertical axis) as a function of the actual speed (horizontal axis) for the three parameter settings. We can see that the relationship between the estimated speed, averaged among the participants, and

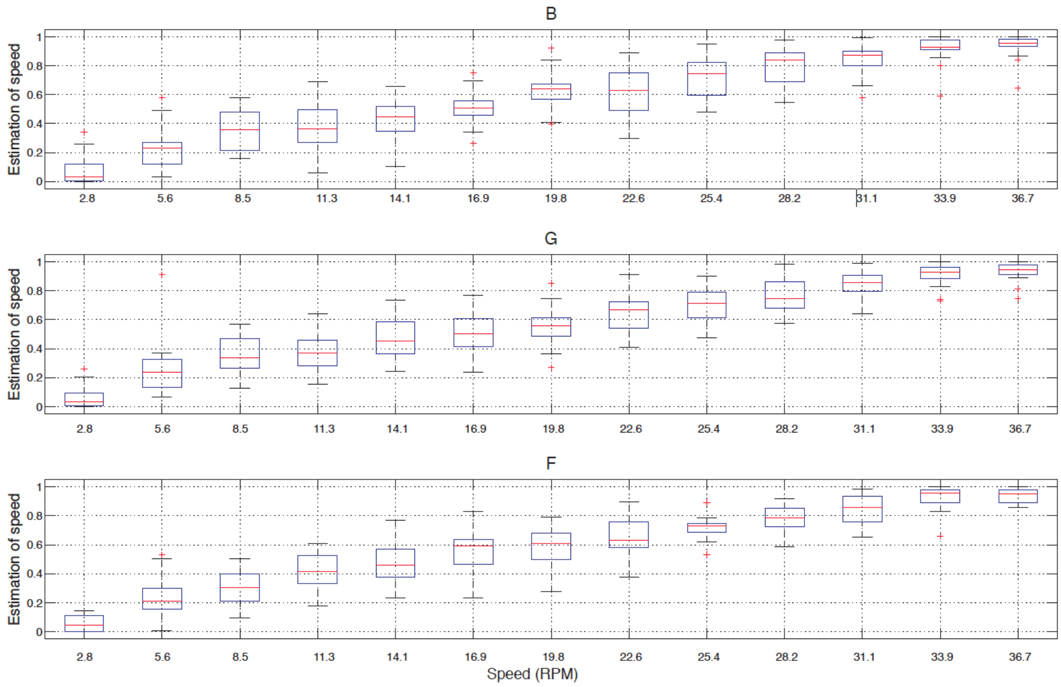


Figure 5.19: Dispersion of the estimation of the speed of the ratchet for the three presets. The red line indicates the median, the box the lower and higher quartiles, the whiskers the maximum values, and the red crosses the outliers.

the actual speed is almost linear for the values of the speed parameter between 0.25 and 0.95. This shows that the perceived speed increases with the increase of the speed parameter. Therefore, listeners could well estimate the speed of the ratchet. Different parameter settings used in the sound model did not affect this ability. Thus, the experiment showed that the estimation of speed is independent of the presets of sound model parameter, unlike the ball in a bowl case where the perceived speed was affected by the presets (see Figure 5.16). In conclusion, the speed of the ratchet can be used as information to guide users' gestures in the learning experiment, but the material can confuse the identification of the sound source.

5.3.6 Iteration of Sound Design: Ratcheted Wheel

Due to the problematic perception of the intended Spinotron metaphor based on wood material, we have chosen to design and to evaluate new parameter settings that could best convey metal as the material of the virtual mechanism. Three different parameter settings were designed using the ratchet patch. Compared to

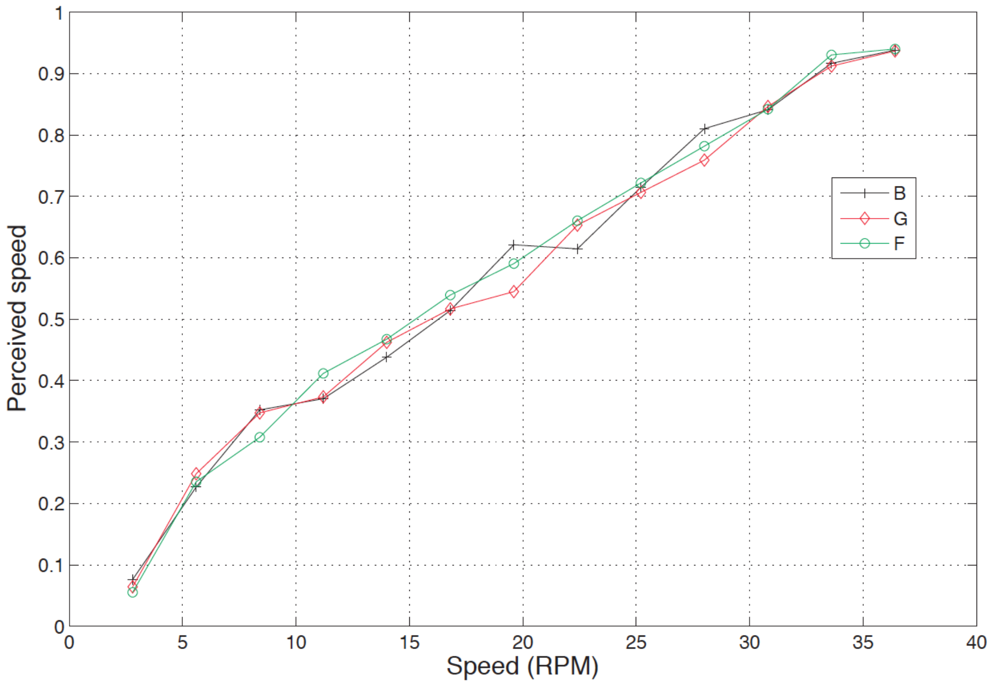


Figure 5.20: The estimation of the speed of the ratcheted wheel for the three 'wood' parameter settings, averaged over participants.

the sounds used in the previous experiment, new sounds were characterised by a lighter mass of the impacting object (hammer mass), and produced sounds with higher modal frequencies and lower decay factors (see groups 1, 2 and 3 on Table 5.2).

These three new parameter settings simulating metal were combined with the two settings from the first experiment, namely settings B and G. All were used to generate two groups of sounds: sounds based on a series of impacts with a constant speed, and sounds made of impacts with an evolving speed representing the acceleration and deceleration of the wheel (and their combination). These two groups were created in order to study the effect of the temporal evolution on the auditory perception. The constant sounds used in the previous experiment appeared to be perceived as discrete sounds, such as hitting an object. Our assumption was that in addition to the perceived material, the evolving patterns would better communicate the intended sound-producing mechanism. In addition, the evolving sound patterns were to be created in the final learning experiment, where the user manipulated the interface and continuously generated sounds.

5.3.7 Listening Experiment: Ratchet Metaphor

The second listening experiment aimed to evaluate whether new parameter settings of the sound model were coherent with a wheel metaphor. Five parameter settings were tested: two from the previous experiment, which aimed to communicate wood material (B and G) and three that were specifically designed to give the impression of a compact metallic mechanism (see Table 5.2 on the previous page).

Experimental Procedure

Participants were divided in two groups: those listening to constant speed sounds and those listening to dynamically evolving speed sounds. None of the 36 volunteered subjects had participated in previous experiments. The procedure was as follows:

1. Free description of the cause of sound:

   Subjects listened to the four sounds for each of the five parameter settings with constant and varying speed and described what the physical cause common to four sounds was.

2. Free description of actions and objects:

   Subjects listened to the four sounds for each of the five parameter setting and described what the actions and the objects causing the sounds were.

3. Choice of actions and materials:

   Subjects chose among several different actions (vibrating, bouncing, banging together, hitting, falling, going clickety-clack, turning, shaking, rolling) and materials (metal, glass, wood, plastic) that were presented for each four sounds. These categories were created from the results of the free verbalisation in the previous experiment, which showed that the expression 'going clickety-clack' (in French: 'cliqueter') was particularly good for describing a ratchet mechanism.

4. Forced-choice verbal portrait selection:

   Subjects had to chose one among eight verbal 'portraits' describing the sound event. These portraits were based on the free verbalization in the previous experiment.

- A saucepan is being hit with a spoon (in French: ‘On frappe avec une cuillare sur une casserole’)
- A ball is bouncing (‘Une bille rebondit’)
- Water is dripping onto a vessel (‘Des gouttes d’eau tombe dans un recipient’)
- A percussion is being struck by sticks (‘On frappe avec des baguettes sur une percussion’)
- A ratchet is going clickety-clack (‘Une roue dente cliquette’)
- Finger tapping (‘On tapote des doigts’)
- A casino roulette is turning (‘Une roulette de casino tourne’)
- A gear is turning (‘Un engrenage tourne’)

Analyses and Conclusion

Newly designed parameter settings (1, 2 and 3) appeared to have less distributed material choices and thus proved to be less ambiguous than settings from the previous experiment (B and G). The results showed that the temporal patterns (constant vs. evolving) had little influence on the perception of the material. However, an evolving temporal pattern appeared to better communicate the ratchet mechanism. The subject’s choice of action categories was most often associated with the ratchet actions: ‘going clickety-clack’, ‘hitting’ and ‘turning’ for newly designed parameter settings (Figure 5.21). As expected, the constant speed sounds were more easily associated with impacts (‘hitting’), whereas the dynamically evolving sounds were linked to a more continuous events such as ‘bouncing’. Among the verbal portraits, parameter settings 2 was most often associated to ‘a ratchet is going clickety-clack’ portrait. Therefore, this setting was chosen for the learning experiment as it proved to be the most suitable for enabling the perception of the ratcheted wheel mechanisms through sound.

At this point, a few conclusions can be made. Firstly, that listening to evolving speed of the ratchet instead of a constant speed leads to a better perception of the mechanism of the ratchet. Secondly, the perception of the material for the three newly designed presets is much more coherent and clear than for the previous presets.

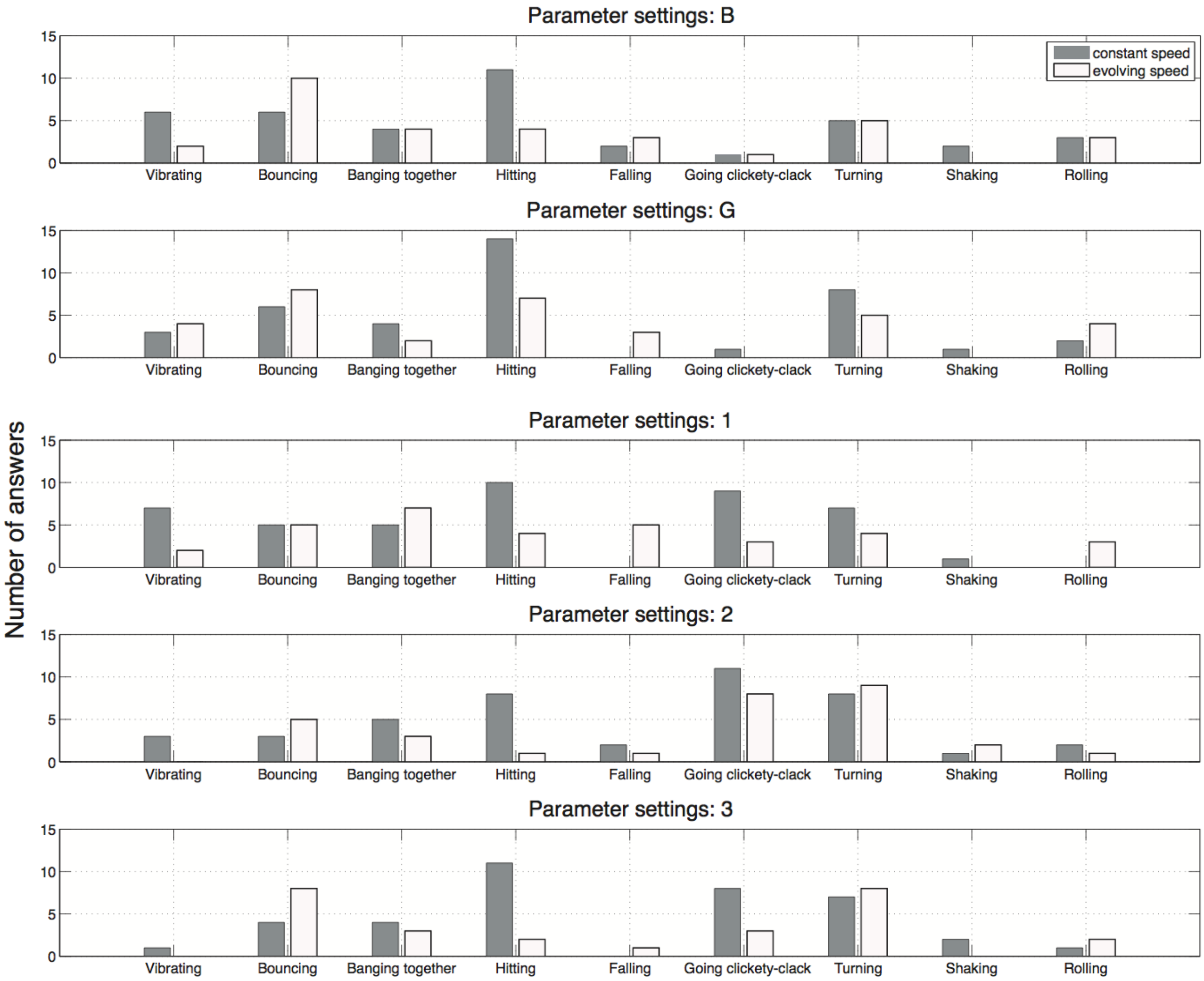


Figure 5.21: Bar plots of the actions selected by the participants, for five parameter settings of the synthesis model. The first group listened only to sounds corresponding to a constant speed of the ratchet whereas the second group listened to sounds corresponding to an evolving speed.

5.3.8 Learning Experiment

The final and main goal of these experiments was to evaluate enactive learning enabled by a sonic interface. The learning experiment was the last step in accomplishing this task and the first time that the Spinotron interface was used as an experimental apparatus (see Figure 5.22). The general question explored was: How can sound support users in learning how to manipulate a tangible interface? Similar to Ballancer hypothesis (Rath and Rocchesso 2005), our assumption was that participants would perform better if continuous auditory feedback was provided. In addition, we wanted to know if the manipulation of the device changed a perceived cause of the sounds and if the continuous control mode of the virtual wheel mechanism helped users learn the performance task more quickly than the simplified quantised response.

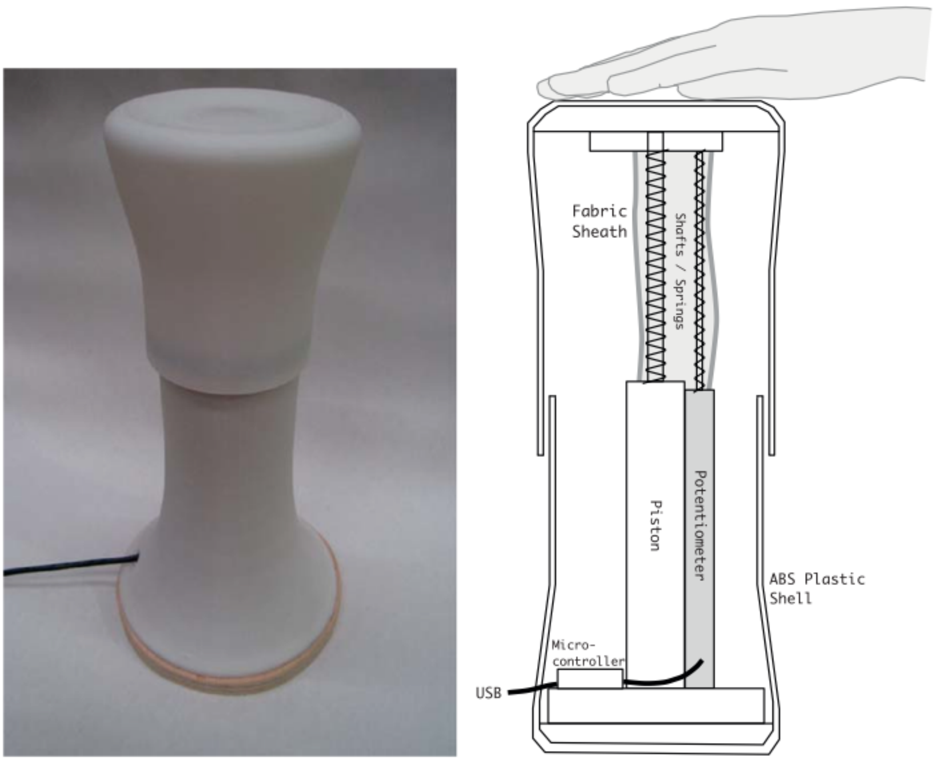


Figure 5.22: The Spinotron apparatus used in the learning experiments (Franinović and Visell, 2007)

Performance Task

The task for the learning experiments consisted of pumping the Spinotron at a constant pace, guided by the constant speed of the ratchet. The advantage of this task was that it could be performed with or without sound. Without sound, it amounted to simply pumping the device at a constant pace. With sound, the control of the pace of pumping was guided through the perceived speed of the virtual ratchet. The target speed was defined to be reachable by pumping the Spinotron at a constant pace of three pumps per second, independently of the mode of interaction.

The effect of sound on users' performance was examined for both control modes of the ratchet model (continuous and quantised). In the quantised case, the auditory feedback was not continuously informative, because it communicated only the piecewise constant speed of the ratchet, while the continuous mode provided a continuously varying indication of the same. Thus, the task difficulty for the two control modes was not identical. Driving the ratchet within the prescribed target range was easier in the quantised mode. However, the main aim in the learning experiments was to assess users' performance with and without auditory feedback, keeping the control mode constant, either continuous or quantised.

Experimental Procedure

Thirty participants (nineteen women and eleven men), aged from nineteen to fifty-seven years, participated in the experiment. They were divided in two groups: those who were provided with sonic feedback during manipulation of the Spinotron (eighteen subjects) and those who used the device without auditory response (twelve subjects). These two groups were formed in order to show the difference in performance under the influence of auditory feedback.

Step 1: Action Listening Experiment

The action listening experiment was conducted with the group that was later provided with sonic feedback during manipulation of the Spinotron, ie. with eighteen subjects. The procedure was the same as in previous listening experiments, consisting of the free description of the sounds and forced-choice methods (materials, actions, portraits). The difference was that in this experiment, the subjects were generating sounds by interacting with the Spinotron, rather than simply listening. The sonic feedback to their actions was synthesised by the ratchet model previously described (parameter setting 2).

Step 2: Enactive Learning Experiment

The manipulation part was conducted by both groups (the twelve subjects performing manipulation of the Spinotron with sonic feedback and the twelve subjects interacting without sound). Each of the two groups was divided in two subgroups of six subjects, one subgroup using continuous interaction model and the other using the quantised control model. In the beginning of the experiment, the participants were shown how to use the interface in order to reach different speed targets (with or without sound). For the group with sonic feedback, during the demonstration the sound was presented over loudspeakers. During the experiment itself a pair of headphones was used to mask the natural sound of the Spinotron (in addition, a fabric sleeve was used to decrease the noise). As usual, the experiments were performed within the sound isolation booth (See Figure 5.23).

Figure 5.23: A participant pumping the Spinotron in a sound isolation booth (with doors open), during introduction by the experimenter.

During the learning experiment, the subject had to use the Spinotron in order to reach and maintain a target speed of the ratchet. In the first training part of the experiment, the visual display communicated to the user what the speed of the ratchet was (see coloured display on Figure 5.24 on the following page). The goal was to show to users how their actions affected the performance task, i.e. how close or far they were from the target area. During the second test part, no visual feedback was provided, so the users had to adjust their movement according to the sonic feedback (first group) or only through the kinaesthetic feedback provided by the interface (second group).

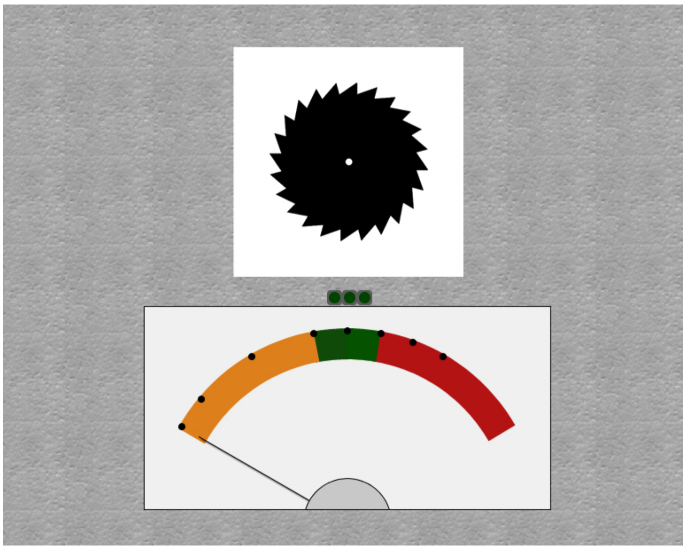


Figure 5.24: The visual display communicated to the participants the speed of the ratchet during the training phase (Houix, 2007).

Each learning experiment was composed of twelve trials during which the user had an opportunity to learn how to adjust his or her gesture in order to keep the speed of the ratcheted wheel constant. Each trial was divided in two six-second-long parts. At the end of each of these two steps, the participants were informed of how long they maintained the speed of the wheel within the target (percentage of time within the target was displayed on the screen). In addition, the participants were asked to judge the manipulation of the Spinotron before and after the learning experiment on three continuous scales:

- easiness: subjects were asked how easy it was to use the device, with the answer range between 'very difficult' to 'very easy'
- preference: subjects were asked to evaluate their appreciation of the device, ranging between 'I do not like it at all' and 'I like it very much'
- naturalness: subjects were asked if they thought that the sound was natural, with the scale from 'not natural at all' to 'totally natural'

The three scales of easiness, preference and naturalness were judged before and after the task performance experiment with the Spinotron. They did not change for the preference and naturalness scales. On the easiness, scale participants judged the Spinotron as less easy and less natural after the experiment, than when they were freely manipulating it (see results on Figure 5.25). .

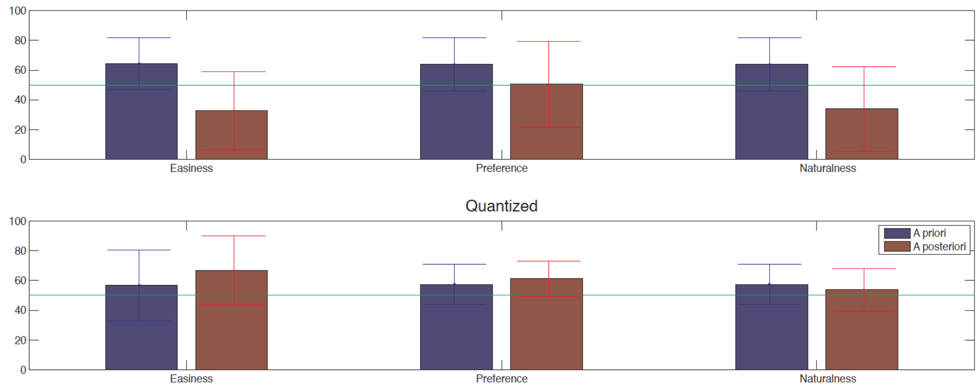


Figure 5.25: Mean and standard deviation values for the three scales (easiness, preference and naturalness), and for the 2 modes of the Spinotron evaluated before and after the Spinotron manupulation.

5.3.9 Results and Analysis

Active Listening Experiments

The goal of the active listening experiment was to explore the differences in perception of the sound cause in two situations: (1) in passive listening where the user was simply exposed to sounds and (2) in action listening where the user self-produced the sounds heard. Our assumption was that the cause of sound would be better identified in an active context, than in a passive setting. The results from this experiment were compared with those of the listening experiment in order to see the differences in three listening situations:

- passive listening to constant ratchet speed (the sounds were simply played back)
- passive listening to evolving ratchet speed (the sounds were simply played back)
- listening while dynamically creating varying ratchet speed (the sounds were caused by the manipulation of the device by the user)

The most significant difference was that the third group identified most correctly the material involved in sound production. The subjects thought that the mechanism producing the sounds was made of metal or glass.[6] The manipulation of the interface has changed the perception of the material involved in sound production (see Figure 5.26). Therefore, we can conclude that the perceived aesthetics of an interactive object may be affected through sound design. In addition, the identification of a single material involved in the sound production increased from the first listening situation to the last ergoauditive one. This may be linked to the fact that, in the constant speed experiments, the actions were most often identified as 'hitting' and therefore imply at least two objects in sound production (the hitting object and the hit object), whereas the evolving speed was associated with actions such as 'bouncing' or 'going clickety-clack'. However, the manipulation of the interface did not increase the perception of the ratcheted wheel as a sound cause, as shown in the analysis of the portraits and action choice (see Appendixes VI and VII). In the free descriptions of the objects and actions during active listening, only a few participants described a ratchet mechanism (e.g. 'I imagine a propeller that rotates less rapidly and hits a sheet of metal.'[7] Several subjects described how their own action on the Spinotron might have caused the sounds (e.g. it is a roller that acts as a lever when you support the upper part of the object. [8]

The initial hypothesis was that the active listening would improve the perception of the virtual metaphor of ratcheted wheel, in comparison to passive listening (constant and evolving speed). However, the experiment did not prove our assumption. One explanation could be that the perception of the wheel metaphor was reduced because users were expecting to haptically feel the variable mechanical resistance due to the virtual spinning wheel. Furthermore, the plastic shell of the Spinotron was (intentionally) designed to contradict the ratchet metaphor, in order to avoid easy association between the physical object and sonic metaphor, and this may have made the sound source identification more difficult.

[6] The glass and metal are expected to be confused as similar materials as shown in (Giordano and McAdams 2006)

[7] My translation of 'j'imagine une helice qui tourne de moins en moins vite et qui cogne sur une plaque de metal'.

[8] My translation of 'c'est un roulis qui fait office de levier quand on appui la partie superieure de l'objet'

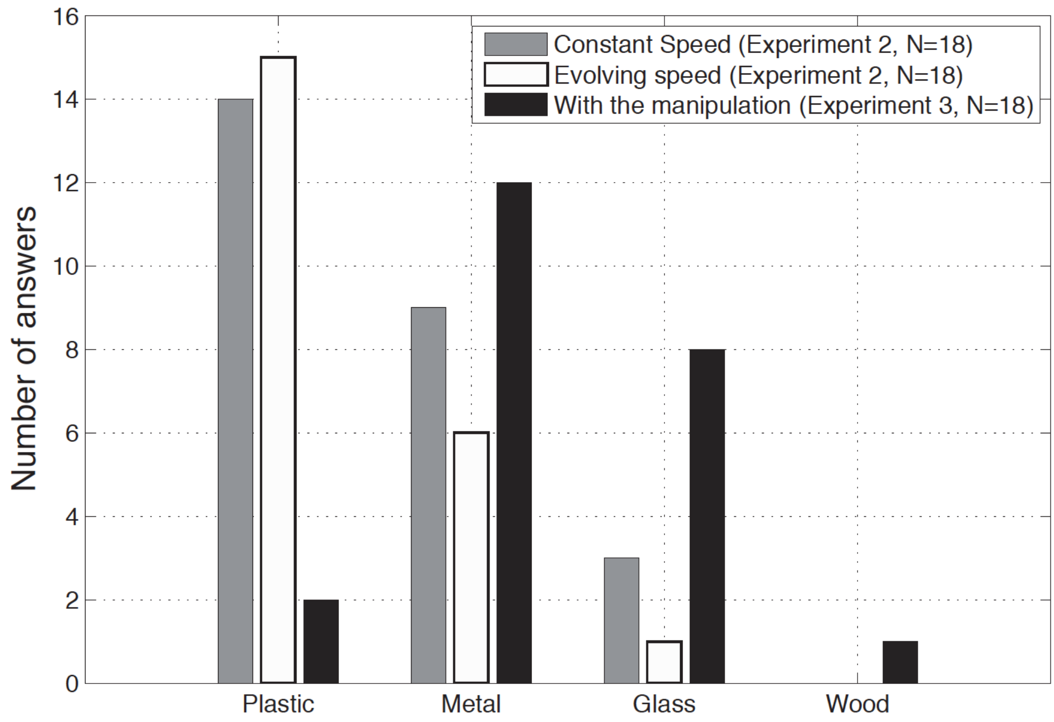


Figure 5.26: Materials perception compared for listening experiment 2 and active listening experiment 3.

Enactive Learning Experiment

The performance measure was hard to define because the two modes of the control model used in the Spinotron led to very different behaviours of the ratchet. Indeed, while the speed of the ratchet evolved in the continuous mode, it could have only discrete values in the quantised modes. For example, using the distance between the target and the actual speed would not be a good measure of performance, because in the case of the continuous dynamics, this distance depends only on the user's performance, while in the other case, it depends also on the quantisation steps. Therefore, it was decided to count how long the speed of the ratchet stayed within the target area as the measure of performance.

For the group using Spinotron with sonic feedback, the performance was shown to increase across trials. This means that learning was taking place and that the subjects improved their movements because of sonic feedback. Figure 5.27 shows that there was no increase in performance in the subjects without sonic feedback while those listening to the virtual ratchet mechanism learned how to perform

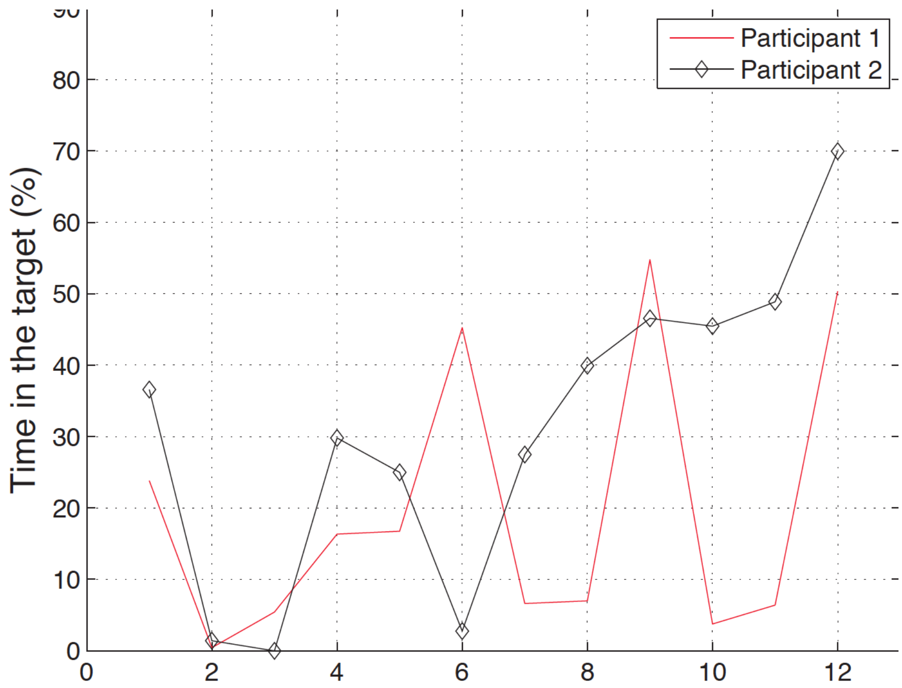


Figure 5.27: Performance of participant 2, who manipulated Spinotron with sonic feedback, improved over time.

better. However, no difference in learning through continuous and quantised control model was found as both groups improved over time, although the task difficulty was different for two control models. Furthermore, the improvement of performance across trials did not exhibit any difference between the two groups, indicating that participants did not learn the continuous mode faster than the quantised. However, the comparisons of two different control models was not entirely revealing because the task difficulty was not the same for those cases.

Therefore, we can conclude that auditory feedback improved the motor performance with tangible interface i.e. that the sounds guided the user to learn how to change his or her gestures in order to accomplish a given task. These findings supported my initial claim that Enactive Sound Design may open up the space for learning new interactions with our physical world.

5.4 Conclusion

The Spinotron experiments present an example of quantitative evaluation methods for enactive sound artefacts. In addition to developing a methodology for quantitative evaluation of Enactive Sound Design, two critical issues were researched: whether the perception of the sonic metaphor changes with manipulation of the object and whether sound can guide enactive learning.

5.4.1 Enactive Learning Results

As listening experiments have shown, the temporal variation of sound pattern had an effect on the perceived sound source and the manipulation had no influence on causal identification of sound. Therefore, everyday sounds can be successfully used as interactive metaphors embedded in tangible interfaces, if they maintain the correct coupling between sound and action, as was the case with the Spinotron that embodies physical sound models.

The performance experiments showed that enactive learning occurred only when the users were provided with sonic responses to their movements. Subjects reported that they focused on performing regular pumping gestures and did not pay much attention to the sound they were hearing. However, the experimental results showed that sonic feedback increased their performance when compared to the performance with passive haptic/proprioceptive feedback only. This was true accross all subjects, even those who did not intentionally focus on sound. Thus, we can conclude that sound can contribute to guiding users' performance as unobtrusive peripheral information. Such use of sonic feedback may be of particular relevance for the settings in which the cognitive load is high or when the action has to be repeated many times. In movement rehabilitation, for example, we can imagine that a wearable interface providing subtle sonic feedback could be worn continuously without requiring the user to be focused on correcting his or her action.

5.4.2 Methods for Evaluating Enactive Sound

The experimental methodology developed in this dissertation can be divided in two parts: the traditional passive listening methods and methods for evaluating performance with a tangible sound interface. The goal of the former is to assess the perception of the auditory information critical for the performance task (in case study: the perception of the height of the ball rolling in a bowl and the speed of the ratchet). After the perceptual accuracy of information critical for performance experiments is confirmed, an additional listening experiment is conducted in order to select the parameters that best represent the sonic metaphor of the virtual mechanism. The second part consists of a learning experiment that evaluates if the sound can guide users' movement in accomplishing a given task (in case study, keeping the constant speed of pumping by listening to the speed of the ratchet). In order to prove the benefit of sonic feedback, two different setups must be tested: one in which the user performs the task with sonic feedback to his or her actions and another in which no sound is produced.

Spinotron evaluation was based on forced-choice experiments, rating on scales and performance measurements. Scaling methods were successful for the passive evaluation of sound properties such as the height of the ball rolling in the bowl and the speed of the ratchet. However, the same methods proved to be unsuccessful in the judgements of easiness, naturalness and preference. This may indicate that the questions were not relevant to the subjects or that these qualities were not well explained. For example, judging the naturalness of an artefact that subjects knew to be digital was confusing for the subject. It also indicated that terminology for describing performative qualities is lacking.

Contrary to the judgements of easiness, preference and naturalness on continuous scales, the measurement of performance in manipulating the Spinotron provided important results. It showed that the sonic feedback guided the users in pumping the interface at a constant pace, and it allowed them to compare the two dynamical modes. The learning experiments revealed that one of the most important issues for the evaluating performance is the correct choice of a performance measure. In abstract artefacts designed specifically for the experimental purposes, the task must be directly embedded in the object and a performance measurement must be closely related to the task of which the object is the manifestation.

5.4.3 The Role of Design Object

Previous research in auditory psychology seems to have underemphasised the ways in which the experimental object and the experiment itself are connected. Even in the studies addressing object manipulation, the experimental object itself has often been taken as a fixed parameter. However, when dealing with enactive interfaces where feedback and shape can dynamically change, we must approach the experiment itself from an embodied perspective, thus considering the experience and the apparatus as a whole. Otherwise, we may encounter the problem of studying an enactive experience with non-enactive tools. My argument here is that the design (and designer) of the interface/apparatus should be considered as an essential part of an enactive experiment.

The Spinotron case study showed the relevance of the experimental object and the work of the designer within a scientific framework. The design of the interface was a key component of the experiment for two reasons. First, because the motor activity was enabled by the physical object and its qualities. Second, because the perception and action were affected by sonic feedback, which had to be iterated over the course of the experiment.

Evaluation: Entangled Transdisciplinary Process

Within the transdisciplinary Spinotron team, I struggled to initiate the process of challenging and expanding existing scientific methods. My goals were guided by the hypothesis that the aesthetic experience and performance can be improved through sonic feedback. To prove such assumptions, our team had to go beyond traditional auditory experiments. We built on the listening methods regularly used by my colleagues from psychology, in order to research the effect of auditory perception on the active manipulation of objects. Thus, traditional methods, used to identify the sonic metaphor that can be best perceived by the users, were expanded by performance experiments and iterative design process, resulting in an alternative framework, grounded in psychophysics, that can explore enactive learning through the sonic manipulation of objects.

In summary, experimental evaluation must be closely connected to the Enactive Sound Design. While the interface examined here was an abstract object, this methodology could be adapted to novel interfaces, particularly those that do not resemble familiar artefacts. Therefore, the performance assessment presented in this chapter might be useful for other researchers to study enactive learning through sound artefacts in many other contexts.

In conclusion, this chapter presented the ways of bridging the gap between scientific and design methods, through collaborative research on the development of new psychophysical procedures. This was a big challenge, and the whole process took more than a year of work with intensive exchange between the psychologists and the designers. However, the results do prove that such collaborations are possible and fruitful.

Chapter 6

Participatory Methods: Engaging Senses

When a novel research area, such as Enactive Sound Design, builds on knowledge from different disciplines, a number of epistemological and educational questions emerge. What constitutes its core problematics and how does it differ from the disciplines it borrows or emerges from? What practices and methods can most benefit the transdisciplinary enactive sound issues? This chapter proposes a holistic participatory approach to sound design focused on engaging a subjective enactive experience. Developed participatory techniques aim to foster collaboration between researchers with different backgrounds and expand their transdisciplinary interests, by grounding their questions and topics in actual experiences that can be felt and tacitly understood.

6.1 Introduction

Enactive Sound Design is an area that necessitates an understanding of sound, touch and movement in real-world contexts. Teaching such an embodied topic is a challenge and it cannot be approached by departing from a specific sense such as audition, or a particular media such as sound, or a particular discipline such as psychoacoustics. The complex questions that emerged in this doctoral research proved to require a truly transdisciplinary collaboration.

In this chapter, I argue that such collaboration can best be enabled by approaching the subject from a holistic perspective and by focusing on the final goal, that of shaping our sonic futures. Thus, I propose and evaluate a number of participatory techniques with the aim of overcoming the challenge of disciplinary thinking. The goal is to develop methods that work, in a tacit and contextualised manner, with the kinaesthetic, auditory and tactile qualities of an enactive sound experience. These practices should allow participants to imagine and design the corresponding instances of movement, sound and form that can affect such experiences. By focusing on such convergent goal of different disciplinary efforts, that of designing meaningful and sustainable sonic interactions, participatory workshops may be seen as points of the cross-fertilisation between different areas of research and practice, and bring together different communities.

The proposed holistic and experience-based approach should have a double outcome. Firstly, it is intended to engage designers and researchers with experiential aspects of sonic interaction by means of novel design methods. Secondly, it should help researchers to unlearn their professional approaches to the subject and shed new light on their own work. Therefore, I have striven to develop methods in which participants are:

- sensitised to sonic and haptic aspects of everyday experiences
- engaged in creatively and physically expressing their own sound design ideas
- encouraged to imagine future experiences with interactive objects.

Finally, it is my hope that the workshops I have organised have an impact on the establishment of the Enactive Sound Design community.

The chapter begins with an introduction of participatory design in which I argue for a larger involvement of sonic and haptic sense in existing methods. I then present the current version of methods that I have developed to satisfy this scope. Their application in seven different workshop settings, in which they have been iteratively developed, is described. Finally, I present the assessment of these events and methods, and conclude by identifying guidelines and strategies for facilitation of participatory workshops on this emerging research topic.

6.2 Participation Design and Embodied Experience

Participatory design is a set of methods and techniques employed to involve different stake holders in the design process. Clients, designers and users may have different or conflicting interests and needs within the same project, but work together to find a concrete design solution through hands-on activities. In HCI, such methods allow designers to detect existing problems that users may not be aware of, or can not describe in words. More importantly, they add to the process of imagining and probing novel experiences. The range of topics covered by participatory workshops extends from multimodal devices (Denef et al. 2008) and sound avatars (Droumeva and Wakkary 2006) to urban planning (Maquil et al. 2009) and robot applications for everyday environments (Ljungblad and Holmquist 2005).

6.2.1 Hands-On

A veteran of participatory design Pelle Ehn, argued that, at the time dominant, systems thinking approach needed to be complemented by a more hands-on participatory design practices (Ehn 1993). He wrote

> I suggest a reinterpretation of design methods to take us beyond the deeply embedded Cartesian mind-body dualism and beyond the limits of formalisation towards an understanding that supports more creative ways of thinking and doing design as participatory work (involving skills of both users and designers). (Ehn 1993, p. 61)

Providing examples from his own projects, he defined methods that would best fit such tasks. They were based on design-by-doing (e.g., prototyping, mock-ups and scenarios) and on collaborative activities such as joint visits to locations where newly designed software, artefacts or systems were to be used. Thus, in

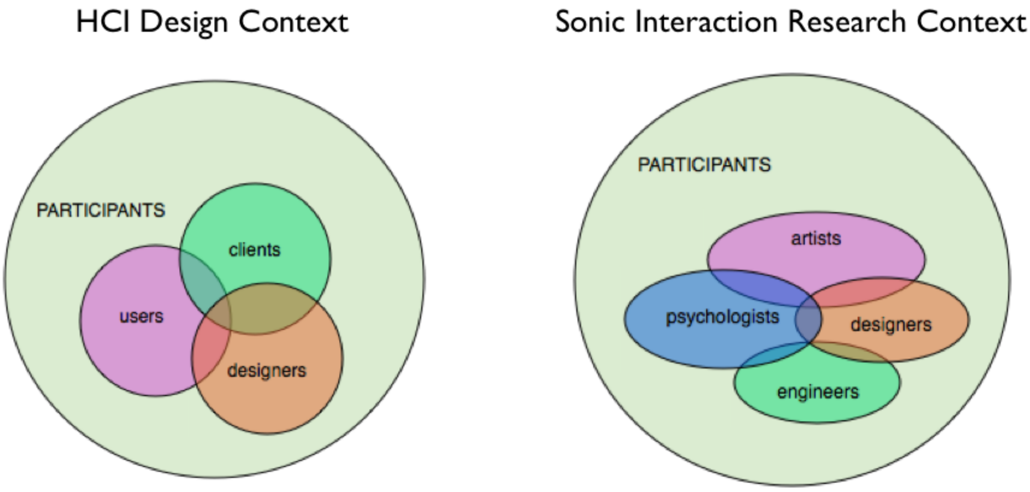


Figure 6.1: The participants in enactive sound workshops include artists, psychologists, computer scientists and other researchers, rather than clients, users and designers

the origins of participatory design, Ehn had already predicted the trend towards an embodied engagement of the user.

I propose to further combine these two approaches - the collaboration and the embodied hands-on exercises - into methods that can enable an exploration of sonic interaction with physical artefacts. I argue that these collaborative hands-on approaches can not only allow participants to develop an embodied knowledge about enactive sound, but can help them imagine and design novel interfaces.

6.2.2 Workshops as a Third Space

In order to create a collaborative atmosphere, a number of problems must be considered, such as the disciplinary terminology or the use of professional tools. What are the important issues that enable participation of people with different backgrounds? Who organises such events and where? What kinds of activities are suitable?

The interaction designer Michael Muller argued that participatory design creates a special kind of 'third space', a term that he borrows from cultural theory (Muller 2003). Such third space is characterised by unpredictable and transforming qualities that emerge through the interactions of different partners.

Using the criteria from cultural theory, Muller analysed the participatory design practices and set general guidelines for creating the third space within the workshop setting (see Figure 6.1).

Overlap between two (or more) different regions or fields (inbetweenness) Marginal to reference fields Novel to reference fields Not "owned" by any reference field Partaking of selected attributes of reference fields Potential site of conflicts between/among reference fields
Questioning and challenging of assumptions Mutual learning Synthesis of new ideas
Negotiation and (co-)creation of… Identities Working language Working assumptions and dynamics Understandings Relationships Collective actions
Dialogues across and within differences (disciplines) Polyvocality What is considered to be data? What are the rules of evidence? How are conclusions drawn?
Reduced emphasis on authority – increased emphasis on interpretation Reduced emphasis on individualism – increased emphasis on collectivism Heterogeneity as the norm

Table 6.1: Michael Muller's summary of claims related to the third space (Muller 2003)

Location

As Muller shows, the location plays an important role in the creation of the third space. In design projects, the most often used locations for participatory activities are the context for which a product is used, such as a workspace or a household. However, if the collaborative activity is taking place in a context that is familiar to some and not to others, this will have a big influence on how the participants respond. For this reason, workshops must be constructed on a 'neutral ground' on which new types of collaborative activities can evolve. As Muller put it:

> Workshops are thus a kind of hybrid or third space, in which diverse parties communicate in a mutuality of unfamiliarity, and must create shared knowledges and even the procedures for developing those shared knowledges. (Muller 2003, p.9)

Thus, one of the most challenging goals is to create activities that can help participants unlearn their own habits and beliefs and to collaboratively construct new ones.

Organiser

Due to the broadness of design thinking, designers seem to be equipped to confront the challenge of facilitating the collaboration between different disciplines. The workshop organiser must make sure that novel procedures do not privilege any group or individual, as this may make others feel less safe to express themselves. This is particularly important in interdisciplinary research, because academic researchers tend to approach the topic from an expert standpoint - a problem that has been already indicated within sound communities (Bernardini et al. 2007).

To avoid such disciplinary positions within the workshops, I propose that common experiences become the focus of such activities. As the sociologist and philosopher Henri Lefebvre argued:

> Everyday life is profoundly related to all activities, and encompasses them with all their differences and their conflicts; it is their meeting place, their bond and their common ground (Lefebvre 1971, p.97)

Thus, Lefebvre argued that everyday life is a place of encounter, a kind of a third space (Lefebvre 1971). I suggest that new participatory methods should guide participants towards an everyday experience that they are designing for, rather than isolating them within their disciplinary questions. In this way researchers may discover holistic goals that stand beyond their expert interests and, in response, this larger view may be able to inform, modify and generate new disciplinary questions. My argument is that designers who work with such holistic applied approach are well equipped to take on a role of transdisciplinary workshop organiser.

6.2.3 From Vision to Sound and Movement

Existing participatory methods use visual media such as cards, photographs, video, maps and sketches. This prevalence of the visual, is influenced by the goals that have been dominant in HCI, particularly those centred on the screen based interaction. In fact, the paper prototypes are often used in order to represent a screen interface. Muller criticised this focus on solely visual experience:

> These approaches violate the emerging requirements of universal usability for people with visual or motor disabilities... Ironically, participatory design, which was founded on the principle of political inclusion, needs new ideas in order to be universally inclusive (Muller 2003, p. 25)

Since his critique in 2003, researchers have started to include sonic and haptic sense in participatory exercises, for example when developing interfaces for visually-impaired users (Fulton Suri et al. 2005; Kuber et al. 2007).

However, one can argue that Muller's critique applies not only to people with disabilities. Dominant visual approaches neglect entire aspects of our world, as well as our senses of hearing, proprioception and touch. The sound communities have begun to work with this challenge. For example, the Mobile Music workshops addressed the use of mobile devices to generate, exchange and listen to music (Gaye et al. 2006). Although the main focus was on the presentations and discussions, these workshops included hands-on activities such as bodystorming, in which participants generated and probed new ideas in a physical way (Oulasvirta et al. 2003). Explorations of tangible sound objects have been fostered within the Sonic Interaction Design European Commission COST Action that I co-founded with international colleagues in 2006 (see the original proposal in the Appendix VIIII). Since then, theatrical strategies have been used to present sonic narratives (Pauletto et al. 2009), the sound design techniques from cinema and gaming were applied (Pauletto et al. 2011; Hug 2009), and voice has been explored as a medium for generating sound ideas (Ekman and Rinott 2010). My colleagues applied several methods developed in this dissertation, such as the action-sound analysis and non-verbal scenarios described below (Ekman and Rinott 2010; Monache et al. 2010; Hug 2010).

6.2.4 From Representation to Enactment

The design of computational artefacts has long been dominated by the task-based cognitive approaches related to software development. Most participatory tools have been employed in a rational problem-solving mode, rather than in an embodied way (Ehn 1993). In this context, the dominance of the visual is accompanied by the dominance of the representational. Even in experimental sound design, we find that most techniques involve a textual description of an imagined future experience. For example, Earbenders is a method for designing auditory interfaces by writing short textual stories (Barrass 1996) (see Figure 6.2). Although such approaches bring in narrative aspects of the experience, they do so in a representational, rather than an enacted way.

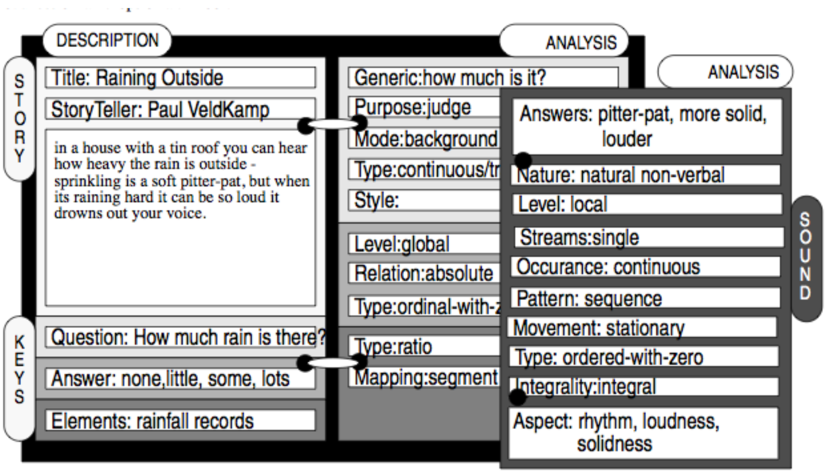


Figure 6.2: The structure of the Earbenders method: an example of a rational, narrative approach to designing sonic ideas (Barrass, 1996)

With the development of tangible and ambient computing, more embodied techniques emerged. The traditional methods were extended by performative activities, often using physical objects to account for design affordances. For example, in the interaction relabelling method any type of object can be used to act out a future scenario with new hybrid interfaces (Djajadiningrat et al. 2000). Although not particularly centred on sound, these methods teach us about the ways in which tangible dimension adds to creativity in participatory contexts and allows to explore and to design interactions by engaging our bodily knowledge. However, not all participants feel comfortable when performing new experiences, as this does not constitute their habitual professional or personal practice.

This challenge of confronting novel ways of expressing oneself may be addressed by making participatory activities playful. Play creates a flowing and absorbing engagement common to all human beings (Csikszentmihalyi 1991) and, in an interdisciplinary setting, these qualities may be utilised to enable participants to forget the expectations that are often linked to their training and background. Furthermore, play may allow them to express themselves without their habitual disciplinary vocabularies. Rather, they may enact their ideas playfully, and collaboratively reveal a new communication strategy.

Most recently, within the SID community, researchers Pauletto, Hug, Barras and Luckhurst deployed a short theatre scene as a method for developing sound designs for everyday activities (Pauletto et al. 2009). Similar to the Non-verbal Scenarios method developed in this thesis (see Section 6.3.4.11.), the authors ask the audience for their interpretation of sounds, but they do so in complete darkness, thus increasing their auditory attention. They then compare the perception of the same sounds when the visual feedback is added, i.e., when the audience sees the actors' actions with the objects. This theatrical approach shows the difference between listening and both seeing and listening to enactive sound actions.

An important benefit of such narrative methods is that they consider the social and cultural aspects in different contexts. Recently, researchers in the Sonic Mapping project criticised the use of existing narrative methods because they are not based on experiences lived in context (Coleman et al. 2008). In the methods they developed, such as the Sonic Map and the Earwitness Account, participants gathered information from the real context. However, these activities are still based on passive observation of the soundscape, as well as the use of annotation, classification and other visual and descriptive strategies.

In summary, the challenge for consolidation of embodied participatory methods is to overcome the limits of visual media and textual descriptions and to engage participants in an enactment of situations, rather than simply rely on their descriptions. The goal of the research developed in this dissertation is to complement visual and description-based methods with those that engage other senses involved in an enactive experience, and to use expressive activities that foster a more creative educational and research atmosphere.

6.3 Participatory Enactive Sound Workshops: A Case Study

By approaching sound design from an enactive prospective, the qualities of experience become the core research issues: sensorimotor knowledge, willed action, multisensoriality and continuity. These broad research topics, discussed in Chapter 2, form a thematic body around which I have developed novel participatory methods.

6.3.1 Context

The enactive sound methods presented here were applied and evaluated in a series of seven workshops between 2007 and 2009, which took place in Zurich, Montreal, Stockholm, Milano and Paris. They were sponsored by the CLOSED project, academic programmes, conferences and art galleries. Several workshops were reported in conference papers (Franinović et al. 2007, 2011), while others have been documented online. The co-organisers of the workshops brought their particular views, and included Yon Visell, whose research concerns haptic perception and interfaces, Lalya Gaye and Frauke Behrendt who previously co-led the workshops on mobile music, and Daniel Hug whose undergraduate degree project addressed action and sound relationships. The summary of for these workshops follows here and more information and videos can be found on the attached DVD in section 4 Workshops.

- Sound Embodied: Acoustic Display and Sound Design, 2007, ZHdK
  - Topic: Future scenarios for interactive sonic objects.
  - Participants: Researchers in product design, electronic music and computer science and master students in interaction design, scenographical design and visual communication.
  - Duration: Two weeks.
  - Collaborators: Yon Visell, Daniel Hug and Simone Lueling
  - Supported by CLOSED (Franinović et al. 2007).
  - Website: http://sonic.wikispaces.com/home.
- Sound, Form, Interaction and Emotion, 2007, ZHdK, Zurich.
  - Topic: methodology for abstracting sonic and action elements from everyday activities

  - Participants: MA students in industrial design and scenographical design
  - Duration: One week.
  - Collaborators: Yon Visell
  - Supported by CLOSED.

- CLOSED Workshop, 2007, Summer School in Sound and Music Computing, KTH The Royal Institute of Technology, Stockholm.
  - Topic: methodology for evaluating sound design
  - Participants: researchers in computer science, engineering, psychology and music computing.
  - Duration: One day.
  - Collaborators: G. Lemaitre, P. Polotti, O. Houix, F. Fontana, N. Misdariis, P. Susini, H. Purwins and K. Adiloglu.
  - Supported by CLOSED.

- From Tangible to Intangible and Back Again, 2008, Oboro gallery Montreal.
  - Topic: embedded sound for artists
  - Participants: artists working with textile, theatre, sculpture, performance, sound and toy design
  - Duration: One week.
  - Collaborators: Yon Visell
  - Supported by Oboro gallery.

- Interactive Sonification for Everyday Artifacts, 2008, Nuova Accademia di Belle Arti, Milano.
  - Topic: Interactive sound in interior design. http://www.youtube.com/watch?v=kfS91LDXE5A
  - Participants: MA Interior Design students, background in architectural, landscape and interior design
  - Duration: One week.

  - Collaborators: Yon Visell
  - Supported by CLOSED.

- Exploring Sonic Interaction with Artefacts in Everyday Contexts, 2008, ICAD conference, Paris.
  - Topic: Future scenarios for everyday interactive sound
  - Participants: Researchers in computer science and engineering, psychology, music computing, media arts and interaction design.
  - Duration: One day.
  - Collaborators: Lalya Gaye and Frauke Behrendt.
  - Supported by SID COST Action. The workshop proposal can be found here (Franinović et al. 2011)
  - Website: http://sonicinteraction.wordpress.com/.
- Research Through Design: Sounding Objects, 2009, ZHdK, Zurich.
  - Topic: Design research methods applied to the ideation of novel sonic interfaces
  - Participants: BA interaction design students
  - Duration: Two weeks.
  - Collaborators: none
  - Supported by Interaction Design program, ZHdK.

In addition, I co-organised three events that gathered international experts on specific enactive sound topics and advised the development of the Sketching SID workshop in 2009 and of the Interactive Product Sound Design Summer School in Stockholm organised by SID action in 2010.

The Sonic Interaction Design: Sound, Information, and Experience workshop at the 26th Intl. ACM CHI Conference in Florence focused on research in the field and was co-organised with a number of colleagues from SID COST Action (Rocchesso et al. (2008)). This event did not involve hands-on exercises, but had a conference format where speakers presented their papers. The workshop proposal and poster as well as all the accepted papers can be found on the attached DVD in the section named 4 Workshops - SID CHI workshop.

In 2009, I organised the Inspirational Session called Sonic Interaction Design: Interactive Sounds in Everyday Life at the Sound and Music Computing conference in Porto. It's goal was to present a broad spectrum of sound design approaches to the Sound and Music Computing community. All the accepted proposals can be found on the attached DVD under the folder named "4 Workshops/Inspirational Session Porto".

The Sonic Gesture workshop took place in 2010 at Zurich University of the Arts and was co-organised together with the music researcher Jan Schacher. International experts from music technology and SID were brought together in a closed workshop to discuss the intersections between musical and sonic gesture. More information can be found on the attached DVD in the section named 4 Workshops - Gesture Workshop ZHdK.

The details about these events are not reported here, because they were based on the presentation and discussion format and did not involve neither hands-on exercises nor participatory methods. However, these events were valuable contributions to the shaping of a research community around enactive sound topics (see attached DVD with additional workshop information on workshops not further discussed in this text, namely sections Gesture Workshop ZHdK, Inspirational Session Porto, SID CHI workshop and SID WG3 Graz workshop).

6.3.2 Audience

The workshops were directed towards two audiences: researchers who were engaged, or wanted to be engaged, with enactive sound research and students who were unfamiliar with sound design. Although these two audiences were quite different, they could both benefit from a designerly introduction to enactive sound. The breadth of the topic attracted participants from a variety of backgrounds and the diversity of geographical workshop locations allowed for not only transdisciplinary, but multicultural participants.

6.3.3 Event Structure

The structure of the workshop depended on the length of the event, extending from one day to two weeks. The format that emerged as the most appropriate for short (up to five days) workshops was composed of the following stages:

6.3.3.0.1 Warm-up Exercises: The workshops began with a number of warm-up exercises that engaged participants in thinking about sounds, objects and tactile experience. Instead of introducing themselves through their professional background, participants were asked to vocally simulate a personal object (see Section 6.3.4.8. Voicing the Object). In this way, they were immediately engaged with playfully expressing sounds themselves. Next, by utilising the Ear Cleansing exercise borrowed from Schafer (Schafer 1967), participants listened to sounds drawn from musique concrete or from the libraries of everyday sounds. They were asked to describe what they heard in their own words.

6.3.3.0.2 Into the Wild: The goal of the following phase was to experience the qualities of sonic objects in a real-world context. The Sound Postcards (Section 6.3.4.1.) explored soundscapes by listening and mapping different sound events graphically or textually. This exercise was followed by Action Postcards (Section 6.3.4.2.), which focused on human action in everyday soundscapes. Similarly, during the Context Gestures exercise (Section 6.3.4.3.), participants would place their attention on observing an action-sound coupling in a real location, and would subsequently actively produce sound within it. If suitable video equipment was available, the participants recorded these interactions. This video material was used in the following analysis phase.

6.3.3.0.3 Multisensory Analysis: Overall, this phase supported the development of an important design skill: the ability to abstract, communicate and conceptualise one's own enactive sound experiences. In the Sonic PlayTable (Section 6.3.4.5.), blindfolded participants explored an object and searched for ways to describe its sonic and tactile qualities. The Speaking Sound exercise (Section 6.3.4.4.) introduced numerous ways of describing everyday sound and was followed by the Action-Sound Analysis (Section 6.3.4.6.), which focused on sonic action and how the context influenced it. Finally, in the Sound Quality exercise (Section 6.3.4.7.), participants compared the sonic advantages and disadvantages of certain materials and mechanisms, and the related sensations they foster. The elements from analytic exercises were later used in the Action-Object Matrix (Section 6.3.4.9.), and knowledge acquired about multisensorial aspects of the experience was used in the ideation stage.

6.3.3.0.4 Design Conceptualisation: Subsequently, the participants were engaged in developing concepts for a novel sonic interaction. The brainstorming was done through an Action-Object Matrix, in a large group in which pairs worked together for ten minutes, allowing all of the participants to encounter each other's ideas and approaches. The favourite concepts were presented to the group and, around these, smaller groups of three to five people were formed. They began to investigate topics and concepts through the Soundstorm method (Section 6.3.4.10.). Some groups started their discussions by applying the ideas generated in the Action-Object Matrix exercise to solve real-world problems, while other's presented ideas that they brought to the workshop.

6.3.3.0.5 Idea Presentation: These concepts were quickly prototyped and acted out as Non-Verbal Scenarios (Section 6.3.4.11.), without explaining or using words in a narrative. This was a test for their sonic concept, as the participants had to guess what each sound meant. The variety of scenarios developed in the groups was also used to kick-start the final discussion in the workshop.

6.3.3.0.6 Final Discussion The workshops closed with a collective discussion about what was learned. In addition, at the end of the last day, individual interviews about the workshop were conducted with participants.

Long Workshops

Figure 6.3: Using cartoon techniques in video presentation (Nuova Accademia di Belle Arti di Milano, 2008)

In the case of the longer workshops, the above stages were complemented by lectures on theoretical and technical topics given by the organisers. Further project development was possible only in the longer workshops. In this setting, my contribution as a workshop facilitator was focused on traditional mentoring techniques such as providing necessary background information, presenting development tools, suggesting the most suitable methods in different phases of the design process and discussing related topics addressed by a specific project idea (see Figure 6.4). Long workshops also allowed the development of video and animation scenarios for presentation purposes (see Figure 6.3).

Figure 6.4: Activities that took place during the development phase: mentoring, electronics development, programming and sound design, rapid prototyping and others (Zurich University of the Arts, 2007)

6.3.4 Evaluation Process

The goal of the assessment conducted during and after the workshops was to gather information about how to improve the participatory methods and the structure of enactive sound workshops.

Data Collection

In order to collect participants' feedback, several methods were applied: a group discussion at the end of the workshop, a set of individual interviews with participants and written questionnaires submitted via email, at least two months after the workshop (see questionnaire examples on the attached DVD in section 4 Workshops - 00 Workshop Questionnaires). The goal of gathering feedback at different times was to understand the long- and short-term effects of the workshop activities. Moreover, different forms of data collection allowed for the collective and individual evaluation of the workshop. Participants were asked about the efficacy of the individual methods, the extent to which the collaboration between different backgrounds succeeded, and further thoughts summarising their experience.

Findings from each of the seven workshops fed into the following one. This iterative evaluation process allowed for:

- improvement of specific methods and the ways in which these are combined
- probing of various strategies that may encourage interdisciplinary collaboration
- testing of the experiences and ideas in an embodied way.

As it would be too lengthy to present the set of iterations for each method, I will now discuss the final version of the methods and summarise the findings that were the most relevant for their development.

6.3.5 Final Version of Methods

The design methods developed over the course of the seven participatory workshops can be grouped into three large areas:

- methods related to contextual inquiry
- analytic methods applied to existing experiences
- creative ideation methods.

Contextual Inquiry Methods

The field exercises were designed with the premise that an understanding of sensory experience is strongly context-dependent. In product design, it is an uncommon practice to work with users in the context, but when such engagement is excluded, many qualities of the experience become lost within the creative process. As the anthropologist David Howes puts it: 'Bringing the issues of emplacement to the fore allows us [researchers] to reposition ourselves in relationship to the sensuous materiality of the world.' (Howes 2005). Thus, a tacit situated knowledge allows for a deeper criticism of design assumptions.

6.3.5.1 Sound Postcards

This exercise aims to raise participants' awareness of sound in everyday contexts through observation and creative recording of sonic landscapes. It is inspired by the Sonic Postcard project, in which participants record sounds of a location and create short sonic compositions which can be shared online (Sonic Arts Network 2005). In Sound Postcards, however, drawings are used to enable quick composition of the postcards in context and without the use of digital technology.

Goal: To consciously experience and to creatively express the relationships between the listener and the surroundings, as well as personal states that may arise from these relationships (emotional, social, cultural, etc.).

Procedure: The groups of four to five participants walk to an urban area selected by the workshop facilitator or chosen by the group. At the location, they close their eyes and listen to their surroundings for few minutes. The leader of the group keeps the time and the security of the others in the group. After the silent and blind observation, each person is given two postcards and asked to create a visual representation of the sound they heard. After approximately five minutes, the participants share their visual annotations and describe what they have perceived. The exercise takes approximately fifteen minutes, from the moment in which the urban area of study is reached.

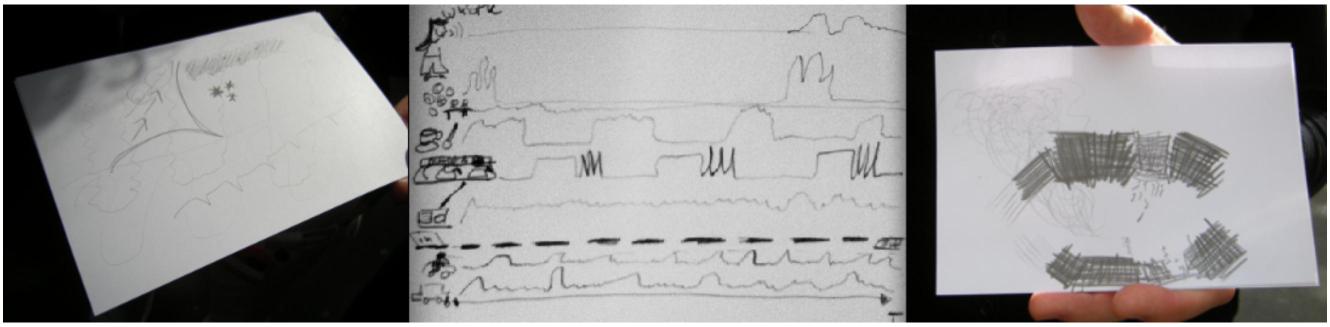


Figure 6.5: The postcards vary from a literal depiction of the sound-event and sound wave representations to abstract drawings and textual descriptions. (Ircam, Paris, 2008)

Workshop Results: The postcards created in the workshops varied from a literal depiction of sound events and wave representations to abstract drawings and textual descriptions (see Figure 6.5). Participants discovered the complexity and richness of everyday soundscapes. With their eyes closed, they began to identify physical phenomena through the sounds these generated (e.g., the movement of the legs, the sound of the heels touching the ground). This allowed them to think of the information that is transmitted through sound and to identify the events that were perceivable solely through sound. This exercise revealed the dominance of machine sounds in an everyday location and brought participants' attention to small and hardly audible sounds. Several ideas for using interactive technology to amplify quiet sounds emerged.

6.3.5.2 Action Postcards

Participants are introduced to observing, studying and visually recording human movement. The audible and inaudible actions of people in the surroundings are discussed in relation to the existing soundscape.

Goal: The goal of Action Postcards is to explore the relationship between human actions and the soundscape and to develop an understanding of action as something that can be designed or affected through sound.

Procedure: This exercise usually takes place immediately after the Sound Postcards exercise. At an urban location, participants are asked to identify and sketch human actions in their surroundings. For five minutes they observe, draw, or take notes about actions happening around them. Because they are involved in creating their postcards while observing, people in the area rarely recognise that they are being observed. After the sketching phase, they discuss how and why they recorded specific actions and associated sonic effects. Overall, the duration of the exercise is about ten to fifteen minutes.

Workshop Results: The participants discovered the auditory aspects of the actions and how they fit into the overall soundscape. Of course, many human actions were very quiet and masked by the sounds of machines, such as cars or a coffee machine. Subtle movements and gestures, or emotional cues such as smiling, crossing legs, or sipping a drink from a glass were described as not audible, but important for the overall experience of sound. Thus, participants often considered how a sonification of silent actions can contribute to the overall soundscape.

6.3.5.3 Context Gestures

The exercise is inspired by soundwalks in which the people carefully listen to all the sounds that can be heard in a specific location (Schafer 1994 (1977; Westerkamp 1974). Participants are asked not only to listen to their surroundings, but also to actively engage in creating sounds with and within different contexts. While experimenting with materials found in the location, they reflect on their own experience of self-produced sound.

Goal: The goal is to explore self-produced soundscapes by listening and generating sounds, thus exploring the effects of one's own actions on the overall soundscape. The hope is that the participant's responsibility for shaping soundscape can be raised when he or she acts as its creator.

Procedure: Groups of two participants are provided with a video camera and a map of the location they need to investigate. The locations may include the train station, an antique store, a canal-side sidewalk, a domestic kitchen or an urban area. Participants are given instructions to listen and to observe people in the area who produce sound. Subsequently, they are asked to produce the sound themselves, at first by repeating the same gestures that they have observed and then by using whatever found object or texture inspires them. They are asked to reflect on their own experiences and contextual issues, while they are producing sounds: How do they feel? Do others in the space engage with them? Is the sound produced annoying anyone? Each group makes video-recordings of these interactions in order to create the video material which is used in the Speaking Sound exercise.

Figure 6.6: Different actions recorded by workshop participants in different context (Zurich University of the Arts, 2007).

Workshop Results: The examples of sound produced through human action that were recorded by the participants showed a range of familiar to unfamiliar sounds and actions (see Figure 6.6 and the video named ActionSoundAnalysisMethodsTicketVending.mov in section on the attached DVD). Through *action listening* and sound producing, participants started to compare everyday sonic actions to unusual ones. Unfamiliar actions performed by participants often created reactions from other people in their surroundings who were curious about or disturbed by, the newly added sounds.

Multisensory Analysis

Multisensory Analysis explores the many dimensions of physical objects that come into play when designing interactive sound: form appearance, design affordances and acoustic qualities. The complex design space they suggest demands new approaches to organisation and management of elements that contribute to the sound experience (Ozcan and Van Egmond 2005). Physical, sonic, haptic and visual qualities of an artefact and its interactive capabilities are strongly linked, and there is a frequent tendency to describe sound in terms of cross-categorical attributes. For example, the word 'pouring' can represent both an everyday sound and an everyday action. One solution that has been suggested is to adopt a fixed lexicon of action categories and terminology to constrain and facilitate the analysis (Ozcan and Van Egmond 2005). However, as I have argued in this dissertation, predefined vocabularies and classifications can fruitfully contribute to design only if grounded in an actual experience (see also Section 4.3.1). Therefore, the following exercises deal with such problems of describing and analysing self-produced sound in an enactive way.

6.3.5.4 Speaking Sound

Participants learn about a range of categories of properties related to interaction and sound, including: the type of interaction involved (e.g., pouring, cutting, stretching), the configuration of the object (its shape, structure, weight), its surface textures, its material properties (especially in relation to vibrational properties, such as elasticity and density), gestalt features or characteristic patterns in space or time, spatial qualities (spaciousness, closedness, echoes), psychoacoustic and other descriptors.

Goal: To learn how to speak about everyday sound and identify sound sources.

Procedure: The workshop facilitator introduces different ways of talking about sound: the psychoacoustic and semiotic descriptors, physical source properties and others. The video recordings of different everyday events (prepared by the organiser or from the Context Gestures exercise) are presented acousmatically (sound only without image). Participants describe sounds through descriptors introduced in the beginning of the exercise; then they try to guess where the sound was recorded and try to individuate single sound sources. They are encouraged to invent their own terms and develop a shared language within the workshop group. Finally, the video with the image is shown to the group, and different ideas and responses are discussed.

Workshop Results: This exercise facilitated reflection on the nature of sonic patterns that are typical of human action. It helped participants to formalise their sonic experiences in words and to search for the qualities related to the descriptors in the sounds they heard. Disciplinary jargons tended to either disappear or to inform the shared terminology.

6.3.5.5 Sonic PlayTable

Haptic qualities of sonic artefacts are at the core of an enactive experience, but they are often neglected in HCI and product design. The Sonic PlayTable allows the participants to tackle the tactile, kinaesthetic and sonic qualities of objects used in sound making.

Goal: The goal of this exercise is to explore tactile and sonic experience by actively engaging with physical materials and objects.

Procedure: The workshop organisers prepare a number of objects of different shape and material such as rubber bands, tubes, fabric, toys and other everyday things (See Figure 6.7). These artefacts are placed on the table and hidden under the cover. Participants work in pairs: one of them selects an object to be explored by the colleague with his or hers eyes closed. The latter, without saying the name of the object, describes the sensations caused through its manipulation (See Figure 6.8). For example, the shape of the object and its material properties that affect sound propagation, or emotional responses, are described. After five to ten minutes, the two participants switch their roles.

Figure 6.7: Sonic PlayTable objects and participant pairs performing the exercise (Ircam, Paris, 2008)

Figure 6.8: With their eyes closed, participants describe different qualities of the objects in their hands (Ircam, Paris, 2008)

Workshop Results: Blindfolded participants had a stronger perception of sound as vibration and the coupling between their movement and sound produced. The participants discovered that physical and acoustic qualities of an object, affect the way in which they manipulated it. In addition to sensory analysis, this exercise created trust and bonding between participants, providing for a more assuring and intimate atmosphere. Sonic PlayTable objects were also used in other stages of the workshop, such as ideation and presentation.

6.3.5.6 Action-Sound Analysis

This method was derived from the action-sound analysis described in Chapter 4. It extends classical task analysis to include performative and auditory aspects.

Goal: Action-Sound Analysis helps participants to understand the coupling between sound and action and the complex relations between the properties of an object that give rise to enactive experience, as opposed to its sonic qualities alone.

Procedure: The action-sound analysis described in Chapter 4 is introduced to the participants. They are asked to analyse a sonic experience that was video-recorded in the Context Gestures exercise. Afterwards, they go to any location of their choice, where they perform that same sonic interaction. They analyse it while in the real situation, and compare it to the analysis done on the recorded material. The results of this exercise are used as source material for the idea generation.

Workshop Results: The approaches that were employed to understand and describe action-sound couplings seemed to vary significantly between cases in which the analysis was performed in the field and when it was accomplished with audiovisual documentation. This seemed to be not only related to the quality of the recorded sounds (which depend critically on microphone technique and other factors), but also to be influenced by the many contextual cues that affect one's perception and cannot easily be recorded. Nonetheless, such features appear to be highly relevant for sound design.

6.3.5.7 Sound Quality

In this exercise, participants explore why products with the same function, but different brands, sound different. To answer this question, a comparative approach to sound quality is taken.

Goal: To explore product sound quality through comparison of different products.

Procedure: Participants choose five different brands of a functional product typically made of similar materials (e.g., scissors, zippers, industrial buttons, paper, doors and keyboards), and video document interactions with those five objects (see Figure 6.9). They describe the object only by looking at it, and then use it and listen to the sound produced. Then, they comparatively analyse the qualities of the sounds by using any terms they find appropriate, and present their analyses for discussion within the group.

Figure 6.9: The sound quality of the zippers from different jackets were compared (frames from the video documentation (Zurich University of the Arts, 2007)

Workshop Results: Participants became aware of how much the sound and the haptics communicated about the quality of an object, especially compared to its visual qualities only. They developed their own vocabularies to describe sound quality, often using terms such as 'cheaper', 'important' or 'unstable'. In addition, this exercise revealed properties that lend different acoustic appearance to a product, such as its mechanisms, size, structure (hollow or full) and materials.

Embodied Ideation

The ideation group of methods encourages the participants to generate their own sonic concepts for novel interactive experiences. The brainstorming is facilitated through an Action-Object Matrix, while prototyping is conducted through the experience design activities in which participants use mockups, props, and voice to act out sonic situations (Buchenau and Suri 2000). At this stage, using voice is an important way of quickly communicating sound ideas. Specific concepts are explored in more detail in smaller group sessions. Three to four participants are joined by the workshop organiser, who acts as a facilitator for the concept development.

6.3.5.8 Voicing the Object

This exercise initiates participants to generate quick sound ideas by means of their own voices. Usually this exercise takes place at the beginning of the workshop. However, the skill of using the voice can be further utilised and developed in later stages of the workshop as participants are encouraged to use voice to communicate their sonic ideas during the ideation and presentation stages of the workshop.

Goal: To use voice to communicate sound ideas and the qualities of objects.

Procedure: Before the workshop begins, each participant is asked to bring along an inspiring everyday object. The everyday object is introduced to other participants by describing its physical qualities. Then, the participant reproduces the sound of the object without using the object itself, mimicking it through his or her voice. Finally, the object is physically manipulated and its real sound is heard (see Figure 6.10). Participants discuss the meaning that the sound lent to the object, the emotions it induced, and how difficult it was to reproduce its sound.

Workshop Results: The use of voice proved to be a quick way to communicate the sonic identity of an object. Participants identified with their objects and showed their potential for use or for stimulating different emotional states. For example, a manual pepper grinder could grind at various speeds, an empty bag of crisps could make one hungry because it recalled the memory of eating crisps, and a can of lemonade could be kicked around or opened or one could hear how full it was by shaking it. This exercise proved to be crucial for the development of Non-Verbal Scenarios.

6.3.5.9 Action-Object Matrix

This brainstorming method, nicknamed design speed-dating, was adopted from the Metapolis and Urban Life workshop at the Ubicomp'05 conference (Paulos et al. 2005). It uses quick encounters between participants as a setting to generate design concepts. In workshops conducted during this doctoral research, concepts were developed from a two-dimensional matrix of preselected parameters gathered from the previous exercises in urban space, and an additional third dimension was added to the matrix: a set of actual physical objects.

Goal: To generate a large number of unusual concepts involving action, context and object, and to allow participants to quickly meet each other in a

Figure 6.10: The participant uses the object so that others may compare the voice simulation with the real sound produced in use (Ircam, Paris, 2008)

creative atmosphere.

Procedure: The organiser prepares an Action-Object Matrix with two dimensions: a set of actions on one axis (for example: walking, blowing, cutting, drinking) and a set of locations on the other (for example: jail, school, hospital or street). The combination of these two axes defines the space of design opportunities that is to be filled by concepts of interactive sound artefacts (see Figure 6.11). The third dimension of the matrix is tangible: a number of physical artefacts (for example: glass, keys, bottle, umbrella) are placed on the table inbetween the opposing chairs. Participants sit on two sides of a long table and close to the wall where an Action-Object Matrix is placed by the workshop organisers. The participants work in pairs: they choose an action-object pair by picking up the card from the wall. They note the three instances (action, location and artefact in front of them) that they use in order to generate a design concept. After ten minutes, the card with the sketch of their idea is placed back onto the matrix on the wall. The partners change (one side of the table moves one step left or right), and new partners choose a new action-object

Figure 6.11: An Action-Object matrix filled in with the ideas after the exercise (Oboro, Montreal, 2008)

pair. The artefacts move in the way that is opposite to the moving partners. In the following ten minutes of conceptualisation, a new idea has to be developed and added to the matrix. This proceeds for one to two hours, usually until the whole matrix is filled. At the end, each person presents his or her favourite concept and discusses it with the group (see Figure 6.13).

Workshop Results: In the first workshops, participants struggled with communicating their concepts to each other. Many were observed to get up and enact their idea to transmit it more quickly (see Figure 6.12). Because words and drawings seemed not to be enough, in the last three workshops, I introduced physical objects as a third, embodied dimension of the matrix (for an example of interaction with objects during the exercise, see the movie named ActionSoundMatrixMethod.mov in the section 06 Workshop Paris June 2008, on the attached DVD). This proved to facilitate the ideation process and better fit the overall enactive sound topic. The physical dimension was particularly useful for the non-design workshop audience, whose drawing skills may not have been very advanced (see Figure 6.12).

Figure 6.12: The physical artefacts facilitate quick communication of ideas between audiences with different backgrounds (Ircam, Paris, 2008)

Figure 6.13: The participants act out their favourite matrix idea (Zurich University of the Arts, 2007)

Overall, the Action-Object Matrix allowed for quick and playful communication between the participants (see Figure 6.14). Due to unusual combinations of the three design parameters, resulting ideas were sometimes extreme scenarios and participants enjoyed letting their fantasies flow without considering the constraints of existing technology (for an example, see the movie named ActionSoundMatrixIdea.mov in the section 06 Workshop Paris June 2008, on the attached DVD). Although it was difficult to conceptualise a functional product, imagining non-probable scenarios stimulated participants' attention to contextual, movement and form attributes. In a synthetic, yet playful way, these methods brought together the core ingredients of Enactive Sound Design - context, action and object - in order to generate future sonic products.

Figure 6.14: The short brainstorming sessions performed in pairs allow participants to interact with all the others in the group (Montreal, 2008)

6.3.5.10 Soundstorm

The Soundstorm method is used to generate ideas by using voice, body and objects to generate sounds. Sounds are produced in real time and can be amplified or modified through the use of a computer (see Figure 6.15). The method draws from existing techniques such as bodystorming, where the body is used to probe and to invent new concepts (Oulasvirta et al. 2003); interaction relabelling that uses mechanical objects to inspire new ideas (Djajadiningrat et al. 2000); and the foley technique (see section 2.2.1.4 Foley: Objects in Sound Design). Here, these methods are combined and applied with a focus on the combination of sonic and haptic sensations.

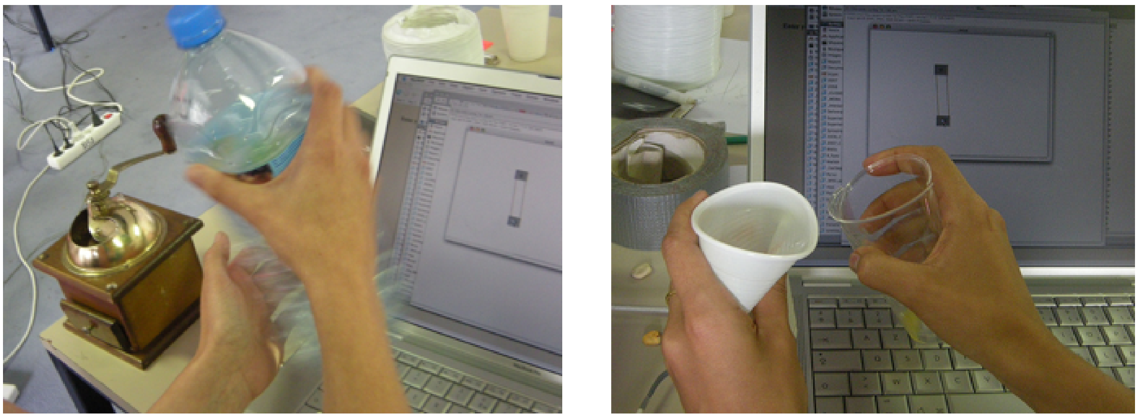


Figure 6.15: In the Soundstorm, the sound of objects is amplified during the idea generation process (Zurich University of the Arts, 2007)

Goal: To quickly develop sonic concepts through the use of voice, objects and bodies.

Procedure: Participants are divided into small groups of three to five people. They choose a concept that they would like to develop (proposed by the group or chosen from the results of the matrix exercise). Using their voices, bodies and objects available, participants generate and probe sound ideas (see Figure 6.16). Finally, they prepare a scenario and act it out, in order to communicate their concept to other participants. This exercise takes from one to four hours depending on the length of the workshop. Each group works separately, but the results are presented to all participants in the next and final stage of the workshop.

Figure 6.16: Testing the perception of sonic vibrations transmitted through the bones, and using the coffee mill as a mediative mobile device (Paris, 2008

Workshop Results: This method allowed participants to quickly communicate and test their ideas in a group. The use of voice, body and physical objects enabled them to intuitively probe new ideas for enactive sonic experiences.

6.3.5.11 Non-Verbal Scenarios

Among different kinds of scenario presentations (e.g., videos, acted out performances with a narrator), the method that proved the most useful for testing participants' ideas was the Non-Verbal Scenario. This presentation technique allows to quickly communicate and test design concepts together with other participants. The method appropriates the Wizard of Oz technique[1], in

[1]Daniel Hug, my colleague who was involved in the first workshop presented here, also utilised these methods with our bachelor students (Hug 2009).

which feedback to users' actions is faked (Kelley 1983). This approach has been used in other workshops, for example, for sound avatar creation (Droumeva and Wakkary 2006). The challenge for enactive sound scenarios is to couple fake responses to users' movements.

Figure 6.17: The movement of the actors and the sounds that they produce are the means through which they have to tell a story (Zurich University of the Arts, 2011)

Goal: To communicate a new sonic idea using non-verbal acting combined with sounds generated through voice, objects and body movement.

Procedure: Participants set up the props and objects necessary to simulate the context (see for example, the bus setting in Figure 6.17). Then, the members of the group act out scenarios to tell the story of their product through their movements and sounds they create (see Figure 6.17). The accompanying sounds can be generated by the actors themselves or by other group members who use voice, body and objects to simulate sonic response to movement (see Figure 6.18). After the acting is finished, other participants describe their understanding of the presented concept. The duration of this exercise varies from fifteen to thirty minutes, depending on the length of discussion. Normally, the scenarios themselves do not extend more than five minutes and the performances are video recorded (for an example, see the movie named NonVerbalScenariosSonicFIshing.mov in the section 01 Workshop Zurich January2007, on the attached DVD).

Figure 6.18: Acting out a sonic toilet experience. The man on the left is generating the sound that accompanies the gestures of the actor on the right (Ircam, Paris, 2008)

Workshop Results: In addition to communicating participants' ideas, this exercise helped them test whether the sounds they have chosen appropriately communicated the intended meaning, sensation or emotion. In addition, the discussion within the group and advice from other participants often not only improved the concept, but also generated new ideas.

6.3.6 Workshop Findings

Across workshops, a number of findings that relate to the topics outlined in the introduction emerged during the evaluation process (see Section 6.3.4.).

Playful Solutions

Playful strategies used in the workshops showed a positive impact on collaboration and creativity. Participants reported that play stimulated their imaginations, helped them relax, allowed them to forget about their disciplinary baggage, and facilitated networking with other participants. Those with a psychology and computer science background were the most positive about the use of playful methods. For example, they found the Action-Object Matrix very challenging, but also the most enjoyable exercise, because it allowed them to think about unusual experiences.

Hands-On

All participants appreciated a 'hands-on approach' because of the way in which the tacit knowledge acquired during the workshop could be related to their previous sonic and haptic experiences. Many said that they learned new skills and creative strategies. As participant and computer scientist Stephen Baumann whose background is in computer science suggested: 'The mixture of design practices being applied in different settings with an interdisciplinary audience was the right way for me to dig deeper into the topic.' (see Baumann's questionnaire on the attached DVD in section 4 Workshops - 00 Workshop Questionnaires - Selected Questionnaires Paris 2008).

Personal Experience

Warm-up and field methods were seen as a good way to start of thinking about sound and enaction. Participants reported becoming aware that contextual and sensorial complexity is often not addressed in their research. The impact of the contextual inquiry was confirmed in the first workshop, where participants not only perceived differently, but analysed differently the same experience within different contexts. One group was asked to observe a specific activity in an everyday context, and to describe it while being there. The other group made video recordings of the same activity and subsequently analysed it. The two groups showed different results: the later displayed less attention to the spatial and social aspects of sound, which often could not be recollected from the memory, while the former had a far more complex and rich understanding of the activity and its relation to the environment. This suggests that different activities should be carried out in context, whenever possible.

Communicating through and about Sound

The multisensory design approach was highly appreciated, but due to the strong interlinkage between different sensory modalities, the focus on sound was difficult. In the first workshops, discussions often drifted away from the sound itself towards its cause: i.e., the action producing it. The most valuable solutions to this problem seemed to be the use of physical objects and voice, because these allowed communication through sound, rather than describing it in words. The Non-Verbal Scenarios proved the benefits of this way of quick ideation and testing, provided the sonic response to action made sense for the user. The participants found it easier to act without using actual words and with the help of props because, as several reported, they felt less embarrassed in front of the others.

Such alternatives to the written or spoken word proved to enrich and complement existing ways of describing sound. For example, in the Sonic Postcards exercise, when visually expressing a sonic experience in urban contexts, participants with different backgrounds chose different representations. While most designers made sketches, most computer scientists made diagrams and wave representations of sound. In this way, multiple disciplinary approaches to sound were compared and discussed. The variety of media and expressive options ensured that the skills required do not privilege a certain discipline. Therefore, the visual output of an exercise should not be limited to a drawing, but should encourage text, collage, or photography. Similarly, the sonic outputs can range from voice, sound produced through objects or even computer generated sound, depending on participants' skills and desires.

Narratives

Participants suggested that an initial exercise focused on narrative exercises might be helpful in order to highlight how to design the more complex social aspects of an enactive sound experience. This welcomed suggestion could also be a good preparation for the final exercise where the sonic experience is presented to the other participants in the form of an enacted story. Another idea from the participants was to develop an exercise in which they could use inappropriate or unusual sounds for actions. This was initially tested through the matrix method, in which participants needed to combine randomly chosen sounds and actions. Unexpected combinations resulted in exciting ideas, but the exercise was abandoned due to redundant naming of sound and action.

Group Size and Autonomy

The optimal size of the group proved to be around twenty participants, because it allowed for suitable sizing of smaller groups. The participants reported that the importance of the feedback of the other participants rose as the workshop progressed and that the feedback was most valuable in the last part of the workshop related to idea evaluation. The balance of autonomous versus guided activities depended on the length of the workshop, because the shorter events required more guidance and preparation. However, the autonomous activities did not rely on the participants' existing knowledge, because they had rather diverse disciplinary backgrounds, especially in the case of the research workshops. Some participants used their own set of skills to generate sounds in real time. For example, during the Non-Verbal Scenarios exercise, one group amplified the sound of cracking the nuts in order to synchronously accompany the members of the group who were performing walking actions.

Personal Interests

Within the short workshops, two participants with backgrounds in art felt that their individual needs and ideas were not taken into account. They were well acquainted both with creative approaches and technical tools and, thus, found that the activities were too general for their expectations. At the same time, they did appreciate the quick prototyping tools such as the Non-Verbal Scenarios and the Soundstorm. They found these methods were useful for imagining new ideas and presenting them to other participants before moving to the development phase.

In the workshops presented here, many personal interests were set aside in order to create a third space. These can be contrasted with the presentation-format workshops that I have organised in which discussions had a more specific research focus. However, those workshops involved experts in the field and not a transdisciplinary audience, as was the case in the participatory workshops presented in this chapter.

Development Challenge

Other comments from artists and designers showed the need for a more applied approach directed towards developing enactive sound interfaces. Surprisingly, participants with a background in psychology, computer science or engineering did not express the same need and preferred the holistic approach focusing on playful and sensory activities. In the longer workshops, in which projects were developed, it soon became obvious that Enactive Sound Design took time. Participants, even those with prior experience with sound as well as software and electronics, were challenged to complete a scenario or prototype in a short amount of time. The complexity of the tools and different levels of participants' skills made it difficult for organisers to provide individual support (see Figure

6.19). This suggests the need for a variety of technical tools accessible to interdisciplinary participants that may enable them to work with continuous gesture, form and sound. It is worth noting that the first steps are taken to construct software tools which may enable designers to generate continuous sonic feedback (Rocchesso and Fontana 2003; Rocchesso and Polotti 2008). On the hardware side, electronic sensing and actuation are becoming more accessible since the growth of the physical computing community. However, designers have often had limited training with such technologies, which are only beginning to be taught in design programs.

Figure 6.19: During project development, participants need various types of support. From left to right: making a new object with paper-mash techniques; recording and sound design; embedding electronics into a ball; programming; weaving sensors into textile (Oboro gallery, Montreal, 2008)

In addition to development of design tools, one solution to this issue could be to precede such a workshop with one in which technical skills are taught.The sensing and actuating technologies and sound software should be introduced in order to assure that participants can confront the prototyping. Without the possibility of introducing new technical skills, the implementation of the working prototypes in one or two weeks turned out to be difficult. Thus, in shorter workshops, it is recommended that the final result consists of a scenario documented in the form of video.[2]

[2]I have not addressed the methods for long-term interdisciplinary collaborations, which often require higher levels of know-how transfer and specialisation training. However, there remains a potential for introducing short exercises in different stages of the research process. In addition, the methods developed in this dissertation can be applied with users in project-based settings,

Co-organisers Feedback

For the co-organisers, these events resulted in a better understanding of the different disciplinary approaches that one can take when working with embodied sound. They reported that these workshops revealed the gaps in collaborative processes that design is capable of filling in and mentioned that this experience further cemented their beliefs that there is a need for new methods that are capable of dealing with the multidimensional aspects of sonic interactivity. They found the exploration of the haptic aspects of embodied sound and of the relationships between sound and everyday gestures to be highly revealing and very inspiring for the participants.

6.4 Conclusion

In summary, this chapter presented a number of participatory methods developed and applied in a workshop setting. This research began with the premise that sensory engagement and playful strategies may facilitate transdisciplinary collaboration and a design-centred view of enactive sound research. This new approach was needed not only to facilitate transdisciplinary interaction, but also because, in the past, vision has been dominating participatory exercises and auditory and tactile experiences have been sadly ignored. Its overall goal was to create the third space in which different disciplinary cultures relevant for Enactive Sound Design could interact. The challenge for those deeply involved with a specific discipline was to unlearn their expert approaches and to open themselves to a less biased view.

I suggested that this problem could be solved by defining the focus of workshop activities that is common to all participants: an embodied lived experience. The encounter with everyday sounds and objects is what we all share, and if it cannot be discussed in words, it can always be felt. Therefore, observing, enacting and representing a subjective experience is at the core of the approach to generating the third space presented here.

The evaluation showed that a welcoming and neutral atmosphere, a third space, was created and that participants managed to temporarily forget about their expert backgrounds. Therefore, we can conclude that the third space of transdisciplinary collaboration can be enabled through an phenomenological

because they require no specialised know-how.

approach to the topic of enactive sound based on three main points:

- a focus on the sensory aspects of subjective everyday experience
- play as a mode of participant involvement
- enactment as the emphatic involvement in design process

The analysis of the conducted workshops showed that a playful atmosphere helped build the confidence needed to reach out of one's own domains of knowledge. Workshops succeeded in fostering participants' awareness of the multisensorial aspects of sonic experiences in daily life. In addition, creative methods facilitated new levels of sensorial and situated design thinking, and allowed for the development of new skills such as body-driven sound sketching. Finally, the workshops gathered researchers and contributed towards the establishment of a research community that continues to work on this topic.

6.4.1 Designer as Workshop Facilitator

The work presented here shows that the designer can have an important role in fostering new innovation areas and bringing relevant disciplines together. The preparation of the workshops on new research topics requires intensive work on the part of the organiser, because the topic is novel and because the interested participants are both interdisciplinary and international. Designers who can apply the holistic thinking to an emergent research area are well equipped to confront this task. As theorist Nigel Cross suggests:

> 'Designers are immersed in this material culture, and draw upon it as the primary source of their thinking. Designers have the ability both to read and write in this culture: they understand what messages objects communicate, and they can create new objects which embody new messages." (Cross (2007), p. 9)

Thus, designer's work is to imagine future experiences enabled by new technological and scientific advances, while considering the existing contexts of their use. Therefore, in an interdisciplinary group, the designer may help researchers to focus on what is relevant in the current situation and to help project their ideas into future scenarios.

The roles that a designer must play inside interdisciplinary workshops shift between those of organiser, activities designer and facilitator. Her or his important tasks include:

- identification and invitation of researchers who play an essential role in the development of an emerging research area
- selection and adaptation of the methods to different timeframes and participants' backgrounds
- search for appropriate locations for workshop activities considering both the inside and the outside spaces
- design of the workshop activities and the overall structure
- creation and maintenance of a good working atmosphere throughout the workshop
- evaluation of the overall success of the workshop and individual methods

Finally, the workshop facilitator should consider a variety of ways of documenting workshop results, because channelling the activities into well recorded results should not be the focus of the participants. Any material from the workshop, such as sketches, videos, interviews and participants' feedbacks, should be recorded for future reference. This can help evaluate the results and serve as a historical archive about the changing interests and themes in the specific research field for others to reference.

6.4.2 Playful and Sensory Third Space

Based on this research, the following recommendations for the creation of the thirds space can be outlined:

- use of expert skills and professional tools should be discouraged throughout the workshops
- playful strategies should be used as a mode of participant involvement
- sensory exercises will put the focus on subjective lived experience, circumventing expert views

As proposed, holistic participatory exercises based on a subjective sensorimotor experience can help researchers find common ground for working with enactive sound. Expressing how an enactive sound experience feels or how we would like it to feel, requires different strategies, skills and tools. Talking about movement and sound can quickly become far too challenging for a workshop group. This problem can be amplified by the fact that participants are an international group using English, rather than their native languages, to communicate, as was the case in the workshops presented here. In this context, the level of play proved to have an essential role in creating an engaging atmosphere and in allowing disciplinary and national differences to fade away. Play allows participants to relax and to open themselves to a new kind of tacit and social knowledge. Based on the workshop evaluation, it was apparent that participants' sensitivity to sounds in relation to their function and context was significantly heightened. As the participants felt the impact of their actions on everyday soundscapes, the responsibility for their own research as a contribution to human experience emerged.

Finding ways to understand, to describe and to design enactive sonic experiences, is an ongoing process that needs to be repeatedly evaluated and extended through suitable strategies. The exercises presented in this chapter were created to help extract and work with embodied knowledge that participants already possess. They help create a neutral ground, a third space shared by all participants. Thinking through their senses, rather than through technical, scientific or theoretical questions, can enable participants to acquire tacit knowledge that can have long term effects.

This phenomenological exploration of sonic and haptic experience is focal to the proposed workshop methodology, but is also an important contribution to the sonic interaction design field in general. However, because multisensory and contextual issues require capabilities to deal with complex information many challenges are left open. It is my hope that the use of the methods developed in this dissertation may broaden others' disciplinary views, and help consider research as a part of the collective contribution towards designing enactive sound experiences, but also towards a future where art and science can better collaborate.

Chapter 7

Conclusion

The final chapter summarises the results of my doctoral project and connects them to its aims and the overall premise. These results show that an enactive sound approach is possible if designers and scientists collaborate to develop new ways of working with sound. At the same time, I discuss how such collaborations have proven to require a lot of effort from involved researchers and had different range of success depending on various contexts. Finally, I recapitulate contributions to new knowledge and discuss further research and design potentials.

7.1 Bridging the gap between soft and hard methods

This dissertation introduced the Enactive Sound Design as an alternative creative practice that supplements and extends the existing reception-based sound design. By arguing that the very discourse surrounding enactive experience requires an embodied, situated and performance-oriented approach, I showed that existing practices in art and science do not meet this goal. Thus, I proposed that soft, creation-centred methods must be modified and combined with hard measurement-focused methods, in order to develop a more solid foundation of methodologies for Enactive Sound Design. By combining explicit and implicit knowledge, I developed methods for analysing, creating and evaluating enactive sound experiences. This practical portion of my doctoral research helped me to bridge the gap between science and design and reflect on the role of the designer within the scientific community that focuses on this emergent research topic. I posited that art and science collaborations are possible beyond an exploitation of mutual benefits, with the aim of deeply transforming both creative and scientific practices.

7.2 Results

In this dissertation, I claimed that the notion of tangible interaction must be expanded to include bodily action as a major focus of design (see Chapter 1). Through embodied theories, I proved that an enactive approach can not only foster a more active engagement of users with their surroundings, but can also raise awareness of their sonic agency in everyday life. Enactive sound was defined as *sound which affects a sensorimotor activity of the user who willingly produces that same sound.* Such sound can affect the quality of everyday life, because it transfers the sonic agency into the hands of the users and thereby raises awareness about the contributions they are making to a soundscape. Moreover, enactive sound can have a profound effect on the user experience as it proves to be a useful feedback for any sensorymotor learning experiences, including movement rehabilitation, gaming or sports.

Further, I identified the main aspects that make an experience of self-producing sound particular: namely sensorimotor knowledge, willed action, multisensoriality and continuity of embodied action (see Chapter 2). These qualities pose design challenges, some of which have been already approached in

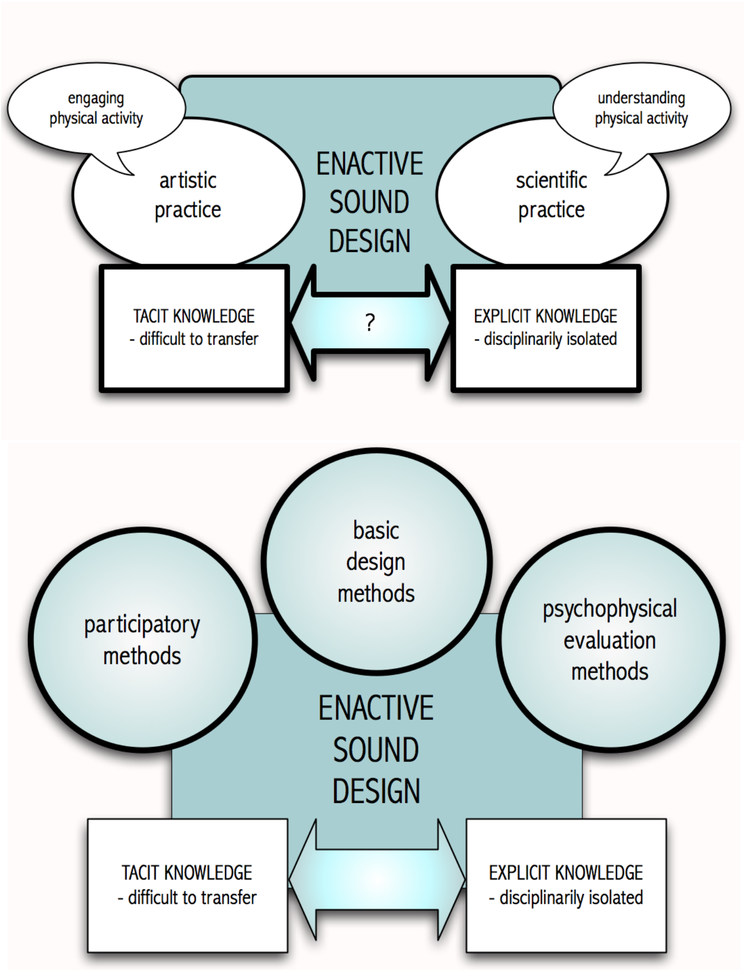


Figure 7.1: The results of the practice-based doctoral research are methods that bridge the gap between scientific and artistic practices.

past artistic and scientific projects. Through a reflective analysis of existing interfaces and installations that aimed to stimulate enactive knowledge and learning, I traced how users' perception and action have been affected by the means of interactive technologies. These projects provided further evidence that interactive technologies can turn sound into a malleable material, one that can be used to guide human action and perception. However, these examples lacked a structured methodology and a reflection about ways of engaging in enactive experiences.

This background analysis and its theoretical base framed some of the most relevant topics for Enactive Sound Design and sound as a medium that can engage expressive bodily action. In Chapter 3, I investigated how existing design approaches relate to these issues. This allowed me to identify both the specific benefits of existing sound design practices that can be carried into Enactive Sound Design methodologies, as well as the obstacles that current auditory design poses for creating enactive sound experiences in daily life. On this conceptual base developed in first three chapters, some challenges for practical research were specified and I suggested a need for a more structured methodology, one that can bring together scientific and artistic sound disciplines.

My practice-based research can be divided in three parts. The first part described in Chapter 4 is an investigation into creative methods grounded in basic design approach. It was based on a number of physical prototypes, named abstract sound artefacts that were later used for the development of evaluation methods and quantitative investigations conducted together with colleagues from psychology, neuroinformatics and sound computing. The main outcome of the first research stage was a basic design methodology that enhances the tacit understanding of existing enactive sound experiences by discovering and analysing their different aspects, and that, in response, can use the results of such analysis for the purpose of creating new ideas and interfaces. I proposed a new way of working with action-sound coupling in everyday activities, rather than within the context of music that currently dominates research on relationship between sound and action. In addition to its practical application, this new methodology extended existing research on interaction gestalt and formulated a notion of basic interaction design by providing a concrete case study (see Abstract Sonic Artefacts case study, pp 88-110).

The creative stage was followed by the quantitative evaluation activities described in Chapter 5 that contributed both to the field of auditory psychology and design. These had double aim: on one hand they provided an example of a novel methodological framework that integrated design of the apparatus with the listening and performance evaluation, and the other, they provided findings about how sound can engage enactive learning. The case study of Spinotron (pp. 120-155) showed that self-produced sound can modulate the perception of the cause of the sound, compared to passive listening situation where the perception of the cause does not change. The primary difference between these two listening cases was the manipulation of a sound producing artefact. However, what was responsible for this modulation in causal identification has yet to be explored. In addition, the results demonstrated that physical interaction allowed users to learn how to better control the sound device relative to the task posed. No improvement was possible without auditory feedback, despite the fact that most users reported that they did not consciously attend to the sounds. Together, these results hold promise for creating a scientific framework for evaluating enactive sound interfaces that is at the same time grounded in the needs of designers.

Having witnessed the difficulties of interdisciplinary collaboration during these evaluation activities, I was confronted with the need to develop ways in which scientific and creative fields could better interact. Therefore, I proposed a number of participatory strategies to achieve this goal, and tested them in a workshop setting. The main premise was that by learning through embodied practices, researchers could meet on a neutral ground and confront the topic of sonic future from a more personal perspective. These practice-based efforts resulted in a number of new participatory methods for Enactive Sound Design, which were grounded on the following strategies: playful engagement and a subjective approach to everyday sound experiences. Finally, I discussed the role of designer as a catalyst of transdisciplinary research and proposed concrete guidelines for facilitation of collaboration within workshop contexts.

7.3 New knowledge

The main contributions to new knowledge in this thesis are methodological and grounded in practice-based research. The theoretical contributions and practical outcomes are summarised in Figures 7.1 and 7.2. They are compared to the aims set at the beginning of this dissertation that are presented in a similar table, together with methods, on page 8.

The tangible computing paradigm and reception-centered sound design were expanded by analyzing the experience of *doing with sound*. This resulted in a definition of a new area of sound design focused on enactive learning and in a proof that interactive technologies can increase materiality of sound and, thus, engage bodily action. Through identification of benefits and disadvantages of current sound practices for Enactive Sound Design and identification of new roles of sound within existing products, I identified topics that need to be addressed in order to foster an alternative approach focused on engaging bodily action.

The above theoretical arguments were supported by practical work that resulted

AIMS	RESULTS	CHAPTER
1. expand the existing frameworks for reception-centered sound design through an enactive approach	◉ framing and definition of enactive sound design ◉ identification of key qualities of enactive sound ◉ analysis of projects exemplifying how those qualities can be shaped ◉ proof that interactive technologies can increase materiality of sound and thus engage with bodily action	Chapter 2
2. identify critical issues that could foster an alternative design approach focused on engaging bodily action	◉ identification of benefits and disadvantages of current sound practices for Enactive Sound Design ◉ identification of new roles of sound within existing products ◉ specification of critical areas within sound practices that need to be addressed in order to foster an alternative approach focused on engaging bodily action	Chapter 2 Chapter 3
3. formulate and test methods for conceptualizing and creating enactive sound artefacts	◉ framing and definition of basic interaction design ◉ analytic methods for identification of basic action-sound relationships from everyday activities ◉ synthetic methods for exploration and creation of the relation between action, sound and form ◉ a number of interactive prototypes and apparatuses for evaluation of sensorimotor performance ◉ design methodology for experimental abstract artefacts	Chapter 4

Table 7.1: Overview of aims, contributions and results - Part 1

AIMS	RESULTS	CHAPTER
4. integrate design and evaluation methods for enactive sound artefacts	◉ methods for evaluating enactive sound ◉ methodology for integrating design of the experimental apparatus with the user evaluation ◉ evidence that interactive sonic feedback can support enactive learning	Chapter 5
5. explore and evaluate the role of the designer within interdisciplinary teams and projects	◉ identification of the roles of designer within a scientific evaluation of user perception ◉ identification of the roles of designer as facilitator of transdisciplinary research	Chapter 5 Chapter 6
6. develop participatory methods based on an enactive approach to sonic interaction	◉ participatory methods that integrate the sonic, tactile and kinaesthetic aspects of user experience ◉ holistic, playful and multisensory strategies for interfacing artistic, scientific and design experts	Chapter 6
7. evaluate if the developed participatory exercises helped construct necessary bridges between artistic and scientific communities	◉ establishment of a community around the topic of enactive sound design	Chapter 6

Table 7.2: Overview of aims, contributions and results - Part 2

in new knowledge. Basic interaction design methods were developed and tested with a number of interactive prototypes and related apparatuses for evaluation of sensorimotor performance. This resulted in an experimental design methodology for analysing existing sound experience and creating new enactive objects. Evaluation of sensorimotor performance developed into a novel methodology for integrating design of the experimental apparatus with the user evaluation. This methodology produced concrete evidence that sonic feedback can support enactive learning. The roles of the designer within the scientific community were defined through strategic and practical contributions within disciplinary, interdisciplinary and transdisciplinary collaboration. Within psychological experiments the designer was involved not only in defining research goals and iteratively designing the apparatus, but also in shaping the evaluation methodology. Finally, the new knowledge was also generated in the workshops where participatory methods were developed using holistic, playful and multisensory strategies to interface scientific, artistic and design know-how. Together, these outcomes contribute to the foundation of Enactive Sound Design.

7.4 Models of Research Collaboration

From a design prospective, research collaborations presented in this dissertation took place with varied success. A reflection on those may exemplify some of the strengths and the weaknesses of different modes of collaboration that a designer may encounter when working within a scientific context. However, an in-depth study of such collaborations would require a field research in which the materials about the collaboration, such as the recordings of the discussions between researchers and interviews with all involved partners, would be collected. An example of such research on sound creation practices within a research environment is the work of the anthropologist Georgina Born who studied the work of researchers and music composers at IRCAM in Paris, and the framing of what she called the institutionalization of the musical avant-garde (Born 1995). Although the aim of this doctoral research was not to study the relationships developing between designers and scientists during the project, but rather the integration of different kinds of knowledge and methods, it is worth reflecting on kinds of interdisciplinary and transdisciplinary collaboration that have emerged during the CLOSED project under whose framework this doctoral research has been conducted.

Interdisciplinary collaboration is based on an exchange between disciplines that join forces within combined activities, for example, within a common research project. While in such interdisciplinary research the boundaries of the specific disciplines remain intact, the transdisciplinary research develops between different fields, resulting in methods and practices that go beyond each individual discipline (Piaget 1972; Nicolescu 2008). It comes as no surprise that the term transdisciplinarity was coined by Jean Piaget, the father of the idea of enactive knowledge. In the 1969, within the workshop called 'Interdisciplinarity - Teaching and Research Problems in Universities', he defined the term transdisciplinarity as follows:

> *Finally, we hope to see succeeding to the stage of interdisciplinary relations a superior stage, which should be 'transdisciplinary', i.e. which will not be limited to recognize the interactions and or reciprocities between the specialized researches, but which will locate these links inside a total system without stable boundaries between the disciplines.*[1] *(L'épistémologie des relations interdisciplinaires, Piaget 1972, p. 144)*

Such transdisciplinary interactions may be of great benefit for design, a discipline which deals with everyday experiences in a holistic manner. I believe that they can develop when the people involved in the project are concerned more with the research topic and are directed to applying their knowledge towards a holistic outcome, and are less constrained by the disciplinary rules and research questions specific to their discipline only. These conditions have emerged to a varied extend within the CLOSED research project.

7.4.1 Design-Science Collaborations within CLOSED project

The CLOSED project was funded from 2006 to 2009 by the European Commission 6th Framework as a New and Emerging Science and Technology project and within a pathfinder initiative called Measuring the Impossible, which aimed to find ways of measuring aspects of human experience that are impossible to measure, such as emotions. Thus, the projects within this initiative had to be planned as high risk research projects, meaning that the

[1] Original text: Enfin, à l'étape des relations interdisciplinaires, on peut espérer voir succéder une étape supérieure, qui serait "transdisciplinaire", qui ne se contenterait pas d'atteindre des interactions ou réciprocités entre recherches spécialisées, mais situerait ces liaisons à l'intérieur d'un système total sans frontières stables entre les disciplines.

topics they explored had to be novel and in early stages of development and that some parts of the project may fail. The specific goal of the CLOSED project was to complete the loop between designing and evaluating interactive sound objects and products through a set of methods and tools which would facilitate iterative design process. Although the project had a focus on the design as explicitly stated in its title 'Closing the Loop of Sound Evaluation and Design', there has been only one designer involved on a continuous, but less than half time employment basis. Thus, in the project group that counted more than twenty researchers over three years, the designers have been an obvious minority, making a context for collaboration rather peculiar.

The CLOSED research group was composed of four partners: the Sound Design and Perception group from the Institut de Recherche et Coordination Acoustique / Musique (IRCAM) in Paris, the Vision, Image Processing and Sound group from University of Verona, the Neural Information Processing group from Technical University of Berlin and the Institute for the Cultural Studies in the Arts and Interaction Design group from Zurich University of the Arts (ZHdK). The first group from France, who was also a project coordinator, was composed of psychologists working in the field of auditory perception, the second from Italy was composed of computer scientists developing physical sound models and the third group from Germany was composed of computer scientists researching information processing in biological systems. The last, design group was composed of Yon Visell, a physicist, engineer and computer scientists, and myself, an architect, artist and interaction designer. Thus, there was only one interaction designer on the whole project team, who was occasionally joined by another researcher Daniel Hug who completed his MA degree within the framework of the CLOSED project and helped with the organisation of the workshop conducted in 2007 in the ZHdK. Between the four partner institutions, a number of collaborations took place.

Evaluation: Auditory Psychology and Design

The longest collaboration sub-project was the Spinotron design and evaluation, performed between the design group and the psychology group. The auditory cognition research conducted by my psychologists colleagues focused on the perception of the cause of the sound, i.e. on the listening condition. Their goal was to understand the difference between the perception of a same sound in a passive listening condition and in an active manipulation condition. This resulted in the first research question for the experiments which explored how did physical manipulation of the sound source modulate the perception of the cause of the sounds. The interest of the design team, however, was on how the real-time continuous sonic feedback could affect physical manipulation and enactive learning with an interactive object. Thus, the second research question posed by designers on how can sonic feedback guide users in learning to control the interface had also to be answered through this collaboration. In an effort to answer set questions and to connect the fields of sonic interaction design and auditory psychology evaluation, my colleagues and I embarked on the challenge of conducting a scientific evaluation of the enactive sound performance with the Spinotron apparatus.

The intricate process of designing and evaluating the experience with interactive sound objects is described in Chapter 5. This process had its benefits and disadvantages for both disciplines. For psychologists, it meant risking the credibility of their statistical results due to many variables involved in the manipulation of an interactive object. For designers, it meant sacrificing some of the principles of enactive design, in order to reach scientifically solid results. Namely, the process of evaluating and designing through manipulation of real objects, i.e. the process of constantly involving sensorimotor experience in the design development, had to be partially substituted by the listening experiments and the design of the final sonic feedback was grounded in the results of such tests. However, the results of the final performance experiments were valuable in showing the impact of continuous sound on enactive learning and the methodology exemplified a case of combined design and evaluation process.

Prototyping: Computer Science and Design

The collaboration of the design team with the University of Verona took place as an exchange of different kinds of disciplinary knowledge. On one hand, the researchers who developed Sound Design Toolkit supported the use of their models by the design team. For example, the development of the liquid sound model for the *Adaptive Bottle* prototype done by my ZHdK colleague Yon Visell, was supported by Carlo Drioli from University of Verona. In this context, my role was the design and the development of the actual prototype as described in Chapter 4, section 4.3.5.4 Sound Prototyping using an Optimisation Tool. On the other hand, researchers from Verona used design concepts and methods developed by the design team. For example, based on the *Sonic Moka* scenario conceptualised as a part of the Twister abstract object, our colleagues developed a prototype within a workshop organised with doctoral students at the Istituto Universitario di Architettura di Venezia (see the section 4.3.5.1 Sonic Moka in chapter 4). Moreover, through participatory workshops organised by the ZHdK, our colleagues from computer science got familiar with various design methods described in the Chapter 6 of this dissertation. For example, the concept and the prototype for the *Sonic Dining* project was developed at the ZHdK workshop: Sound Embodied: Acoustic Display and Sound Design (see the project video at the following webpage http://sonic.wikispaces.com/Sonic+Dinning (Accessed on 20 January 2012)). The project explored the dinning experience by coupling everyday sounds to user's gestures with the cutlery, captured through a table equipped with piezoelectric microphones. My role in this project was the guidance in conceptualisation and development phase through exercises and mentoring, and the construction of the prototype, while the sound models were developed by the colleagues from the University of Verona. The project, later called called *Gamelunch*, was further developed at the University of Verona (Polotti et al. 2008).

The interaction between the design group and the computer science group included: the advising about the Sound Design Toolkit models, the facilitation of design process through design exercises and mentoring, and the collaboration on the first prototype development. The CLOSED project facilitated the exchange of concepts, tool and methods developed by the respective partners, but it did not deeply affect the ways of working of neither the designers, nor the computer scientists. Certain amount of redundancies in the work of the two groups have developed, as the researchers at the interaction design group at ZHdK worked on the development of the sound modelling, and the sound modelling group from Verona worked on creating their own design prototypes. The presence of the computer scientist in the design group made the sound modelling challenges solvable, but such tasks would have been extremely hard to solve without the engineer in our design group. The lack of design expertise in the computer science group led to the use of existing everyday objects integrated with commercial game controllers (e.g. Nintendo Wii) as sensing platforms. Thus, while the research questions remained bounded to the specific disciplines, the outcomes of the work at University of Verona started being closer to an interaction design group, resulting in physical prototypes and demonstration. This has also been stimulated by the transfer of Davide Rocchesso, the project leader for Verona partner, to an interaction design program in a design school, namely the Istituto Universitario di Architettura di Venezia.

Developing: Neuroinformatics and Design

The collaboration between the design group and the Neural Information Processing group from TU Berlin had a more focused goal and held promise of exciting outcomes at the start of the subproject. Previous to the start of the this collaboration, I have followed a class in Artificial Intelligence and Machine Learning at McGill University in order to better understand the questions raised by my colleagues and go beyond the boundaries of disciplinary jargons. My role on the team involved the conceptualisation, the design, the electronics and the prototyping of the *Adaptive Bottle*, while the sound modelling was done by my colleague Yon Visell from the ZHdK. The optimisation design tool was developed by TU Berlin who also conducted the experiments with subjects (see the section 2.3.5.4 Sound Prototyping using an Optimisation Tool in chapter 4 for more details about this research).

During the conceptualisation phase, neuroinformatics researchers understood the need for an enactive design process, i.e. the use of the physical object in the sound design process. Thus, unlike the listening experiments, the actual physical object was involved in the evaluation and sound design. However, although the final deliverable of this subproject was an adaptive sound tool for designers, the actual involvement of the designer on the team was limited to the project planing and the production of the interactive sound prototype to be used in the experiments. My concerns about the tool during its development, specifically about too linear and too long process of selecting sounds and lack of exploration, were not considered by my colleagues from neuroscience. They focused on the optimisation algorithms and machine learning problems, thus neglecting the improvement of the actual design tool. This resulted in a screen interface in which the preferred sounds could be selected via mouse. However, the user could not guide this process by selecting parameters as the four sounds were generated automatically. The tool did not allow for any exploration of the sound parameters in question and left the designer limited by the four choices provided by the computer. My opinion is that sound design tools should allow for a far more creative and explorative way (for an example of exploratory sound design see videos of Graz workshop which can be found on the attached DVD in section 4 Workshops - SID WG3 Graz workshop - Graz Video). The lack of exploration essential for an enactive approach and the low usability of the tool made the outcomes of this collaboration of low relevance for design research.

7.4.2 Disciplinary, Interdisciplinary and Transdisciplinary Models

The research sub-projects conducted by designer together with three partners, can be abstracted in three models of collaboration: disciplinary, interdisciplinary and transdisciplinary, each with their own strengths and weaknesses.

The collaboration with the neuroscientists from the Technical University of Berlin was the least successful from a design perspective, but also in terms of its results. Although the Adaptive Bottle project followed the idea of designing sound by directly using a physical object, the actual adaptive optimisation tool did not prove useful during the sound design process. Due to the lack of the attention to design issues and the practicality of the developed tool, I have abandoned the last phase of the project during which the experiments were conducted. While the results may be meaningful for neuroscience (the results of our work have been published at the International Computer Music Conference), the designer did not gain any new research results or insights. This collaboration can be described as a service provision from the side of a designer, in the prospective of fulfillment of scientific goals. Thus, the work took place in a disciplinary setting rather than a research collaboration.

During the collaboration with University of Verona on the development of different prototypes, both design and computer science groups have learned more about each others skills, and thus expanded and enriched their own fields of expertise. This collaboration could be called interdisciplinary, as the researchers extended their knowledge by integrating methods and practices from other fields. However, the existing disciplinary methods remained intact. Although such collaboration was less risky then the one with Paris, it also resulted in less innovative outcomes. Moreover, there was a risk of producing a mediocre results because the experts such as those developing sound models were not the part of the design group, but only provided remote advice. Thus, it may be advisable to aim for a closer and collocated collaboration, and to contribute one's own expertise to the common project, while also learning about the practices of the other discipline.

The collaboration between psychologists and designers can be seen as a truly transdisciplinary example of research. Although extremely risky and demanding on both sides, the process of negotiating a new way of working was extremely exciting for the designer, led to new findings and opened new research directions. Also, I believe that the psychologist on the team gained a deep insight into the practices and concerns of design research. In fact, both of them now work in design universities, Guillaume Lemaitre at the Istituto Universitario di Architettura di Venezia and Olivier Houix teaches at L'ecole des Beaux Arts du Mans. Without openness to the risk of possible failure and the dedication to understand new ways of working, such collaboration would not have been possible. Thus, transdisciplinary collaboration can take place only if the involved researchers are willing to transgress the boundaries of their own disciplinary research and practice, and perhaps abandon parts of their approach or disciplinary beliefs.

7.5 Further Research

The findings and new knowledge developed in this dissertation are only an initial investigation into the field of sound design that engages bodily action. Further research and practice are still required to develop this emergent area, and to continue to bring together both scientific and designerly ways of working. The final goal of these efforts is that of developing actual products that will increase the quality of our interactions and soundscapes. Keeping this goal as a background for our research activities, can help us not get lost in specific questions and disciplinary problems, but direct them towards shaping future design practices and everyday sonic interactions. As argued in this thesis, facilitating and involving design research through the development of tools and contexts where science, technology, creativity and critical thinking meet is the key to a richer sonic future.

The creative basic design methods proposed in this dissertation could also be further expanded and compared to other approaches, such as pattern language in which solution models for certain design problems are formulated. Designers still need to explore and understand interactive materials, specifically those that involve movement as the focus of interactivity. These questions, such as the one of action-sound materials, is relevant not only for designers, but also for the artists who wish to further the discourse on the aesthetics of interactivity.

In this thesis, the psychophysical evaluation revealed new findings about the sensorimotor performance under the influence of sonic feedback with an object. These results need to be extended in order to evaluate enactive sound interfaces within the context of their use. Thus, the integration of user-centered and ethnographic methods is necessary for the development of real-world applications and products. In this respect, I currently work on two research projects that explore how arm rehabilitation and walking rehabilitation after the stroke could be stimulated through enactive interfaces (A-Int: Engaging activity interaction in neurological gait training (2011-2012, KTI funding) and a project for a new rehabilitation polyclinic called Cereno (see http://www.cereneo.ch/en)). They are conducted in collaboration with neurologists, therapists, doctors and engineers from University of Zurich, ETH Zurich and a number of hospitals. In addition to the evaluation of sensorimotor performance, these projects consider stoke patients' motivation to exercise and specific contexts in which exercise takes place (e.g. home, clinic, outdoors). Therefore, these projects begin to combine ethnographic methods with quantitative experimental results. These are initial efforts to combine psychological research with concrete product development, and much work is needed to formulate methods to approach this problem.

Although my participatory workshops have proved that methods and strategies can bring together different disciplines, the results have left open a number of issues for other researchers to explore. For example, various ways of using narratives to present sound concepts, need to be further applied and evaluated within the enactive context. Furthermore, technical problems make prototyping difficult and so tools for designers to quickly sketch their interactive sound ideas need to also be developed. Consequently, with the support of Sonic Interaction Design action, I began to create a tool for the sketching and improvising of sonic interaction through the use of voice and gesture (see http://blogs.iad.zhdk.ch/vogst/).

My other colleagues within our Sonic Interaction Design network keep pushing the boundaries of what interactive sound means and how it is designed (for an overview see http://sid.soundobject.org/). Many of them have been stimulated by the discourse fostered from the process and analysis in this dissertation (from 2005 to 2012) and during this period the international sonic interaction design community evolved considerably. The relevance of this new design area, together with the most current projects, has been gathered in the book entitled 'Sonic Interaction Design' that I co-edited together with computer scientist, Stefania Serafin (2013, MIT Press). My continuous efforts to raise design questions within scientific research teams are grounded in this dissertation.

The benefits for designers to work with the experience of *doing with sound* are that these experiences open up new fields for applications (e.g. rehabilitation and sports). Moreover, the topic fosters needed connections with the scientific community, thus allowing designers to be better integrated and to shape important research processes. For users, having a well designed enactive interface, means to engage more physically within everyday soundscapes and become more aware of sonic actions and surroundings.

The premise of this thesis posited that a shift from reception-based to performance-grounded sound design can be achieved only if scientific and design practices are being seamlessly integrated. It is my hope that this thesis will continue to contribute to designerly research and that the results will be used, shared and extended by other researchers in order to develop a more integrative methodology: one that combines scientific rigour with design sensibilities.

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Glossary of Terms

aesthetics of interaction
Aesthetics of interaction refers to the aesthetic interplay among different aspects of an interactive artefact, system or experience. It refers not only to visual appearance of an object, but also to the way it behaves and affects all human senses and sensorimotor experience.

affordance
Affordance is a quality of an object or space to invite human to act, to manipulate and to use it. While the concept of affordance coming from an ecological approach to perception considers only physical properties of an object for engaging action, the notion of design affordance refers to an additional layer of cultural and social conditioning which affect our interaction with the world.

design material
Traditional design fields occupy themselves with specific material. For example, graphic designers work with two-dimensional means such as lines, shapes and colours. The materials of interaction design is harder to specify as it includes not only two- or three-dimensional media and transient media such as sound and light, but also include the relationship between those media and human action affecting them (e.g. ways in which sonic feedback is coupled to action causing it).

digitally augmented objects
Augmented objects or digitally augmented objects refers to object with embedded digital technology.

embodied
In the context of interaction design, embodied stands both for a physically embodied action as well as for the ways in which the context, be it physical, cultural or social affects user experience. Situated and tangible

enactive design
This term is related to an approach to design which aims to include, affect or modify sensorimotor experience of the user.

enactive knowledge
While symbolic and iconic knowledge can be communicated through symbols and icons, enactive knowledge is bodily knowledge that, once learned, appears intuitive and seamless.

enactive learning
Also called sensorimotor learning, enactive learning, is the type of learning which has to take place through physical interaction with the world (e.g. such as walking, swimming or bicycling).

enactive sound
Enactive sound is sound which affects a sensorimotor activity of the user who willingly produces that same sound

enactive sound design
Enactive sound design is design of sonic feedback that can affect, guide and support the physical movement of the user who generates sound.

implicit and explicit knowledge
Implicit learning or `knowing how' can be contrasted with explicit knowledge or `knowing that'. While the former is grounded in bodily experience, the latter is based on facts, a collection of data that can be codified and stored.

HCI or human-computer interaction
Human-computer interaction stands for the ways in which humans interact with computers, and is a field of research and practice grounded in computer science, engineering and experimental psychology, thus using quantitative evaluation methods.

interaction design
Interaction design is a field that considers human interaction with technological devices and systems by putting in focus qualitative aspects of interactive experiences. In other words, it is less based on performance and efficiency, and more on cultural, social and emotional aspects. Thus, it is grounded in artistic and design disciplines combined with ethnographic, anthropological and cultural studies fields.

interaction gestalt
Interaction gestalt is a way in which users perceive interactive behaviour a meaningful whole, rather than a sum of action-reaction couplings and design materials.

interactive sound
Interactive sound is sound which interactively responds to user action.

natural
In this dissertation, natural stands for a relationship between human action and the interactive feedback produced, which is grounded in a mechanical and acoustical phenomenal found in analogue world.

schizophonia
The phenomenon when sound is separated from its source through technological means (in time or space, or both).

schizoagency
The phenomenon is the separation of human action from the effects it causes (in time or space, or both).

self-produced sound
The self-produced sound is sound that is caused and perceived by the same person.

sonic feedback
Sonic feedback is a sonic response of an interactive system to human action.

Table of DVD Content

supplement to a dissertation **Amplifying Actions: Towards Enactive Sound Design by Karmen Franinović** submitted to the University of Plymouth in partial fulfilment for the degree of **DOCTOR OF PHILOSOPHY (Ph.D.)**

0 Appendixes Folder

Appendix I Flops conference paper
Appendix II Emotion Experiments papers
Appendix III CLOSED deliverable 3.1
Appendix IV CLOSED deliverable 3.2
Appendix V CLOSED deliverable 3.3
Appendix VI CLOSED deliverable 4.1
Appendix VII Spinotron article
Appendix VIII MINET report
Appendix VIIII Sonic Interaction Design Action Proposal

1 Videos of Kitchen Activities Folder
Video Data Collected in Kitchen Studies

2 Abstract Sonic Artefacts Folder

01 Twister
- 00 images
- 01 patches
- *01TwisterCaffettiera.mov*

02 Crushhh
- 00 images
- 01 patches

03 AdaptiveBottle
- 00 images
- 01 patches
- *AdaptiveBottleVideo.mov*

04 Spinotron
- *00 Spinotron Ball in a Bowl Model.mov*
- *00 Spinotron Ratchet Model.mov*
- 00 images
- 01 patches

3 Spinotron Performance Experiments Folder

Various Ratchet Sounds Tested
    Constant Speed Sounds tested for Quantized Version
    Evolving Speed Sounds tested for Continuous Version

Free Descriptions of Sounds.txt

00 continuous Ratchet Model.mov
Evolving Speed - Ratchet Sound Used in Learning Experiment.wav

00 quantized Ratchet Model.mov
Constant Speed - Ratchet Sound Used in Learning Experiment.wav

Performance Experiment Videos

4 Workshops Folder

00_Workshop_Questionnaires

01_Workshop_Zurich_January2007

02_Workshop_Zurich_July2007

03_Workshop_Stockholm_August2007

04_Workshop_Montreal_February2008

05_Workshop_Milano_June2008

06_Workshop_Paris_June2008

07_Workshop_Zurich_January2009

Gesture Workshop ZHdK
    00 images
    gesture_workshop_2010.pdf

Inspirational Session Porto
    00 selected proposals
    SID_call_InspirationalSession_SMC.pdf

SID CHI workshop
    00 selected proposals
    CHI paper.doc
    SID Poster.ppt

SID WG3 Graz workshop

  00 images

  00 videos

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